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(54) ELEPHANT FLOW DETECTION IN A COMPUTING DEVICE

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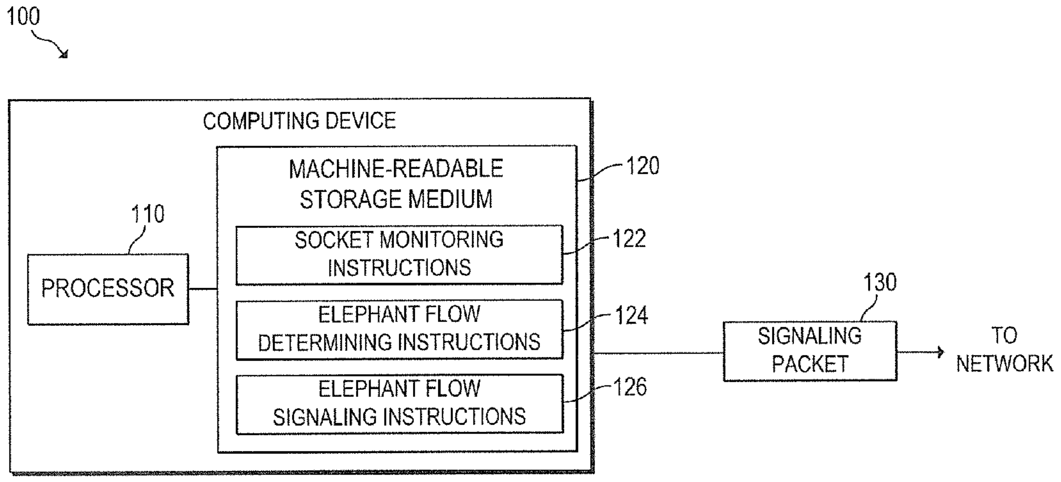
(57) **ABSTRACT**

Example embodiments relate to elephant flow detection in a computing device. In example embodiments, a computing device may monitor a socket for a given flow. The computing device may then determine whether the flow is an elephant flow based on the monitoring of the socket. If so, the computing device may signal the network that transmits the flow that the flow is an elephant flow.


100
COMPUTING DEVICE
MACHINE-READABLE STORAGE MEDIUM
120
110
PROCESSOR
SOCKET MONITORING INSTRUCTIONS
122
ELEPHANT FLOW DETERMINING INSTRUCTIONS
124
ELEPHANT FLOW SIGNALING INSTRUCTIONS
126
130
SIGNALING PACKET
TO NETWORK

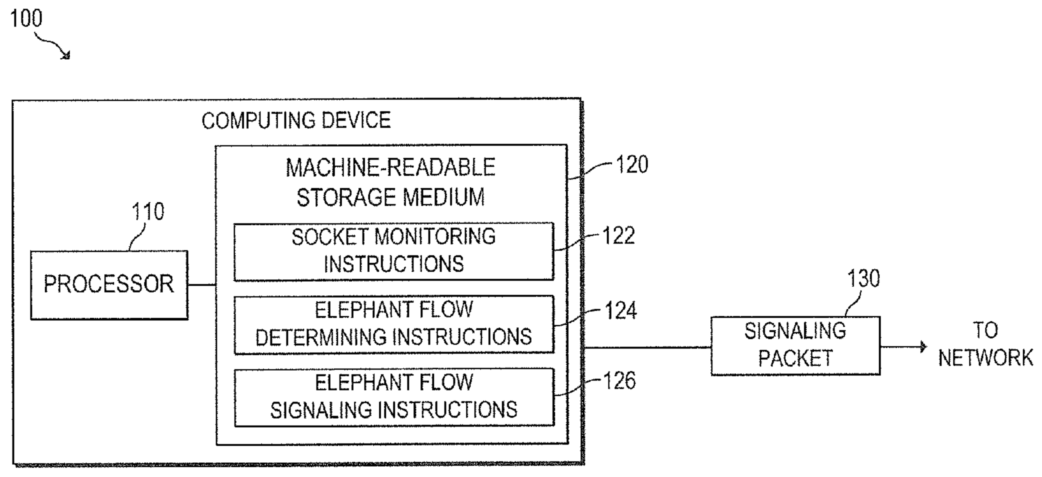

100
COMPUTING DEVICE
MACHINE-READABLE STORAGE MEDIUM
120
110
PROCESSOR
SOCKET MONITORING INSTRUCTIONS
122
ELEPHANT FLOW DETERMINING INSTRUCTIONS
124
ELEPHANT FLOW SIGNALING INSTRUCTIONS
126
130
SIGNALING PACKET
TO NETWORK

