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(54) **DETECTING DATA EXFILTRATION AND COMPROMISED USER ACCOUNTS IN A COMPUTING NETWORK**

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CPC *H04L 63/1425* (2013.01); *H04L 63/1441* (2013.01)

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CPC H04L 63/1425; H04L 63/1441
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(57) **ABSTRACT**

Aspects of the disclosure relate to monitoring a computing network to determine data exfiltration. A computing platform may use time-series modeling to determine anomalous network activity with respect to outgoing data. Additional aspects of this disclosure relate to analysis of web activities associated with a user to determine compromised user accounts/devices. The computing platform may use domain categorization to determine if web activity associated with a user is anomalous.
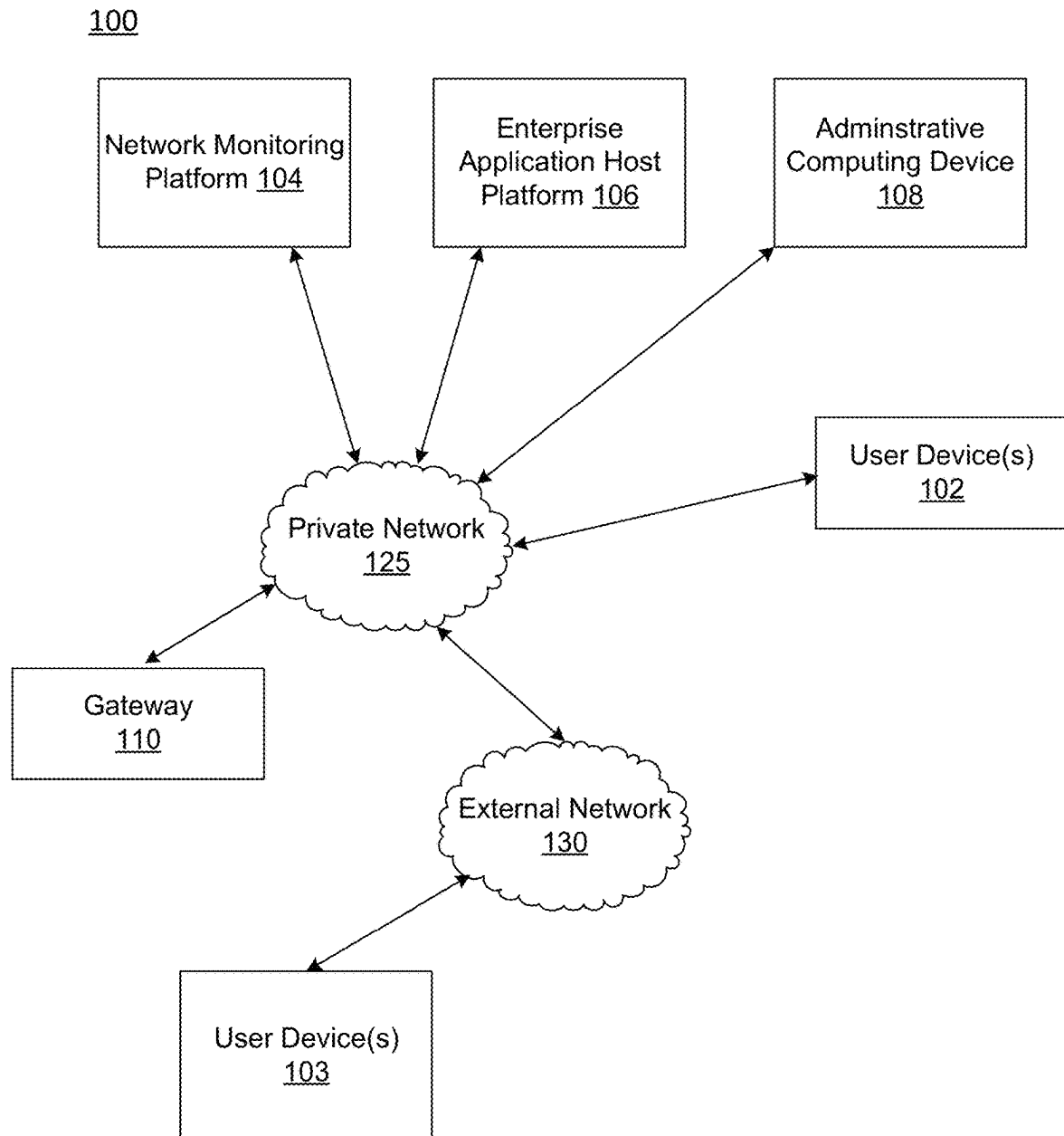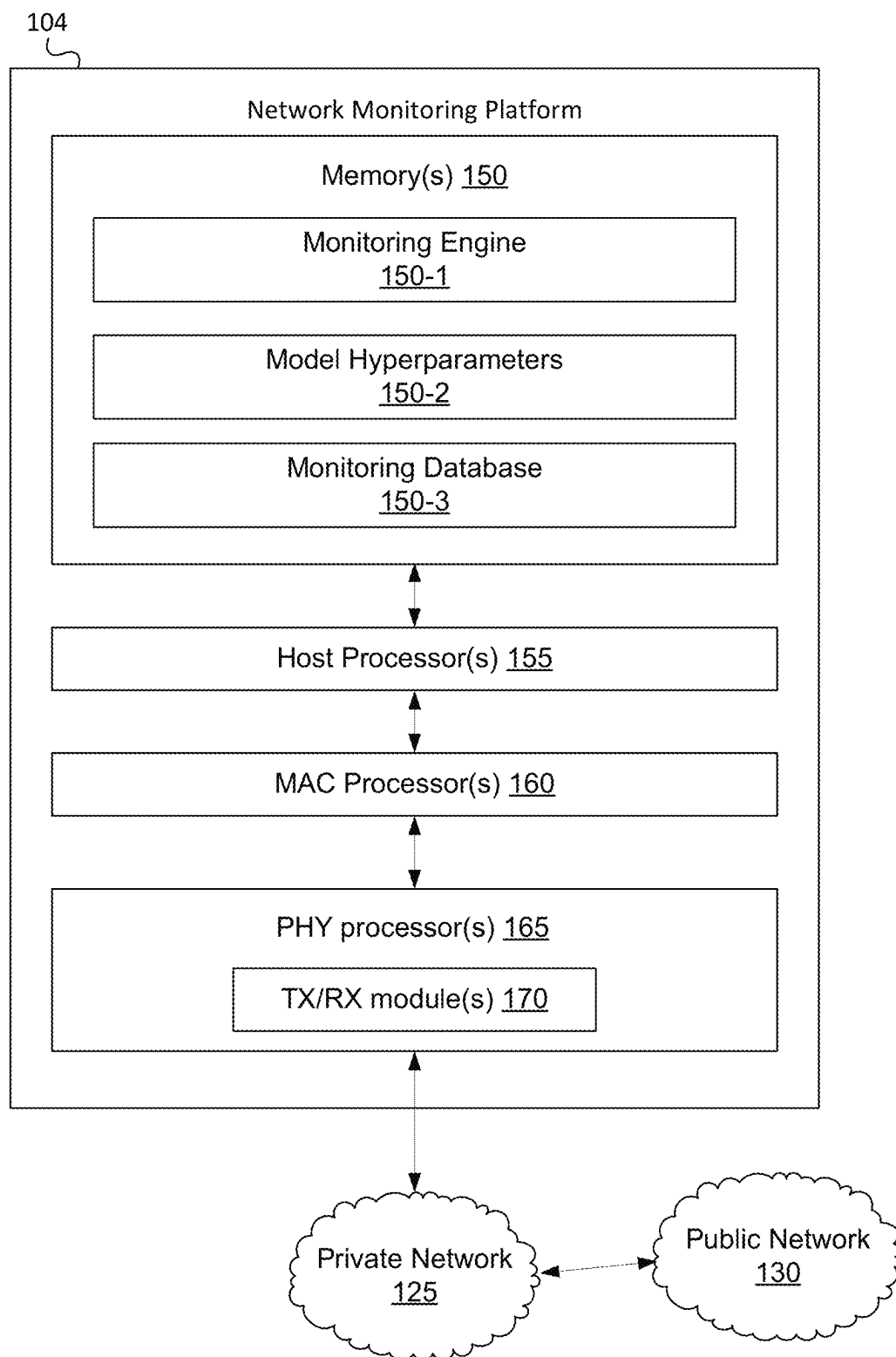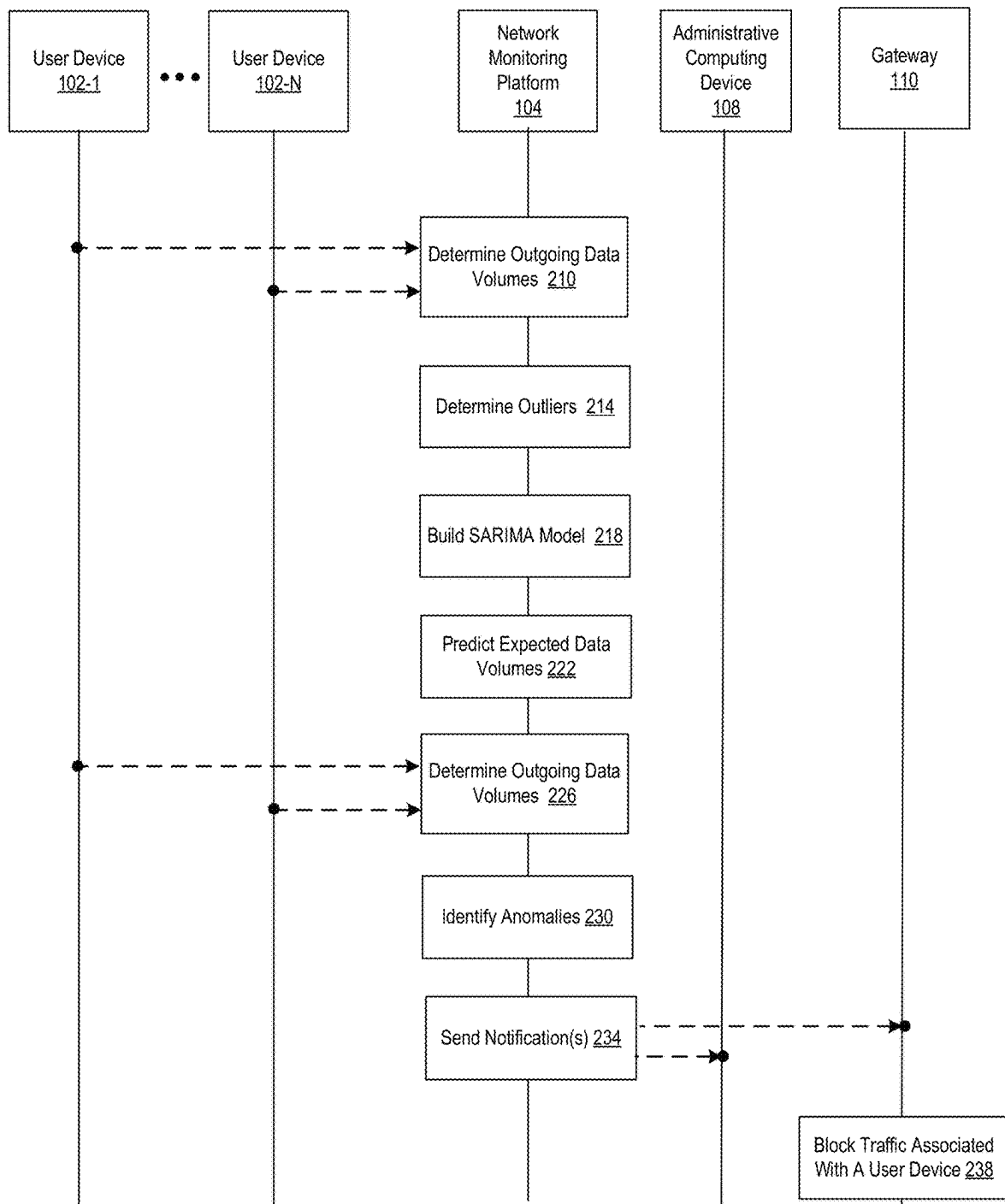
20 Claims, 9 Drawing Sheets
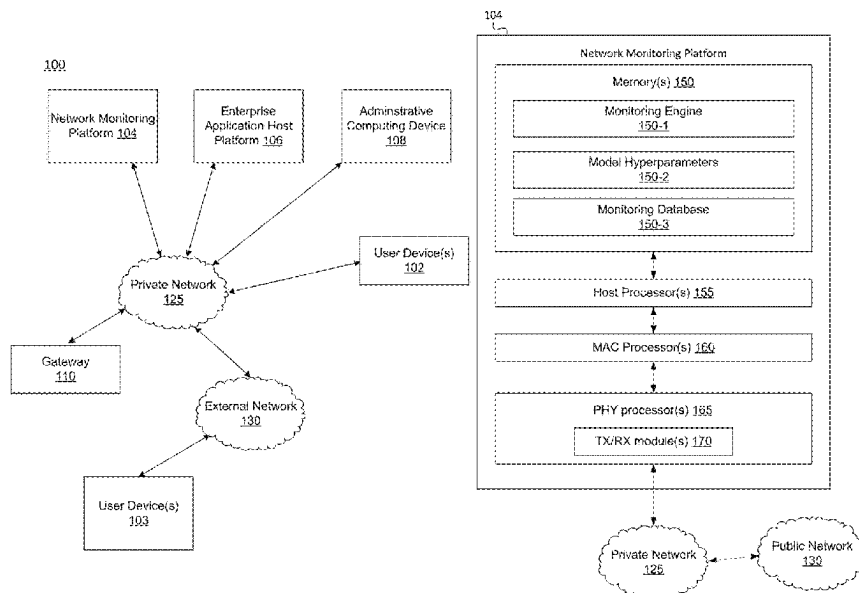
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100