FIG. 1

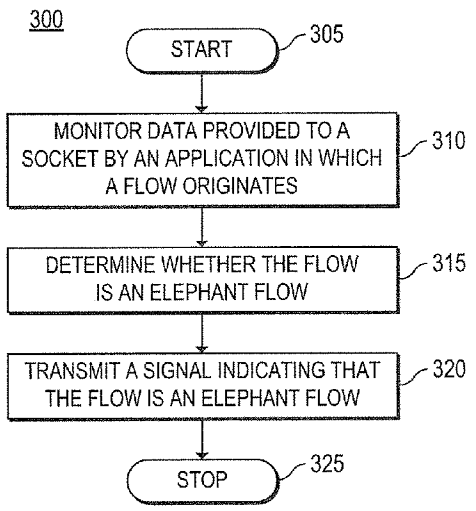

300
START
305
MONITOR DATA PROVIDED TO A SOCKET BY AN APPLICATION IN WHICH A FLOW ORIGINATES
310
DETERMINE WHETHER THE FLOW IS AN ELEPHANT FLOW
315
TRANSMIT A SIGNAL INDICATING THAT THE FLOW IS AN ELEPHANT FLOW
320
STOP
325

FIG. 3

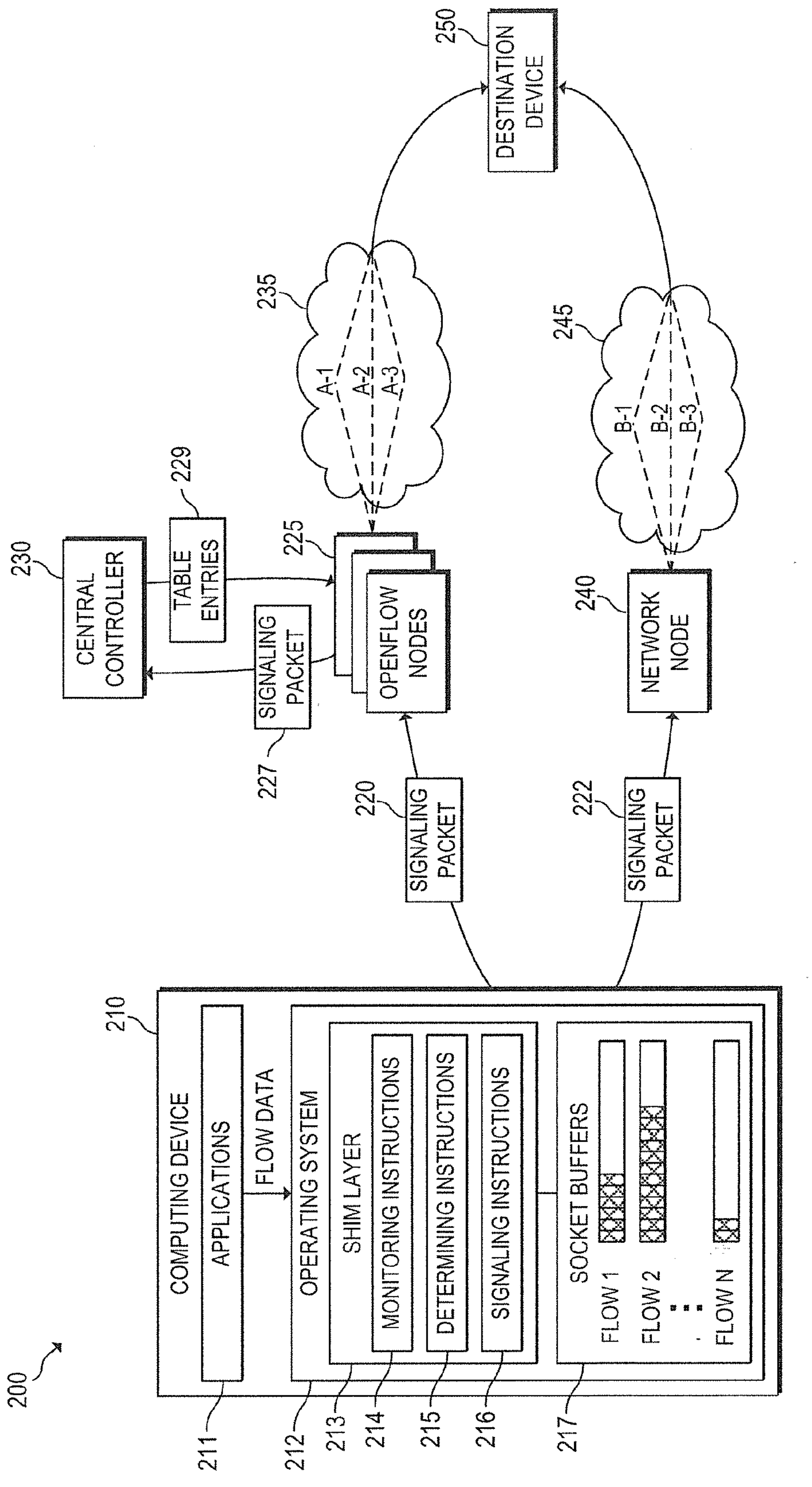

200
210
COMPUTING DEVICE
APPLICATIONS
FLOW DATA
OPERATING SYSTEM
SHIM LAYER
MONITORING INSTRUCTIONS
DETERMINING INSTRUCTIONS
SIGNALING INSTRUCTIONS
SOCKET BUFFERS
FLOW 1
FLOW 2
FLOW N
211
212
213
214
215
216
217
220
SIGNALING PACKET
222
SIGNALING PACKET
225
OPENFLOW NODES
227
SIGNALING PACKET
229
TABLE ENTRIES
230
CENTRAL CONTROLLER
235
A-1
A-2
A-3
240
NETWORK NODE
245
B-1
B-2
B-3
250
DESTINATION DEVICE

FIG. 2

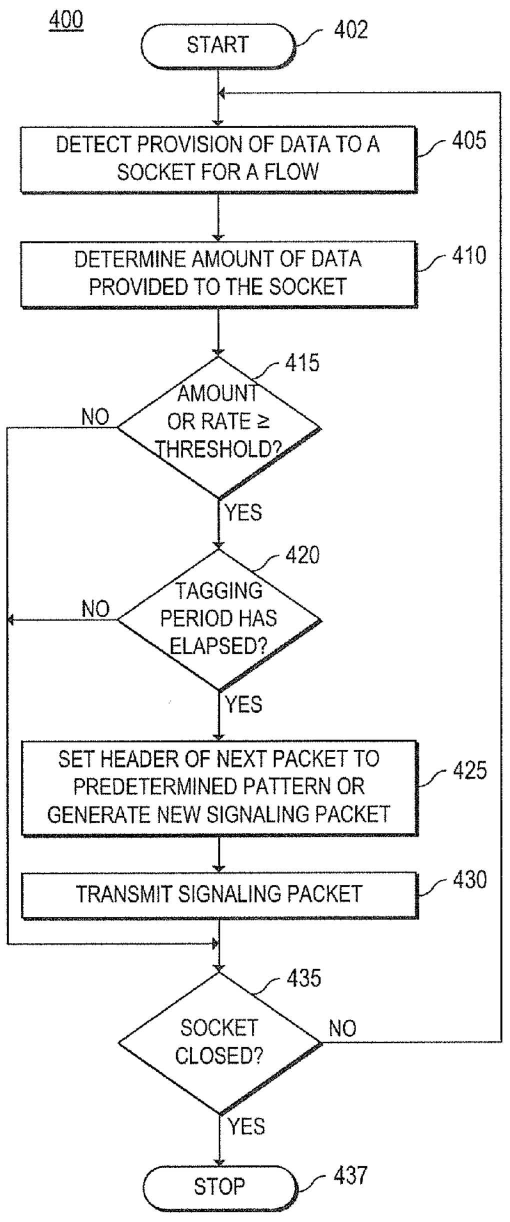

400
START
402
DETECT PROVISION OF DATA TO A SOCKET FOR A FLOW
405
DETERMINE AMOUNT OF DATA PROVIDED TO THE SOCKET
410
AMOUNT OR RATE ≥ THRESHOLD?
415
NO
YES
TAGGING PERIOD HAS ELAPSED?
420
NO
YES
SET HEADER OF NEXT PACKET TO PREDETERMINED PATTERN OR GENERATE NEW SIGNALING PACKET
425
TRANSMIT SIGNALING PACKET
430
SOCKET CLOSED?
435
NO
YES
STOP
437

FIG. 4A

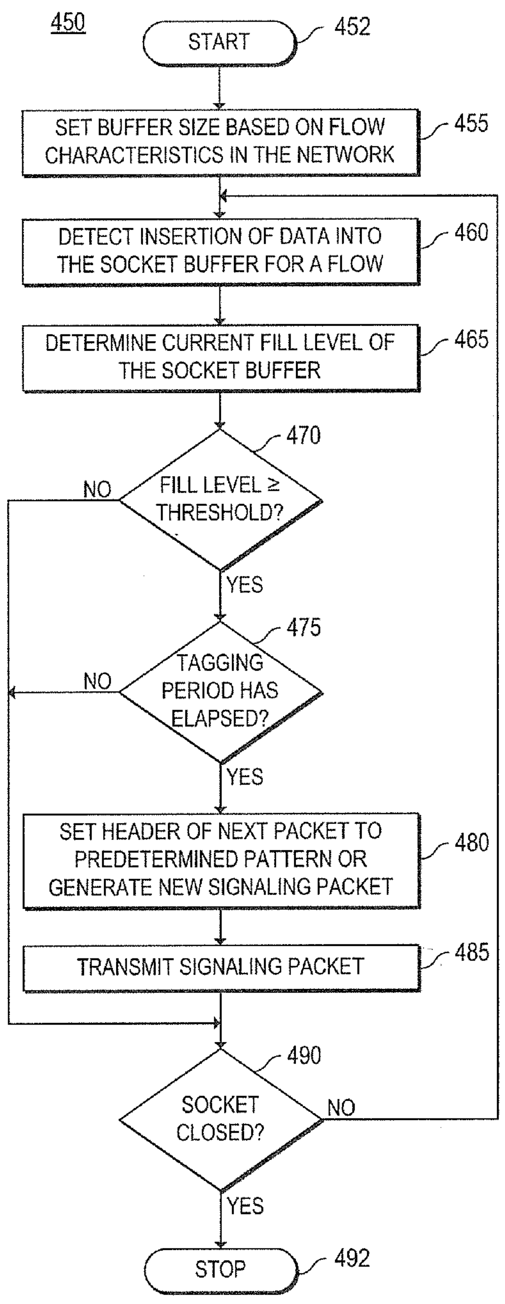

450
START
452
SET BUFFER SIZE BASED ON FLOW CHARACTERISTICS IN THE NETWORK
455
DETECT INSERTION OF DATA INTO THE SOCKET BUFFER FOR A FLOW
460
DETERMINE CURRENT FILL LEVEL OF THE SOCKET BUFFER
465
FILL LEVEL ≥ THRESHOLD?
470
NO
YES
TAGGING PERIOD HAS ELAPSED?
475
NO
YES
SET HEADER OF NEXT PACKET TO PREDETERMINED PATTERN OR GENERATE NEW SIGNALING PACKET
480
TRANSMIT SIGNALING PACKET
485
SOCKET CLOSED?
490
NO
YES
STOP
492