| Network Monitoring Platform 104 | Enterprise Application Host Platform 106 | Adminstrative Computing Device 108 |

Private Network 125

User Device(s) 102

Gateway 110

External Network 130

User Device(s) 103

FIG. 1A

104

Network Monitoring Platform

Memory(s) 150

Monitoring Engine
150-1

Model Hyperparameters
150-2

Monitoring Database
150-3

Host Processor(s) 155

MAC Processor(s) 160

PHY processor(s) 165

TX/RX module(s) 170

Private Network
125

Public Network
130

FIG. 1B

User Device
102-1

• • •

User Device
102-N

Network
Monitoring
Platform
104

Administrative
Computing
Device
108

Gateway
110

Determine Outgoing Data
Volumes 210

Determine Outliers 214

Build SARIMA Model 218

Predict Expected Data
Volumes 222

Determine Outgoing Data
Volumes 226

Identify Anomalies 230

Send Notification(s) 234

Block Traffic Associated
With A User Device 238

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

Day 1

Category	Hits	Threshold	Anomaly
Coding	163	654	No
News	17	87	No
Law	2	7	No
Finance	9	28	No
Social	0	0	No

Day 2

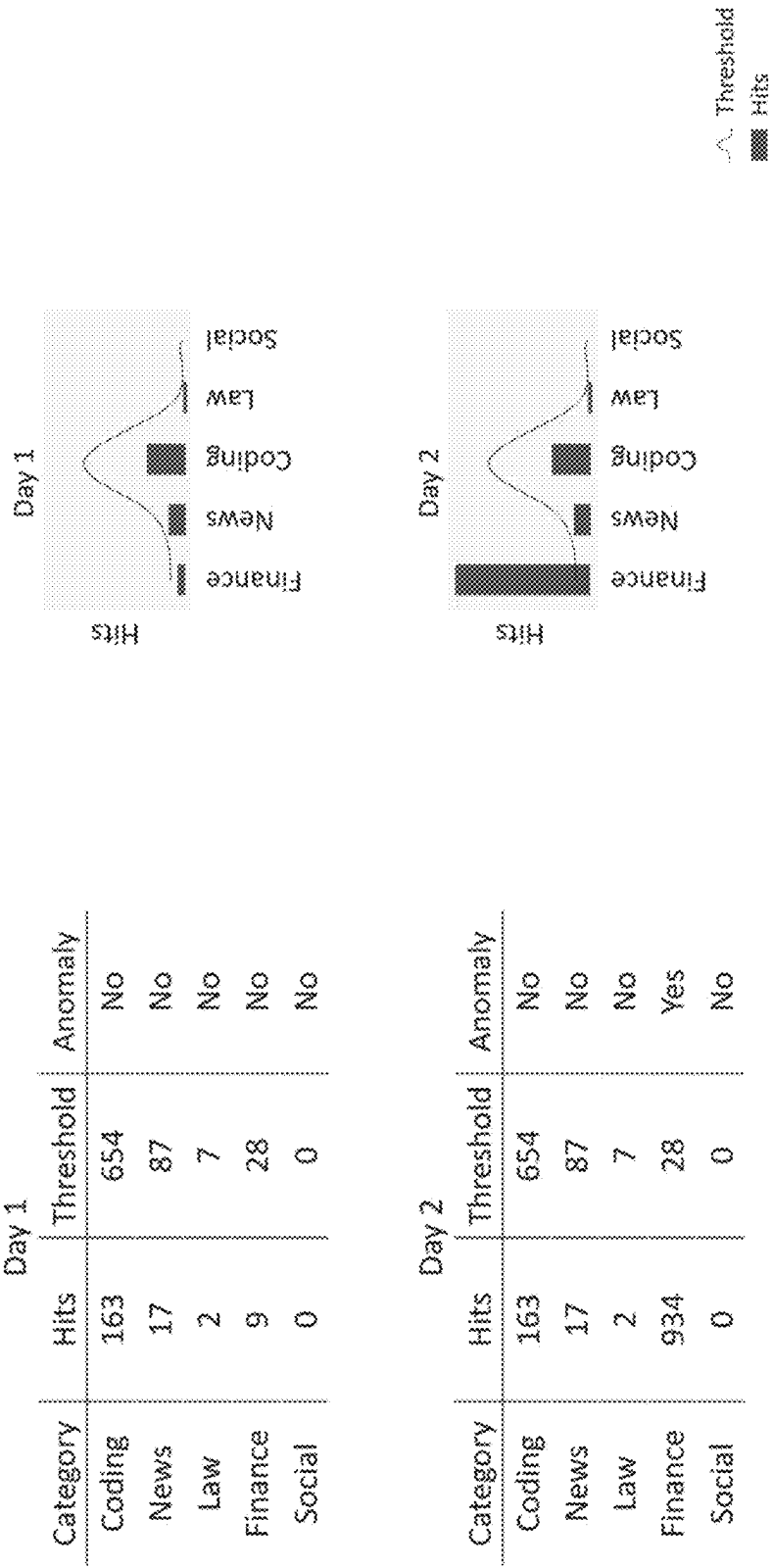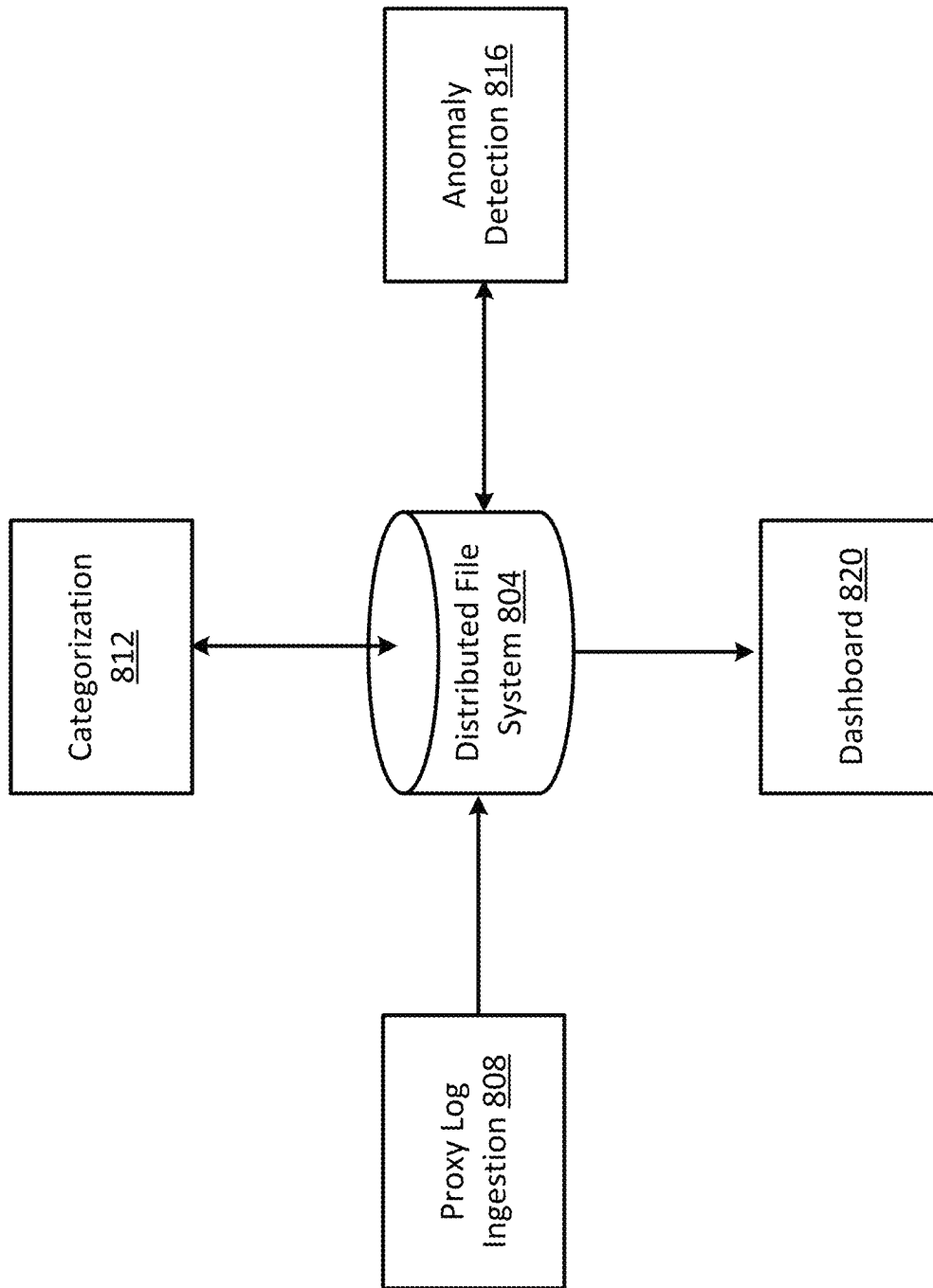| Category	Hits	Threshold	Anomaly
Coding	163	654	No
News	17	87	No
Law	2	7	No
Finance	934	28	Yes
Social	0	0	No

FIG. 7

FIG. 8

DETECTING DATA EXFILTRATION AND COMPROMISED USER ACCOUNTS IN A COMPUTING NETWORK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 17/317,257, filed May 11, 2021, the contents of which is hereby incorporated by reference it its entirety.

FIELD

Aspects described herein generally relate to the field of cybersecurity, and more specifically to monitoring a communication network by analyzing network traffic and user activity.

BACKGROUND

Monitoring data traffic to detect unauthorized data exfiltration from a computing network (e.g., a private computing network) is a common approach for detecting potentially malicious activity. For example, an enterprise organization may use systems that scan data outgoing from their private networks to determine if it is unauthorized or potentially malicious. However, this approach may be extremely resource intensive, thereby making it unsuitable for large networks (e.g., comprising hundreds or thousands of connected devices).

Another issue in computing networks is detection of unauthorized access to a user device or a user account associated with a computing network. Detection of compromised access to a user device or a user device is generally based on static triggers. For example, a computing network may determine unauthorized access based on repeated failed logins to a user account, use of different locations/internet protocol (IP) addresses for login attempts, etc. Such static approaches can be easily circumvented by a malicious actor.

SUMMARY

Aspects of the disclosure provide solutions that address and overcome technical problems associated with network security. In particular, one or more aspects of the disclosure relate to detection of data exfiltration based on time-series forecasting approaches. Additional aspects of this disclosure relate to detection of unauthorized access to a user account/ user device based on modeling of web browsing activity.

In accordance with one or more arrangements, system may be used for detecting and blocking data exfiltration, from a user device, associated with a computing network, to an external network. The user device may be configured to send data to one or more devices in the computing network and the external network. The system may comprise a network monitoring platform that is communicatively coupled to the user device and the external network. The network monitoring platform may comprise at least one processor, a communication interface communicatively coupled to the at least one processor, and memory storing computer-readable instructions. The computer-readable instructions, when executed by the at least one processor, may cause the network monitoring platform to perform one or more operations described herein. The network monitoring platform may monitor outgoing data from the user device to the external network. The network monitoring platform may predict, based on a seasonal autoregressive

integrated moving average (SARIMA) model of data volumes, expected data volumes of outgoing data for a first set of time intervals. Further, the network monitoring platform may measure data volumes of outgoing data for the first set of time intervals without inspecting content of the outgoing data for the first set of time intervals. Based on the expected data volumes for the first set of time intervals and the measured data volumes for the first set of time intervals, the network monitoring platform may identify anomalies in the measured data volumes of outgoing data for the first set of time intervals. The network monitoring platform may send, via the communication interface and based on the identification of anomalies, a notification to disconnect the user device. Disconnecting the user device may comprises blocking outgoing data from the user device to the external network.

In an arrangement, the network monitoring platform may measure data volumes of outgoing data for a second set of time intervals. The network monitoring platform may build, based on the measured data volumes for the second set of time intervals, the SARIMA model of data volumes.

In an arrangement, building the SARIMA model of data volumes may comprise determining one or more hyperparameters of the SARIMA model that result in a best fit between the measured data volumes of outgoing data for the second set of time intervals and expected data volumes of outgoing data for the second set of time intervals. The expected data volumes of outgoing data for the second set of time intervals may be determined based on the SARIMA model.

In an arrangement, identifying the anomalies may be based on a difference between a measured data volume and an expected data volume for a time interval in the first set being greater than a threshold value. The threshold value may be a multiple of a standard deviation of the expected data volumes for the first set of time intervals. The threshold value may be a multiple of a standard deviation of differences between the expected data volumes and the measured data volumes for the first set of time intervals. In an arrangement, the network monitoring platform may send, via the communication interface and based on the identification of anomalies, an alert notification to another user device.