FIG. 4B

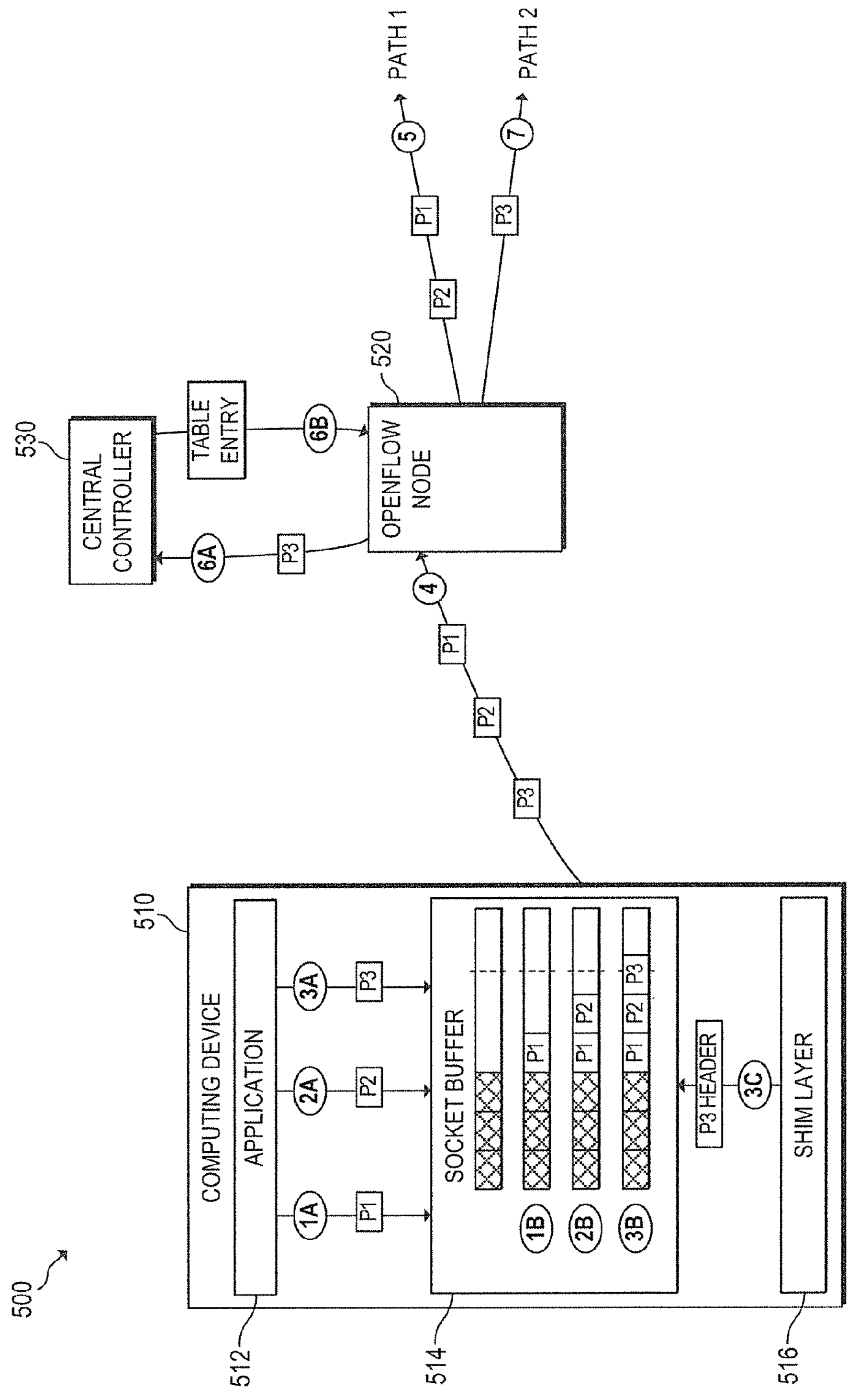

500
510
COMPUTING DEVICE
APPLICATION
512
1A
2A
3A
P1
P2
P3
SOCKET BUFFER
514
1B
2B
3B
P1
P2
P3
P3 HEADER
3C
SHIM LAYER
516
4
520
OPENFLOW NODE
530
CENTRAL CONTROLLER
6A
6B
TABLE ENTRY
5
PATH 1
7
PATH 2

FIG. 5

ELEPHANT FLOW DETECTION IN A COMPUTING DEVICE

BACKGROUND

[0001] Modern communication networks are capable of transferring a massive amount of data in a small period of time. For example, a typical data center may include hundreds or even thousands of servers, each capable of transmitting numerous gigabits of data per second. Although the capabilities of networks are ever increasing, so too is the amount of data transferred by applications that utilize these networks. Traffic management is therefore important in ensuring efficient utilization of the available network bandwidth.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] The following detailed description references the drawings, wherein:

[0003] FIG. **1** is a block diagram of an example computing device for detection of elephant flows;

[0004] FIG. **2** is a block diagram of an example system for detection of elephant flows based on monitoring of a socket buffer by a shim layer included in an operating system of a computing device;

[0005] FIG. **3** is a block diagram of an example method for detection of elephant flows;

[0006] FIG. **4**A is a block diagram of an example method for detection of elephant flows based on monitoring of an amount or rate of data provided to a socket;

[0007] FIG. **4**B is a block diagram of an example method for detection of elephant flows based on monitoring of a fill level of a socket buffer; and

[0008] FIG. **5** is a block diagram of an example operation flow illustrating the processing of example packets by a computing device.

DETAILED DESCRIPTION

[0009] As detailed above, traffic management is important in ensuring that a network operates in an efficient manner by optimizing performance and minimizing congestion. For example, when a network includes multiple available paths for a given flow of data, an effective traffic management strategy ensures that the flow uses the most efficient path. In a typical network, a small percentage of flows consumes the large majority of bandwidth and therefore has the greatest impact on performance of the network. It is therefore a central problem of any traffic management strategy to identify and manage the flows that consume a large amount of bandwidth, sometimes known as "elephant flows." In particular, because elephant flows typically account for the majority of the data, proper management of these flows will have the greatest effect on the performance of the network.

[0010] Existing solutions for identifying elephant flows are deficient in a number of ways. For example, in some solutions, each application is responsible for marking flows that consume a significant amount of bandwidth. Although efficient, this approach can be problematic, as every application must be modified to support this behavior. Furthermore, this solution may be subject to abuse, as the application may be modified to mark flows in a manner inconsistent with the purpose of the traffic management strategy.

[0011] In other solutions, a switch in the network monitors each flow that passes through to gather statistics. The switch may then transfer these statistics to a central controller on a periodic basis to enable the controller to classify flows. This approach is not scalable to large networks for several reasons. First, the process of monitoring each flow at a given switch consumes a significant amount of resources, as it generally requires a Ternary Content-Addressable Memory (TCAM) entry for each flow. In addition, transfers of statistics may consume a significant amount of bandwidth between each switch and the central controller, such that the transfer of statistics becomes the bottleneck in the network.

[0012] In yet another solution, a central controller samples a small percentage of packet headers from all ports of the switches in a network (e.g., 1 out of every 1,000 packets). In this approach, the central controller analyzes the sampled packet headers to classify flows. While this approach uses little bandwidth, it is also slow to detect elephant flows, sometimes requiring a flow to transfer upwards of 15 megabytes before it is detected as an elephant flow. Furthermore, this approach imposes a significant amount of overhead on the central controller, since the controller must process each sampled packet.

[0013] Thus, in summary, current solutions require modification of each application, require a large amount of bandwidth or switch processing, or are too slow to be effective. To address the problems with current solutions, example embodiments disclosed herein implement elephant flow detection by monitoring outgoing data provided to a socket in the computing device by an application in which the flow originates. For example, the computing device may monitor outgoing data provided to a socket by a User Datagram Protocol (UDP) flow or monitor outgoing data provided to a socket buffer used to queue packets belonging to a Transmission Control Protocol (TCP) flow. If the computing device determines that the flow is an elephant flow based on the monitoring, the computing device may then signal the network that transmits the flow that the flow is an elephant flow.

[0014] By identifying elephant flows based on examination of the data provided to a socket in the source computing device, example embodiments minimize or eliminate the need for modification of applications in the computing device. Furthermore, because the elephant flow determination may be performed at the source of the flow, rather than in the network, example embodiments minimize the overhead required for transmission of statistics and/or sampled packets. In this manner, example embodiments allow for faster identification of elephant flows with low overhead and minimal or no modification of applications. Additional embodiments and applications of such embodiments will be apparent to those of skill in the art upon reading and understanding the following description.

[0015] Referring now to the drawings, FIG. **1** is a block diagram of an example computing device **100** for detection of elephant flows. Computing device **100** may be, for example, a notebook computer, a desktop computer, a slate computing device, a wireless email device, a mobile phone, a server in a data center or other network, or any other computing device. In the embodiment of FIG. **1**, computing device **100** includes processor **110** and machine-readable storage medium **120**.

[0016] Processor **110** may be one or more central processing units (CPUs), semiconductor-based microprocessors, and/or other hardware devices suitable for retrieval and execution of instructions stored in machine-readable storage medium **120**. Processor **110** may fetch, decode, and execute instructions **122**, **124**, **126** to implement the elephant flow detection procedure described in detail below. As an alternative or in addition to retrieving and executing instructions, processor **110** may include one or more integrated circuits (ICs) or other electronic circuits that include a number of electronic components for performing the functionality of one or more of instructions **122**, **124**, **126**.