In accordance with one or more arrangements, system may be used for detecting and blocking data exfiltration, from a user device, associated with a computing network, to an external network. The system may comprise the external network comprising a malicious actor device; the user device communicatively coupled to the external network and configured to send data over the computing network to at least the malicious actor device; and a network monitoring platform on the computing network, communicatively coupled to the user device and the external network. The network monitoring platform may comprise a processor, a communication interface communicatively coupled to the processor, and one or more memories comprising a user profile database and storing computer-readable instructions that, when executed by the processor, cause the network monitoring platform to perform one or more operations. The network monitoring platform may monitor outgoing data from the user device to the external network. The network monitoring platform may count, in the outgoing data for a first time period, an actual quantity of requests by the user device to domains associated within a domain category without inspecting webpage content at the domains. The network monitoring platform may predict, based on a user profile associated with the user device that is stored in the

user profile database, expected quantity of requests to the domain category by the user device for the first time period. The network monitoring platform may, for the first time period, based on the expected quantity of requests and the actual quantity of requests, identify anomalies in the outgoing data of the user device classified in the domain category. The network monitoring platform may send, via the communication interface and based on the identified anomalies, a notification to disconnect the user device. Disconnecting the user device may comprise blocking the outgoing data from the user device to the external network. Identifying of the anomalies, by the network monitoring platform, may be based on at least one of deviation from a mean, deviation exceeding a multiple of a standard deviation, and/or deviation from an upper or lower limit of an interquartile range.

In an arrangement, the network monitoring platform may classify requests in the outgoing data from the user device to the external network into one of a plurality of domain categories, wherein the outgoing data extends for a plurality of time periods including the first time period. The network monitoring platform may build a statistical model based on the classifying of the requests, wherein the statistical model comprises at least one of: an average quantity of requests per a time period, a standard deviation of a quantity of requests per the time period, an interquartile range of a quantity of requests per the time period, or combination thereof. The network monitoring platform may update the user profile, which is stored in the user profile database, associated with the user device based on the statistical model.

In an arrangement, the building of the statistical model may comprise, for the plurality of time periods, monitoring Internet website browsing patterns of a user of the user device by domain category without inspecting webpage content from the external network. The network monitoring platform may calculate, for each of the plurality of time periods, a respective quantity of requests to each of a plurality of domain categories. The plurality of domain categories may be seventy-three categories. The building of the statistical model may comprise determining one or more hyperparameters of the statistical model that result in a best fit.

In an arrangement, the requests in the outgoing data from the user device may represent Internet website browsing patterns of a user of the user device.

In an arrangement, sending the notification to disconnect the user device may comprise determining an anomaly score associated with the identified anomalies, wherein the anomaly score is based on a difference between the expected quantity of requests and the actual quantity of requests. The network monitoring platform may send the notification to disconnect the user device based on the anomaly score exceeding a threshold score.

In an arrangement, sending the notification to disconnect the user device may comprise sending the notification to a gateway server associated with the user device.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is illustrated by way of example and not limited in the accompanying figures in which like reference numerals indicate similar elements and in which:

FIG. 1A shows an illustrative computing environment for network monitoring and control, in accordance with one or more example arrangements;

FIG. 1B shows an example network monitoring platform, in accordance with one or more example arrangements;

FIG. 2 shows an illustrative event sequence for building seasonal autoregressive integrated moving average (SARIMA) models of outgoing data volumes and detecting anomalies, in accordance with one or more example arrangements;

FIG. 3 shows an example comparison between predicted data volumes and measured data volumes for a set of time intervals, in accordance with one or more example arrangements;

FIG. 4 shows an example graph of data volumes used to train a SARIMA model for a user device and predicted data volumes based on the SARIMA model, in accordance with one or more example arrangements;

FIG. 5 shows an example block diagram with various modules that may be used by the network monitoring platform for detecting data exfiltration, in accordance with one or more example arrangements;

FIG. 6 shows an illustrative event sequence for detecting anomalies in internet browsing patterns of a user, in accordance with one or more example arrangements;

FIG. 7 shows example categorization of web activity for two time intervals, in accordance with one or more example arrangements; and

FIG. 8 shows an example block diagram with various modules that may be used by the network monitoring platform for detecting anomalous browsing patterns, in accordance with one or more example arrangements.

DETAILED DESCRIPTION

In the following description of various illustrative embodiments, reference is made to the accompanying drawings, which form a part hereof, and in which is shown, by way of illustration, various embodiments in which aspects of the disclosure may be practiced. It is to be understood that other embodiments may be utilized, and structural and functional modifications may be made, without departing from the scope of the present disclosure.

It is noted that various connections between elements are discussed in the following description. It is noted that these connections are general and, unless specified otherwise, may be direct or indirect, wired or wireless, and that the specification is not intended to be limiting in this respect.

A computing network (e.g., associated with an enterprise organization) may comprise multiple user devices that may communicate with each other (or to external networks). Users associated with the user devices may be employees of the enterprise organization or authorized external users that can connect to the network to access various services. For example, the computing network may be associated with a financial institution (such as a bank). External users may connect to computing resources within the network to access various banking services.

Malicious actors may obtain unauthorized access to devices in the computing network and use this to retrieve confidential data and send/exfiltrate to data to external devices. While many tools exist to scan data outgoing from the network (e.g., to determine if data is confidential and not authorized for export to external networks), this approach may be extremely resource intensive for large networks. Data exfiltration may be detected based on analyzing traffic volume associated with a user device/user account within the computing network. Merely using traffic volume avoids the necessity of content inspection and reduces resource usage. However, this approach may lead to detection of false positives or false negatives at an unacceptable rate. For example, a static threshold of traffic volume may be used to

detect data exfiltration from the user devices. Different user devices may be associated with different functions within the computing network. Some user devices may send large quantities of data to external networks as part of normal operations. Other devices may normally send minimal quantities of data to the external networks. Using a same threshold for all devices may result in detection of false positives or false negatives. For example, the monitoring tool may detect that a user device that generally sends large quantities of outgoing data as part of normal operations is performing malicious activity.

Further, approaches that use static data volumes as thresholds do not account for trends, seasonality, randomness, or other factors that may affect volumes of outgoing data. Outgoing data from a user device may shows variations based on, for example, a day of the week. A static threshold does not account for this variation and may result in detection of a false positive even though higher data may be due to a seasonal variation and part of normal operations.

Various examples described herein determine data exfiltration based on customized time-series models for user devices. The time series models may be used to determine expected data volumes for a set of time intervals. The actual data volumes for the set of time intervals may then be compared with the expected data volumes to determine anomalous network activity. The use of customized models for different user devices enable the system to account for difference in network activity among the different user devices. Further, the use of time-series models enables the system to account for seasonal variations and trends in network activity. These factors advantageously reduce detection of false positives and false negatives. Anomalies in training data used to generate time-series models may impact accuracy of predictions. Various aspects of this disclosure further relate to identifying outliers in the training data, and replacing the outliers with corrected values to generate a more accurate model prediction.

Malicious actors may use various actor vectors (e.g., compromised passwords, brute-force attacks, malware injection, man-in-the-middle attack) to gain control of user devices (or user accounts) associated with a computing network of an enterprise organization. For example, a user may be an employee of the organization or a client associated with the organization. For example, the enterprise organization may be a financial institution, and a malicious actor may gain access to a user banking account and initiate unauthorized fund transfers. As another example, a malicious actor may gain access to internal systems/databases associated with the financial institution and retrieve confidential information.

Detection of such attacks may generally be based on static triggers. For example, a monitoring tool may detect a potential attack based on a quantity of attempted logins to a user account. Another method may be to determine if the attempted logins are from different locations. However, malicious actors are generally wary of these security mechanisms and may employ techniques to avoid detection.

Various examples herein describe detecting unauthorized access to a user account and/or a user device based on distribution analysis of web activity associated with the user account and/or user device. A monitoring platform may track web activity of a user account and categorize the domains accessed by the user into domain categories. The monitoring platform may determine a statistical model of user activity associated with each of the domain categories. The statistical model may then be used to analyze future browsing activity to determine if it is anomalous. Tracking

user web activity via domain categories rather than individual domains reduces the resources (e.g., server time, processing/memory resources) required for detecting unauthorized access to a user account.

A sequence of data volumes of outgoing data from a user device, in consecutive time intervals, may be considered to be a time series and time series forecasting approaches may be used to predict future data volumes. A time series forecasting approach comprises building a time series model based on historical values of the sequence (e.g., training values) and using the model to predict future values of the sequence.

FIG. 1A shows an illustrative computing environment **100** for network monitoring, in accordance with one or more arrangements. The computing environment **100** may comprise one or more devices (e.g., computer systems, communication devices, and the like). The computing environment **100** may comprise, for example, a network monitoring platform **104**, an enterprise application host platform **106**, an enterprise user computing device **108**, a gateway **110**, and/or one or more user devices **102**. The one or more of the devices and/or systems, may be linked over a private network **125** associated with an enterprise organization (e.g., a financial institution). The computing environment **100** may additionally comprise one or more user devices **103** connected, via an external network **130** (e.g., a public network), to the devices in the private network **125**. The devices in the computing environment **100** may transmit/exchange/share information via hardware and/or software interfaces using one or more communication protocols. The communication protocols may be any wired communication protocol(s), wireless communication protocol(s), one or more protocols corresponding to one or more layers in the Open Systems Interconnection (OSI) model (e.g., local area network (LAN) protocol, an Institution of Electrical and Electronics Engineers (IEEE) 802.11 WIFI protocol, a 3rd Generation Partnership Project (3GPP) cellular protocol, a hypertext transfer protocol (HTTP), etc.).