[0017] Machine-readable storage medium **120** may be any electronic, magnetic, optical, or other physical storage device that contains or stores executable instructions. Thus, machine-readable storage medium may be, for example, Random Access Memory (RAM), an Electrically Erasable Programmable Read-Only Memory (EEPROM), a storage drive, a Compact Disc Read Only Memory (CD-ROM), and the like. As described in detail below, machine-readable storage medium **120** may be encoded with a series of executable instructions **122**, **124**, **126** for detecting elephant flows based on sockets corresponding to flows that originate in computing device **100**. In some embodiments, instructions **122**, **124**, **126** may be implemented in the operating system of computing device **100**, thus minimizing the need to modify the applications of computing device **100**.

[0018] Machine-readable storage medium **120** may include socket monitoring instructions **122**, which may monitor data provided to a socket in computing device **100** by an application in which a particular data flow originates (e.g., the source endpoint of a flow). The socket may be a mechanism provided by the operating system for use by the application when transmitting outgoing data packets or other protocol data units. For example, the operating system may create a socket upon receipt of a request from an application or thread via an Application Programming Interface (API). The application may be any application that exchanges data with a remote device (e.g., a web server or browser, a Peer-to-Peer application, a File Transfer Protocol (FTP) server, a storage server, etc.). When the application has a data packet ready for transmission to the destination, the source application may provide the data packet to the socket and the operating system may then manage transmission of the data packet toward the destination.

[0019] Because the operating system manages the socket buffer, monitoring instructions **122** may be implemented as a shim layer in the operating system of computing device **100**. The shim layer may be logic configured to examine data transmitted between two layers of the network protocol stack (e.g., between the transport and network layers), thereby leaving the structure of the existing network protocol stack intact. Thus, monitoring instructions **122** may have visibility of all data provided to each socket by each application. Monitoring instructions **122** may therefore observe the amount of data provided to a socket and, as detailed below, determining instructions **124** may analyze this data to identify elephant flows.

[0020] The mechanism used to monitor the socket may vary according to the protocol to be used for transmission of the data. For example, the operating system may provide a socket buffer for some protocols, such as the Transmission Control Protocol (TCP). The socket buffer may be a portion of memory in storage medium **120** or another storage medium accessible to computing device **100** that temporarily queues data belonging to a particular flow prior to transmission. Thus, the socket buffer may be, for example, a Transmission Control Protocol (TCP) buffer to temporarily store packets to be transmitted over a TCP connection from a source application in computing device **100** to a destination application in another computing device. In implementations in which the protocol uses a socket buffer, monitoring instructions **122** may monitor a fill level of the buffer, a total amount of data added to the buffer, or a rate at which data is added to the buffer.

[0021] On the other hand, the operating system of computing device **100** may not provide a buffer for some protocols. For example, the User Data Protocol (UDP) typically does not utilize a buffer in the operating system. In such implementations, monitoring instructions **122** may directly monitor the data provided to the socket via the API or other interface from the application to the operating system. For example, monitoring instructions **122** may monitor a total amount of data provided to the socket or a rate at which data is provided to the socket. It should be noted that, in some implementations, monitoring instructions **122** may directly monitor the data provided to the socket, rather than the buffer, even if the operating system provides a buffer for a particular protocol. Several example approaches for monitoring data provided to a socket are described below in connection with FIGS. **4**A & **4**B.

[0022] Machine-readable storage medium **120** may further include elephant flow determining instructions **124**, which may determine, based on the amount of data provided to a particular socket by a particular application, whether the corresponding flow is an elephant flow. The determination of whether a given flow is an elephant flow may depend on the particular network. For example, in a high-bandwidth network, such as a data center, the size of a typical elephant flow is greater than in a lower-bandwidth network, such as a cellular network. The sizes of typical elephant flows will be apparent to those of skill in the art based on the particular network utilized by computing device **100**.

[0023] As one example implementation of determining instructions **124**, when monitoring instructions **122** provide information regarding the total amount of data or the rate at which data belonging to the flow is provided to the socket, instructions **124** may compare this amount or rate to a predetermined threshold. When the total amount of data or rate at which the source application is providing data to the socket exceeds the threshold, determining instructions **124** may determine that the corresponding flow is an elephant flow.

[0024] As another example, when monitoring instructions **122** provide information regarding the current fill level of a socket buffer corresponding to the socket, determining instructions **124** may compare the fill level to a predetermined threshold (e.g., 50% full, 75% full, completely full). When the current fill level reaches the predetermined threshold fill level, determining instructions **124** may determine that the corresponding flow is an elephant flow.

[0025] Finally, machine-readable storage medium **120** may include elephant flow signaling instructions **126**, which may signal a network used for transmission of the particular flow when it is determined that the particular flow is in fact an elephant flow. For example, signaling instructions **126** may utilize an in-band signaling mechanism to notify one or more switches, routers, controllers, or other network nodes that the flow is an elephant flow.

[0026] The particular signaling mechanism utilized for notifying the network of an elephant flow may vary by embodiment. In some embodiments, signaling instructions **126** may utilize a portion of the header of a packet belonging to the flow. For example, signaling instructions **126** may add a predetermined pattern of bits to the Differentiated Services Code Point (DSCP) field, a Virtual Local Area Network

(VLAN) Priority Code Point (PCP), or another field of the Internet Protocol (IP) header of a packet belonging to the flow. As a specific example, signaling instructions **126** may set the DSCP field to "000011," as the code point space corresponding to "xxxx11" is generally reserved for experimental or local usage. In other embodiments, signaling instructions **126** may utilize one or more packets to transmit a separate elephant flow notification message into the network, provided that these packets include information sufficient to uniquely identify the flow.

[0027] In response to receipt of a notification of an elephant flow, the network may utilize the signal to, for example, assign the flow to the best available path in the network. Additional details regarding the use of the elephant flow signal to reconfigure the network are provided below in connection with network nodes **225**, **230**, **240** of FIG. **2**.

[0028] FIG. **2** is a block diagram of an example system **200** for detection of elephant flows based on monitoring of a socket buffer **217** by a shim layer **213** included in an operating system **212** of a computing device **210**. As detailed below, system **200** may include a computing device **210** that transmits data to a destination device **250** via network nodes **225**, **240** and networks **235**, **245**.

[0029] As with computing device **100** of FIG. **1**, computing device **210** may be a notebook computer, a desktop computer, a slate computing device, a wireless email device, a mobile phone, a server, or any other computing device. Computing device **210** may include a processor (not shown), such as a processor **110** described above in connection with FIG. **1**. Computing device **210** may also include a machine-readable storage medium encoded with executable instructions. For example, operating system **212** and instructions **214**, **215**, **216** included in shim layer **213** may be encoded on the machine-readable storage medium and executed by the processor.

[0030] Operating system **212** may include a series of executable instructions for managing the hardware of computing device **210**. Furthermore, operating system **212** may provide an interface to applications executing on computing device **210** (e.g., an API), such that the applications may access the hardware. For example, operating system **212** may provide one or more sockets to each application for transmission of data packets from computing device **210** to a destination device **250**. After an application provides data packets to the sockets, the operating system may then manage transmission of the data using a corresponding hardware interface, such as a network interface card. In some embodiments, operating system **212** may provide a socket buffer **217** for each flow to temporarily queue data packets prior to transmission via the appropriate interface.

[0031] Because operating system **212** has a view of the data packets transmitted by each application via the sockets, a shim layer **213** may be included in operating system **212** to inspect the data provided to the sockets or corresponding socket buffers **217**. For example, shim layer **213** may include logic for examining data transmitted between two layers of the network stack to identify elephant flows. Thus, shim layer **213** may include monitoring instructions **214**, determining instructions **215**, and signaling instructions **216**, each described in turn below.

[0032] Monitoring instructions **214** may monitor outgoing data provided from an application to a socket provided by operating system **212**. This outgoing data may be associated with a particular flow originating in the application. For example, the flow may include data transmitted by a server (e.g., a web server or storage server), a peer-to-peer file sharing program, a web browser, or any other application that transmits data belonging to a flow to a destination device **250**.

[0033] In operation, monitoring instructions **214** may monitor the data provided to a socket and, in some cases, to a socket buffer **217** corresponding to a flow. For example, monitoring instructions **214** may monitor an amount of data provided by an application to the socket or socket buffer **217** over a predetermined period of time. Alternatively, monitoring instructions **214** may track a total amount of data provided to the socket or socket buffer **217** since the socket was opened by the application for the particular flow. As another alternative, monitoring instructions **214** may monitor the fill level of a socket buffer **217** with respect to the total capacity of the buffer **217**.

[0034] Determining instructions **215** may determine, based on the monitoring performed by instructions **214**, whether the particular flow is an elephant flow. For example, determining instructions **215** may determine that a flow is an elephant flow when the total amount of data provided to the socket during a predetermined period of time exceeds a given threshold value. The threshold may be, for example, a total number of bytes or a rate at which the data was transmitted during the period in, for example, bytes per second. Similarly, determining instructions **215** may determine that a flow is an elephant flow when the total amount of data transmitted since the socket was opened exceeds a given threshold value. As another example, determining instructions **215** may determine that the flow is an elephant flow when the fill level of the socket buffer **217** corresponding to the particular flow meets or exceeds a given level (e.g., 75% or more full).

[0035] It should be noted that the thresholds used by determining instructions may vary depending on the application, the network used for transmission of the flow, and other factors. For example, when the network is a high-bandwidth network, such as those used in a data center, the threshold for the amount of data or the transfer rate may be higher than when the network is a cellular or wireless network. Suitable data amounts and transfer rates will be apparent to those of skill in the art.

[0036] Based on the determination made by instructions **215**, signaling instructions **216** may generate and transmit a signal **220**, **222** into the network used for transmission of the particular flow. This signal **220**, **222** may notify the network that the flow is an elephant, such that the network may properly route the flow. As with signaling instructions **126** of FIG. **1**, signaling instructions **216** may utilize a portion of the header of a packet belonging to the flow or may instead use a dedicated signaling packet.