The network monitoring platform **104** may comprise one or more computing devices and/or other computer components (e.g., processors, memories, communication interfaces) configured to perform one or more functions as described herein. Further details associated with the architecture of the network monitoring platform **104** are described with reference to FIG. 1A.

The enterprise application host platform **106** may comprise one or more computing devices and/or other computer components (e.g., processors, memories, communication interfaces). In addition, the enterprise application host platform **106** may be configured to host, execute, and/or otherwise provide one or more enterprise applications. With reference to the example where the private network **125** is associated with a financial institution, the enterprise application host platform **106** may be configured to host, execute, and/or otherwise provide one or more transaction processing programs, such as an online banking application, fund transfer applications, and/or other programs/applications associated with the financial institution. The enterprise application host platform **106** may comprise various servers and/or databases that store and/or otherwise maintain account information, such as financial account information including account balances, transaction history, account owner information, and/or other information. In addition, the enterprise application host platform **106** may process and/or otherwise execute transactions on specific accounts

based on commands and/or other information received from other computer systems comprising the computing environment **800**.

The administrative computing device **108** may be a personal computing device (e.g., desktop computer, laptop computer) or mobile computing device (e.g., smartphone, tablet) associated with user who may have administrative privileges within the private network. For example, the administrative computing device **108** may be used to monitor the operation of and provide commands for execution at the network monitoring platform and/or the gateway **110**.

The user device **102** may be a personal computing device (e.g., desktop computer, laptop computer) or mobile computing device (e.g., smartphone, tablet). In addition, the user device **102** may be linked to and/or operated by a specific enterprise user (who may, for example, be an employee or other affiliate of the enterprise organization). While FIG. 1A shows only a single user device, it may be understood that the private network **125** may comprise a plurality of user devices **102** that may access the various servers, applications, and/or databases in the private network **125** and/or communicate with servers/device via the external network **130**.

The gateway **110** may comprise a server that controls access of devices in the private network **125** to the external network **130**. The gateway **110** may act as an intermediary for communications associated with devices, connected in the private network **125**, and the external network **130**.

The user device **103** may be a computing device (e.g., desktop computer, laptop computer) or mobile computing device (e.g., smartphone, tablet) connected to the external network **130**. The user device **103** may be configured to enable the user to access the various functionalities provided by the devices, applications, and/or systems in the private network **125** via the external network **130**. While FIG. 1A shows only a single user device in the external network **130**, it may be understood that the external network **130** may comprise a plurality of user devices **103** that may access various servers, applications, and/or databases in the private network **125** and/or communicate with servers/device via the external network **130**.

In one or more arrangements, the network monitoring platform **104**, the enterprise application host platform **106**, the enterprise user computing device **108**, the gateway **110**, and/or the one or more user devices **102/103**, and/or the other devices/systems in the computing environment **100** may be any type of computing device capable of receiving input via a user interface, and communicating the received input to one or more other computing devices in the computing environment **100**. For example, the network monitoring platform **104**, the enterprise application host platform **106**, the enterprise user computing device **108**, the gateway **110**, and/or the one or more user devices **102/103**, and/or the other devices/systems in the computing environment **100** may, in some instances, be and/or include server computers, desktop computers, laptop computers, tablet computers, smart phones, wearable devices, or the like that may comprised of one or more processors, memories, communication interfaces, storage devices, and/or other components. Any and/or all of the network monitoring platform **104**, the enterprise application host platform **106**, the enterprise user computing device **108**, the gateway **110**, and/or the one or more user devices **102/103**, and/or the other devices/systems in the computing environment **100** may, in some instances, be and/or comprise special-purpose computing devices configured to perform specific functions.

FIG. 1B shows an example network monitoring platform **104** in accordance with one or more examples described herein. The network monitoring platform **104** may comprise one or more of host processor(s) **155**, medium access control (MAC) processor(s) **160**, physical layer (PHY) processor(s) **165**, transmit/receive (TX/RX) module(s) **170**, memory **150**, and/or the like. One or more data buses may interconnect host processor(s) **155**, MAC processor(s) **160**, PHY processor(s) **165**, and/or Tx/Rx module(s) **170**, and/or memory **150**. The network monitoring platform **104** may be implemented using one or more integrated circuits (ICs), software, or a combination thereof, configured to operate as discussed below. The host processor(s) **155**, the MAC processor(s) **160**, and the PHY processor(s) **165** may be implemented, at least partially, on a single IC or multiple ICs. Memory **150** may be any memory such as a random-access memory (RAM), a read-only memory (ROM), a flash memory, or any other electronically readable memory, or the like.

Messages transmitted from and received at devices in the computing environment **100** may be encoded in one or more MAC data units and/or PHY data units. The MAC processor(s) **160** and/or the PHY processor(s) **165** of the network monitoring platform **104** may be configured to generate data units, and process received data units, that conform to any suitable wired and/or wireless communication protocol. For example, the MAC processor(s) **160** may be configured to implement MAC layer functions, and the PHY processor(s) **165** may be configured to implement PHY layer functions corresponding to the communication protocol. The MAC processor(s) **160** may, for example, generate MAC data units (e.g., MAC protocol data units (MPDUs)), and forward the MAC data units to the PHY processor(s) **165**. The PHY processor(s) **165** may, for example, generate PHY data units (e.g., PHY protocol data units (PPDUs)) based on the MAC data units. The generated PHY data units may be transmitted via the TX/RX module(s) **170** over the private network **155**. Similarly, the PHY processor(s) **165** may receive PHY data units from the TX/RX module(s) **165**, extract MAC data units encapsulated within the PHY data units, and forward the extracted MAC data units to the MAC processor(s). The MAC processor(s) **160** may then process the MAC data units as forwarded by the PHY processor(s) **165**.

One or more processors (e.g., the host processor(s) **155**, the MAC processor(s) **160**, the PHY processor(s) **165**, and/or the like) of the network monitoring platform **104** may be configured to execute machine readable instructions stored in memory **150**. The memory **150** may comprise (i) one or more program modules/engines having instructions that when executed by the one or more processors cause the network monitoring platform **104** to perform one or more functions described herein and/or (ii) one or more databases that may store and/or otherwise maintain information which may be used by the one or more program modules/engines and/or the one or more processors. The one or more program modules/engines and/or databases may be stored by and/or maintained in different memory units of the network monitoring platform **104** and/or by different computing devices that may form and/or otherwise make up the network monitoring platform **104**. For example, the memory **150** may have, store, and/or comprise the monitoring engine **150-1**, the model hyperparameters **150-2** (e.g., hyperparameters associated with a determined time series models as described herein), and/or the monitoring database **150-3**. The monitoring engine **150-1** may have instructions that direct and/or cause the network monitoring platform **104** to perform one or more operations of the network monitoring platform **104** as discussed herein. The monitoring database

150-3 may store information corresponding to web activity associated with users in the computing environment **100** categorized into domain categories.

While FIG. 1A illustrates the network monitoring platform **104**, the enterprise application host platform **106**, the enterprise user computing device **108**, the gateway **110**, and/or the user device **120** as being separate elements connected in the private network **125**, in one or more other arrangements, functions of one or more of the above may be integrated in a single device/network of devices. For example, elements in the network monitoring platform **104** (e.g., host processor(s) **155**, memory(s) **150**, MAC processor(s) **160**, PHY processor(s) **165**, TX/RX module(s) **170**, and/or one or more program/modules stored in memory(s) **150**) may share hardware and software elements with and corresponding to, for example, the enterprise application host platform **106**, the enterprise user computing device **108**, or the user device **102**.

As described herein, a time series model may be used to determine anomalous data traffic from user devices in the private network **125**. An autoregressive integrated moving average (ARIMA) model of a time series y (e.g., a sequence of data volumes) may be represented by a model equation:

$$Y_t = \alpha + (\beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \ldots \beta_p Y_{t-p}) - \quad \text{Equation (1)}$$

$$(\theta_1 e_{t-1} - \theta_2 e_{t-2} - \ldots \theta_q e_{t-q})$$

where $(\beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \ldots \beta_p Y_{t-p})$ is the autoregression (AR) component, and $(\theta_1 e_{t-1} - \theta_2 e_{t-2} - \ldots \theta_1 e_{t-q})$ is the moving average (MA) component. Y_t, Y_{t-1}, Y_{t-2}, $\ldots Y_{t-p}$ may correspond to model fit values of the time series or the model fit values with one or more differencing transformations applied. e_{t-1}, e_{t-2}, $\ldots e_{t-q}$ may correspond to errors between values of the time series y and the model fit values. Building the ARIMA model may comprise determining values of α, β_i, and θ_i based on historical values of time series y (e.g., training values). The model equation may then be used to predict future values of the time series y.

A time series that exhibits a certain degree of periodicity with time may be said to be seasonal and a seasonal ARIMA (SARIMA) model may be used to model the time series. A SARIMA model equation may have additional terms (e.g., MA components, AR components) that apply seasonality to the ARIMA model. The additional terms may use values of Y corresponding to prior seasons in a model equation. Outgoing data volumes from a user device, for example, may exhibit a weekly periodic behavior. The SARIMA model may account for this periodicity.

FIG. **2** shows an illustrative event sequence for building SARIMA models of outgoing data volumes and detecting anomalies, in accordance with one or more example arrangements. At step **210**, a network monitoring platform **104** may determine/measure, for a first set of time intervals, data volumes of outgoing data from each user device (e.g., user device **102-1** . . . **102-N**) of a plurality of user devices **102**. The plurality of user devices **102** may correspond to user devices connected in the private network **125** associated with an enterprise organization. A time interval, in the first set of time intervals, may correspond to any period of time (e.g., 1 hour, 6, hours, 1 day, etc.). Outgoing data may correspond to data transmitted from a user device **102** to the external network **130**. As described herein, the network

monitoring platform **104** may determine SARIMA models for outgoing data volumes from each of the plurality of user devices **102**.

At step **214**, the network monitoring platform **104** may determine outliers in the data volumes of outgoing data from a user device **102** (e.g., as determined at step **210**). The outliers may not be used for generating the SARIMA model for the user device. For example, an outlier may correspond to a data volume of 0, which may be indicative that the user device **102** was not connected to the private network **125** or the external network **130**. Other approaches may be used to detect outliers. For example, an interquartile approach may be used wherein data volumes that are not in an interquartile range of data volumes may be ignored for training the SARIMA model.

At step **218**, the network monitoring platform **104** may determine a SARIMA model of data volumes for the user device **102** based on the determined data volumes for the first set of time intervals. Determining the SARIMA model may comprise determining a set of hyperparameters associated with a SARIMA model equation (e.g., of α, β_i, θ_i, p, q, trend, parameters associated with a seasonal portion of the SARIMA model equation, etc.). The SARIMA model equation may account for an observed trend in the series of determined data volumes (e.g., y). The trend may be "constant" if the values of y are approximately at a same level over time (e.g., y≈c, where c is a constant). The trend may be "linear" if the values of y show a linear dependence with time (e.g., y≈at, where a is a slope and t corresponds to time intervals). Determining a set of hyperparameters for the SARIMA model equation may comprise using different sets with different combinations of values of hyperparameters, and determine which set results in generation of values that most closely fit the determined data volumes in the first set of time intervals.

At step **222**, the network monitoring platform **104** may predict estimated outgoing data volumes for a second set of time intervals (e.g., time intervals different from the first set of time intervals used for building the SARIMA model) and for the user device **102**. The network monitoring platform **104** may use the SARIMA model built at step **218** for predicting the estimated data volumes for the second set of time intervals.

At step **226**, the network monitoring platform **104** may measure, for the second set of time intervals, actual data volumes of outgoing data from the user device **102**. At step **230**, the network monitoring platform **104** may, to determine anomalous activity, compare the measured data volumes for the second set of time intervals (e.g., as determined at step **226**), with the estimated data volumes for the second set of time intervals (e.g., step **222**). The network monitoring platform **104** may, for example, calculate differences between the estimated data volumes and the measured data volumes. If a difference between an estimated data volume and a measured data volume for a time interval is greater than a threshold, the network monitoring platform **104** may determine that the measured data volume is anomalous.

The network monitoring platform **104** may use a SD of SARIMA-modeled data volumes of outgoing data (e.g., data volumes based on the SARIMA model for the first and/or second set of time intervals) to determine the threshold. The threshold may be equal to or a multiple of the SD (e.g., the multiple may 1.5, 2, 3, or any other value).

FIG. **3** shows an example comparison between predicted data volumes and measured data volumes for the second set of time intervals. The network monitoring platform **104** may determine the differences between the predicted data vol-

umes and measured data volumes and compare the differences with the threshold. With respect to FIG. 3, for example, a threshold value may be set as 1.5 times the SD of predicted data volumes. For a time interval time T1, the network monitoring platform 105 may determine that a difference between a measured data volume and a predicted data volume is greater than 1.5SD. As a result, the network monitoring platform may determine that the measured data volume is anomalous at a time interval T1.

At step 234, the network monitoring platform 104 may send one or more notifications to one or more devices in the private network 125 based on detection of anomalies at one or more time intervals. For example, the network monitoring platform may send a notification to the gateway 110 indicating that measured data volume(s) corresponding to the user device 102 is showing anomalies at the one or more time intervals. At step 238, and based on receiving the notification, the gateway 110 may block the user device 102 from communicating to the external network 130. For example, the gateway 110 may block any outgoing data traffic from the user device 102 to the external network 130.

Additionally or alternatively, the network monitoring platform 104 may send a notification to the administrative computing device 108 indicating that measured data volume(s) corresponding to the user device 102 is showing anomalies at the one or more time intervals. A user associated with the administrative computing device 108 may review the anomalies and determine to block the user device 102 from communicating to the external network 130. The administrative computing device 108 may send a notification to the gateway 110 to block traffic associated with the user device 102. The gateway 110 may block any outgoing data traffic from the user device 102 to the external network 130 based on receiving the notification.

One or more other operations may be performed in response to detections of anomalies in one or more time intervals. For example, the gateway 110 may send packet captures of data sent/received by the user device 102 to the network monitoring platform 104 for inspection. The network monitoring platform may initiate a scan of the user device 102 to detect malware or spyware potentially installed on the user device 102. The network monitoring platform 104 may initiate additional monitoring procedures for traffic associated with user device 102. For example, the network monitoring platform 104 may start inspecting data traffic from the user device 102. The network monitoring platform 104 may perform scanning and profile analysis of an external destination of traffic from the user device 102. The network monitoring platform 104 may sent a take-down request to an internet service provider (ISP) associated with the external destination of the traffic from the user device 102. The network monitoring platform 104 may reduce/revoke network access privileges for the user device 102. The network monitoring platform 104 may isolate the user device 102 from the public network 130. Any of these approaches may be based on manual review of activity associated with the user device 102 by a user associated with the administrative computing device 108.

The gateway 110 may control data traffic from the user devices 102 to the external network 130. The network monitoring platform 104 may analyze data traffic from the user devices 102 to the gateway 110 to determine the outgoing data volumes (e.g., at step 210 and 226). In another example arrangement, the network monitoring platform 104 may receive, from the user devices 102, respective indications of outgoing data volumes. In another example arrangement, the network monitoring platform 104 may receive,

from the gateway 110, indications of outgoing data volumes corresponding to the user devices 102.

Determining threshold data volumes based on SARIMA models for each user device may reduce detection of false positives and false negatives in comparison with approaches that use a static threshold. For example, a first user device may, during normal operation, transmit large quantities of data (e.g., 500 MB per day) to the external network 130 while other user device may transmit smaller quantities (e.g., 10 MB per day). For example, the first user device may correspond to a data backup system that periodically sends large quantities large quantities of data to external systems via the external network 130, while the second user device may correspond to an individual user who may only use the external network 130 for light internet activities (e.g., sending/receiving emails). If a static threshold is used (e.g., 50 MB), the network monitoring platform 104 may flag the first user device as being associated with potentially malicious activity (false positive detection). If the second user device sends 30 MB of data during a particular day, the network monitoring platform 104 may ignore this (false negative) even though this is anomalous activity for the second user device. Generation of individualized SARIMA models of data volumes for each user device may enable the network monitoring platform 104 to account for the differences between network activities associated with different users/user devices and enable more accurate detection of anomalies.

FIG. 4 shows an example graph of data volumes used to train a SARIMA model for a user device 102 and predicted data volumes based on the SARIMA model. FIG. 4 shows an example embodiment in which a time interval of 1 day is used. The training data volumes 410 may correspond to data volumes determined for the first set of time intervals (e.g., step 210). The network monitoring platform 104 may not use outliers 415 within the training data volumes 410 where there is no connection between the user device 102 and the public network 130 (e.g., step 214). The network monitoring platform 104 may determine the SARIMA model based on the training data volumes 410. The network monitoring platform 104 may determine predicted data volumes 420 for the second set of time intervals (e.g., step 222) based on the SARIMA model. The network monitoring platform 104 may further determine a prediction interval 425 based on a SD of the predicted data volumes 420. The prediction interval 425 may correspond to a multiple of the SD (e.g., 1.5SD). A normal range of data volumes may be equal to (PV(T)±PI), where PV(T) may be equal to a predicted data volume at a time interval T and PI may be equal to a prediction interval 425. A measured data volume, for the time interval T, that is outside the normal range may be considered to be anomalous.

FIG. 5 shows an example block diagram with various modules that may be used by the network monitoring platform 104 for performing the steps of FIG. 2. A distributed file system 504 may store the determined/measure outgoing data volumes for a plurality of user device 102. A proxy log ingestion module 508 may be used to determine the outgoing data volumes. A data preparation module 512 may be used to remove outliers in training data volumes used for generation of the SARIMA models (e.g., as described with respect to step 218). A time series modeling module 516 may be used to generate the SARIMA models based on the training data. The dashboard module 520 may be used to present the determined anomalous data volumes (as determined at 230) to the administrative computing device 108. The various modules described with respect to

FIG. **5** may correspond to hardware and/or software elements associated with the network monitoring platform **104**. One or more of the modules may correspond to computing devices that may be associated with the private network **125**.

FIG. **6** shows an illustrative event sequence for detecting anomalies in internet browsing patterns of a user, in accordance with one or more example arrangements. At step **610**, the network monitoring platform **104** may determine, for a first set of time intervals, web activities (e.g., internet browsing patterns) associated with each user device (e.g., user devices **102**, user devices **103**). A user device may be associated with the private network **125** corresponding to an enterprise organization or may be associated with the external network **130** (e.g., public network, such as Internet). The user device may be used for accessing content and/or services provided by device/servers in the computing network **100**. The user corresponding to the user device may be associated with a user account. For example, the user account may be associated with an account used to access various databases and/or applications within the private network **125**.

The network monitoring platform **104** may correspond to the enterprise organization which may monitor web activity associated with employees of the enterprise organization. The network monitoring platform **104** may correspond to an internet service provider (ISP) which may monitor web activity associated with clients of the ISP. The web activity associated with the user device may correspond to domains (e.g., web pages) requested by the user via the user device. The network monitoring platform **104** may monitor outgoing data from the user device to determine requests from the user device to access various domains. A time interval, in the first set of time intervals, may correspond to any period of time (e.g., 1 hour, 6, hours, 1 day, etc.). The network monitoring platform may **104** determine web activity corresponding to the user device for each time interval in the first set of time intervals.

At step **614**, the network monitoring platform **104** may categorize/classify the web activity corresponding to user device (e.g., domains requested by the user device), for each time interval in the first set of time intervals, into a plurality of domain categories. For example, if a web page/domain requested by the user device corresponds to a news website, the network monitoring platform **104** may determine that the web page corresponds to a "news" category. As another example, if a web page/domain requested by the user device corresponds to a social media website, the network monitoring platform **104** may determine that the web page corresponds to a "social media" category. The network monitoring platform **104** may categorize the domain without inspecting the content of the domain. The network monitoring platform **104** may be associated with a database that maps domains (e.g., domain addresses) with associated domain categories. The network monitoring platform **104** may categorize the domains requested by the user device based on the mapping.

For each time interval, in the first set of time intervals, and for each domain category, the network monitoring platform **104** may determine a respective count. A count may be equal to a quantity of "hits"/requests for access to domains associated with a domain category in a time interval. For example, for a first time interval in the first set of time intervals, the network monitoring platform **104** may determine respective counts associated with respective domain categories as accessed by the user device. For example, for the first time interval, the network monitoring platform may determine that a count for the "news" category is 85 (e.g., 85

web pages associated with news websites were requested by the user device in the first time interval) while the count for the "social media" category is 0 (e.g., no web pages associated with social media websites were requested by the user device in the first time interval).

Web activity information (e.g., indications of domains requested by the user) may be provided by the gateway **110**, for example, if the user device is associated with the private network **125** and the network monitoring platform **104** is monitoring network activity (e.g., outgoing data) of user devices **102** connected to the private network. Web activity information may be provided/sent by a server associated with an ISP, for example, if the user device is associated with a public network (e.g., Internet). Web activity information may be determined by a browser extension associated with a web browser of the user device (or any other local application associated with the user device) and sent by the user device to the network monitoring platform **104**.

At step **618**, and based on the web activity for each time interval in the first set of time intervals, the network monitoring platform **104** may build a user profile for the user device. The user profile may comprise, for each domain category, a corresponding statistical model. A statistical model for a domain category may comprise a corresponding average value of counts per time interval for the first set of time intervals. The statistical model for a domain category may comprise a corresponding SD of counts for the first set of time intervals. The statistical model for a domain category may comprise a corresponding interquartile range of counts for the first set of time intervals. Based on the statistical model of a domain category, the network monitoring platform **104** may determine an expected/predicted range of a count for the domain category and/or a threshold count for the domain category. An expected/predicted range of a count for a domain category may correspond to (average value per time interval±nSD), wherein n is any multiple. An expected range of a count for a domain category may correspond to an interquartile range of counts for the domain category in the first set of time intervals. A threshold count for a domain category may correspond to (average value per time interval+nSD), wherein n is any multiple.

In an example arrangement, the statistical model may comprise a time-series model (e.g., as described with respect to FIG. **2**) of counts for the domain category. Building the statistical model may comprise determining hyperparameters for the time series model based on web activity in the first set of time intervals. Based on the time-series model the network monitoring platform **104** may determine an expected/predicted range of a count for the domain category for a future time interval. An expected/predicted range of a count for a domain category may correspond to (predicted value for the time interval±nSD).

At step **622**, the network monitoring platform **104** may determine, for a time interval (e.g., following the first set of time intervals), web activity associated with the user device. Similar to step **614**, the network monitoring platform **104** may categorize the web activity corresponding to user device, for the time interval, into a plurality of domain categories. The network monitoring platform **104** may further determine counts (e.g., quantity of requests for domains associated with a domain category) for each of the domain categories in the time interval based on the web activity (e.g., as described with reference to step **614**).

At step **626**, the network monitoring platform **104** identify anomalies in counts determined at step **622** for the time interval. The network monitoring platform **104** may compare a determined count for a domain category with the

threshold count for the domain category. The network monitoring platform **104** may determine that the count for the domain category is anomalous if the count exceeds the threshold count. The network monitoring platform **104** may compare a determined count for a domain category with the interquartile range of counts for the domain category. The network monitoring platform **104** may determine that the count for the domain category is anomalous if the count is outside the interquartile range for the domain category. The network monitoring platform **104** may compare a determined count for a domain category with the expected range of counts for the domain category. The network monitoring platform **104** may determine that the count for the domain category is anomalous if the count is outside the expected range for the domain category.

FIG. **7** shows example categorization of web activity for two different days (e.g. a time interval is equal to one day). Web activity associated with a user may be categorized into 5 categories. The network monitoring platform may determine a quantity of requests (count) for domains associated with each category and compare it with a threshold for the category. Thresholds for each of the categories may be determined based on the user profile as determined at step **618**. For example, for day 1, all counts for the categories are below the threshold. However, for day 2, a count for the "finance" category is found to exceed a threshold for the category. This may be flagged as an anomaly for the user/ user device (e.g., step **626**).

A count that is outside an expected range of counts for the domain category as determined at step **618** may be flagged as anomaly. The network monitoring platform **104** may determine an anomaly score for the user/user device based on a quantity of categories that are showing anomalies. For example, a higher anomaly score may be assigned to a user/user device if a larger number of categories are showing anomalies in counts. An anomaly score may be directly proportional to a quantity of categories showing anomalies.

The network monitoring platform **104** may further determine anomaly scores for each domain category. An anomaly score may be proportional to a difference between a determined count for the domain category and the threshold count for the domain category. An anomaly score may be proportional to a difference between a determined count for the domain category and the upper/lower limit of an interquartile range (or expected range) of counts for the domain category.

The network monitoring platform **104** may update the user profile (e.g., as described with respect to step **618**) based on the web activity determined at step **622**. The network monitoring platform **104** may update the user profile based on the web activity determined at step **622**, for example, if no anomalies are identified for the time interval (e.g., at step **626**).

At step **630**, the network monitoring platform **104** may send one or more notifications to one or more devices in the private network **125** based on detection of an anomaly at step **626**. For example, the network monitoring platform **104** may send a notification to the gateway **110** indicating that an anomaly was detected at the user device. At step **634**, and based on receiving the notification, the gateway **110** may block the user device from communicating via the interval network **125** and/or the external network **130**. For example, the gateway **110** may block any outgoing data traffic from the user device **102** to the external network **130**. The network monitoring platform **104** may send one or more notifications to a server associated with the ISP based on detection of an anomaly at step **626**. The server may block

requests from the user device to access a network. The network monitoring platform **104** may send one or more notifications to the user device based on detection of an anomaly at step **626**. The browser extension associated with a web browser of the user device may disconnect the user device from the network (e.g., deactivate a modem).

Additionally or alternatively, the network monitoring platform **104** may send a notification to the administrative computing device **108** indicating that an anomaly was detected at the user device. A user associated with the administrative computing device **108** may review the anomaly and determine to block the user device **102** from communicating via the interval network **125** and/or the external network **130**. The administrative computing device **108** may send a notification to the gateway **110** to block traffic associated with the user device **102**. One or more of the steps described with respect to step **630** may be performed based on an anomaly score. For example, the network monitoring platform **104** may send a notification to the administrative computing device **108** if an anomaly score is below a threshold score. However, the network monitoring platform **104** may send a notification to the gateway **110**/ server associated with the ISP to block traffic from the user device if an anomaly score is greater than or equal to a threshold score.

FIG. **8** shows an example block diagram with various modules that may be used by the network monitoring platform **104** for detecting anomalous browsing patterns. A distributed file system **804** may store a listing of domains as requested by a plurality of user devices as well as generated user profiles based on domain categorization. A proxy log ingestion module **808** may be used to determine domains requested by the user devices. A categorization module **812** may be used to categorize the domains into domain categories. An anomaly detection module **816** may be used to detect anomalous browsing patterns. The dashboard module **820** may be used to present the determined anomalies (as determined at step **626**) to the administrative computing device **108**. The various modules described with respect to FIG. **5** may correspond to hardware and/or software elements associated with the network monitoring platform **104**, or in communication with the network monitoring platform **104** via the private network **125** and/or public network **130**. One or more of the modules may correspond to computing devices that may be associated with the private network **125**.

Various examples described herein may enable efficient detection of anomalies in user browsing patterns by the use of domain categorization and without content inspection. Detection of anomalies in user browsing patterns may enable detection of malicious activity (e.g., data exfiltration, unauthorized financial transactions, etc.). The domain categorization approach may be flexibly applied for detecting compromised user accounts/devices in both private and public networks.

One or more aspects of the disclosure may be embodied in computer-usable data or computer-executable instructions, such as in one or more program modules, executed by one or more computers or other devices to perform the operations described herein. Generally, program modules include routines, programs, objects, components, data structures, and the like that perform particular tasks or implement particular abstract data types when executed by one or more processors in a computer or other data processing device. The computer-executable instructions may be stored as computer-readable instructions on a computer-readable medium such as a hard disk, optical disk, removable storage media, solid-state memory, RAM, and the like. The func-

tionality of the program modules may be combined or distributed as desired in various embodiments. In addition, the functionality may be embodied in whole or in part in firmware or hardware equivalents, such as integrated circuits, application-specific integrated circuits (ASICs), field programmable gate arrays (FPGA), and the like. Particular data structures may be used to more effectively implement one or more aspects of the disclosure, and such data structures are contemplated to be within the scope of computer executable instructions and computer-usable data described herein.

Various aspects described herein may be embodied as a method, an apparatus, or as one or more computer-readable media storing computer-executable instructions. Accordingly, those aspects may take the form of an entirely hardware embodiment, an entirely software embodiment, an entirely firmware embodiment, or an embodiment combining software, hardware, and firmware aspects in any combination. In addition, various signals representing data or events as described herein may be transferred between a source and a destination in the form of light or electromagnetic waves traveling through signal-conducting media such as metal wires, optical fibers, or wireless transmission media (e.g., air or space). In general, the one or more computer-readable media may be and/or include one or more non-transitory computer-readable media.

As described herein, the various methods and acts may be operative across one or more computing servers and one or more networks. The functionality may be distributed in any manner, or may be located in a single computing device (e.g., a server, a client computer, and the like). For example, in alternative embodiments, one or more of the computing platforms discussed above may be combined into a single computing platform, and the various functions of each computing platform may be performed by the single computing platform. In such arrangements, any and/or all of the above-discussed communications between computing platforms may correspond to data being accessed, moved, modified, updated, and/or otherwise used by the single computing platform. Additionally, or alternatively, one or more of the computing platforms discussed above may be implemented in one or more virtual machines that are provided by one or more physical computing devices. In such arrangements, the various functions of each computing platform may be performed by the one or more virtual machines, and any and/or all of the above-discussed communications between computing platforms may correspond to data being accessed, moved, modified, updated, and/or otherwise used by the one or more virtual machines.

Aspects of the disclosure have been described in terms of illustrative embodiments thereof. Numerous other embodiments, modifications, and variations within the scope and spirit of the appended claims will occur to persons of ordinary skill in the art from a review of this disclosure. For example, one or more of the steps depicted in the illustrative figures may be performed in other than the recited order, and one or more depicted steps may be optional in accordance with aspects of the disclosure.

What is claimed is:

1. A system comprising:
  a user device in communicate via a communication network; and
  a network monitoring platform communicatively coupled to the user device and the communication network, the network monitoring platform comprising:

  at least one processor;
  a communication interface communicatively coupled to the at least one processor; and
  memory storing computer-readable instructions that, when executed by the at least one processor, cause the network monitoring platform to:
    monitor outgoing data associated with the user device and communicated via the communication network;
    predict, based on a seasonal autoregressive integrated moving average (SARIMA) model of data volumes of the outgoing data associated with the user device, expected data volumes of outgoing data for a first set of time intervals;
    measure, without inspecting content, data volumes of outgoing data for the first set of time intervals;
    based on the expected data volumes for the first set of time intervals and the measured data volumes for the first set of time intervals, identify anomalies in the measured data volumes for the first set of time intervals; and
    send, via the communication interface and based on the identification of anomalies, one or more notifications indicating the user device.

2. The system of claim 1, wherein the computer-readable instructions, when executed by the at least one processor, cause the network monitoring platform to:
  measure data volumes of outgoing data for a second set of time intervals; and
  build, based on the measured data volumes for the second set of time intervals, the SARIMA model of data volumes.

3. The system of claim 2, wherein the instructions, when executed by the at least one processor, cause the network monitoring platform to build the SARIMA model of data volumes by causing determining one or more hyperparameters of the SARIMA model that result in a best fit between the measured data volumes for the second set of time intervals and expected data volumes for the second set of time intervals, wherein the expected data volumes for the second set of time intervals are determined based on the SARIMA model.

4. The system of claim 1, wherein the instructions, when executed by the at least one processor, cause the network monitoring platform to identify the anomalies by causing identifying the anomalies based on a difference between a measured data volume and an expected data volume for a time interval in the first set of time intervals being greater than a threshold value.

5. The system of claim 4, wherein the threshold value is a multiple of a standard deviation of the expected data volumes for the first set of time intervals.

6. The system of claim 4, wherein the threshold value is a multiple of a standard deviation of differences between the expected data volumes and the measured data volumes for the first set of time intervals.

7. The system of claim 1, wherein the one or more notifications cause blocking the user device from communicating via the communication network.

8. The system of claim 1, wherein the instructions, when executed by the at least one processor, cause the network monitoring platform to, based on the identification of anomalies, perform at least one of:

initiate a scan of the user device;

send packet captures of the data associated with the user device; or

perform profile analysis of a destination of the data associated with the user device.

9. A method comprising:

monitoring outgoing data associated with a user device and communicated via a communication network;

predicting, based on a seasonal autoregressive integrated moving average (SARIMA) model of data volumes of the outgoing data associated with the user device, expected data volumes of outgoing data for a first set of time intervals;

measuring, without inspecting content, data volumes of outgoing data for the first set of time intervals;

based on the expected data volumes for the first set of time intervals and the measured data volumes for the first set of time intervals, identifying anomalies in the measured data volumes for the first set of time intervals; and

sending, based on the identification of anomalies, one or more notifications indicating the user device.

10. The method of claim 9, further comprising:

measuring data volumes of outgoing data for a second set of time intervals; and

building, based on the measured data volumes for the second set of time intervals, the SARIMA model of data volumes.

11. The method of claim 10, wherein the building the SARIMA model of data volumes comprises determining one or more hyperparameters of the SARIMA model that result in a best fit between the measured data volumes for the second set of time intervals and expected data volumes for the second set of time intervals, wherein the expected data volumes for the second set of time intervals are determined based on the SARIMA model.

12. The method of claim 9, wherein the identifying the anomalies is based on a difference between a measured data volume and an expected data volume for a time interval in the first set of time intervals being greater than a threshold value.

13. The method of claim 12, wherein the threshold value is a multiple of a standard deviation of the expected data volumes for the first set of time intervals.

14. The method of claim 12, wherein the threshold value is a multiple of a standard deviation of differences between the expected data volumes and the measured data volumes for the first set of time intervals.

15. The method of claim 9, wherein the one or more notifications cause blocking the user device from communicating via the communication network.

16. The method of claim 9, further comprising: based on the identification of anomalies, performing at least one of:

initiating a scan of the user device;

sending packet captures of the data associated with the user device; or

performing profile analysis of a destination of the data associated with the user device.

17. A non-transitory computer readable medium storing instructions that, when executed, cause:

monitoring outgoing data associated with a user device and communicated via a communication network;

predicting, based on a seasonal autoregressive integrated moving average (SARIMA) model of data volumes of the outgoing data associated with the user device, expected data volumes of outgoing data for a first set of time intervals;

measuring, without inspecting content, data volumes of outgoing data for the first set of time intervals;

based on the expected data volumes for the first set of time intervals and the measured data volumes for the first set of time intervals, identifying anomalies in the measured data volumes for the first set of time intervals; and

sending, based on the identification of anomalies, one or more notifications indicating the user device.

18. The non-transitory computer readable medium of claim 17, wherein the instructions, when executed, cause:

measuring data volumes of outgoing data for a second set of time intervals; and

building, based on the measured data volumes for the second set of time intervals, the SARIMA model of data volumes.

19. The non-transitory computer readable medium of claim 18, wherein the instructions, when executed, cause the building the SARIMA model of data volumes by causing determining one or more hyperparameters of the SARIMA model that result in a best fit between the measured data volumes for the second set of time intervals and expected data volumes for the second set of time intervals, wherein the expected data volumes for the second set of time intervals are determined based on the SARIMA model.

20. The non-transitory computer readable medium of claim 17, wherein the instructions, when executed, cause the identifying the anomalies based on a difference between a measured data volume and an expected data volume for a time interval in the first set of time intervals being greater than a threshold value.

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