[0037] The type of signaling packet and the corresponding response in the network may vary based on the type of network. For example, in networks operating according to the OpenFlow specification, a central controller **230** is responsible for managing the routing tables stored on each OpenFlow node **225**. In particular, upon receipt of a packet, if an OpenFlow node **225** does not have an entry in the routing table matching the packet, the node **225** forwards the packet to the central controller **230**, which responds with a routing table entry. OpenFlow nodes **225** may also contain table entries specifying particular packets to be forwarded to the central controller **230**, such as packets with a particular pattern in the header.

[0038] Signaling instructions **216** may utilize the OpenFlow architecture to ensure that elephant flows are properly routed. When the network is initialized, central controller **230** may instruct all nodes **225** to forward all packets containing a particular pattern in the header (e.g., a DSCP value of "000011") to central controller **230**. Subsequently, when computing device **210** detects an elephant flow, signaling instructions **216** may set the header of a packet to the pattern and transmit the signaling packet **220** to an appropriate OpenFlow node **225**.

[0039] Upon receipt of the signaling packet **220** identifying an elephant flow, the OpenFlow node **225** may forward the packet **227** to central controller **230**, which will respond to one or more nodes **225** with table entries **229** specifying how the elephant flow is to be routed through network **235**. For example, controller **230** may compute the best available path through network **235** and the table entries **229** may define this path. Each node **225** may then install these table entries **229** into its routing table. As a result, upon receipt of subsequent packets in the flow, the OpenFlow node **225** may forward the packet to destination device **250** via the next node in the path computed by the central controller **230** (e.g., Path A-1, A-2, or A-3).

[0040] In some embodiments, central controller **230** may implement a mechanism to control the number of packets forwarded by the nodes **225** based on its processing load. For example, setting the elephant flow threshold in computing device **210** to a value that is too low may result in controller **230** being inundated with signaling packets **227**. Accordingly, when controller **230** is receiving too many signaling packets **227**, controller **230** may transmit a signal to each computing device **210**, instructing the computing device **210** to raise its threshold. As an alternative, multiple packet header values may correspond to different levels of thresholds. For example, when using DSCP values, a value of xxxx11 may denote a flow that has more than 100 kilobytes (KB) of data, a value of xxx111 may denote more than 1 megabyte (MB) of data, a value of xx1111 may denote more than 10 MBs of data, etc. In such embodiments, central controller **230** may dynamically regulate the number of signaling packets **227** it receives based on its load by modifying the table entries in each node **225** to correspond to a particular threshold value.

[0041] In other networks, a network node **240** may select a path for a flow based on a priority or bandwidth-requirements of the flow. For example, network node **240** may associate a predetermined Quality of Service (QoS) with each of a number of paths, B-1, B-2, B-3, in network **245** and may utilize these paths according to the requirements of each flow. Accordingly, in some implementations, signaling instructions **216** may generate and transmit a signaling packet **222** indicating that the flow is an elephant and, in response, network node **240** may select the best-available path for transmission of the elephant flow. Upon receipt of subsequent packets belonging to the elephant flow, network node **240** may then transmit the packets to destination device **250** via the identified path.

[0042] FIG. **3** is a block diagram of an example method **300** for detection of elephant flows. Although execution of method **300** is described below with reference to computing device **100**, other suitable components for execution of method **300** will be apparent to those of skill in the art (e.g., computing device **210**). Method **300** may be implemented in the form of executable instructions stored on a machine-readable storage medium, such as storage medium **120**, and/or in the form of electronic circuitry.

[0043] Method **300** may start in block **305** and proceed to block **310**, where computing device **100** may monitor data provided to a socket by an application in which a particular flow originates. For example, a shim layer included in the operating system of computing device **100** may monitor an amount of data provided from the application to the socket. The amount of data may be, for example, a total amount of data provided since the application opened the socket, an amount or rate of data provided to the socket during a predetermined period of time, or a fill level of a socket buffer corresponding to the socket. Additional details regarding two example methods for monitoring a socket are provided below in connection with FIGS. **4**A & **4**B.

[0044] In block **315**, computing device **100** may determine whether the flow is an elephant flow based on the amount of data provided to the operating system. For example, computing device **100** may determine that the flow is an elephant flow when the amount of data provided to the socket exceeds a predetermined threshold.

[0045] When computing device **100** determines in block **315** that the flow is an elephant flow, method **300** may proceed to block **320**, where computing device **100** may transmit a signal indicating that the particular flow is an elephant flow. For example, computing device **100** may set one or more fields in the header of a packet belonging to the flow to a predetermined pattern. Alternatively, computing device **100** may generate and transmit a dedicated signaling packet into the network. After appropriately notifying the network of the presence of an elephant flow, method **300** may proceed to block **325**, where method **300** may stop. It should be noted that method **300** may be repeated multiple times for a given flow while the socket remains open, since a flow may switch between being an elephant and a non-elephant flow while the flow is transmitting data.

[0046] FIGS. **4**A & **4**B, each described below, are methods **400**, **450** that detect an elephant flow based on data provided from an application to a socket or socket buffer. Although methods **400**, **450** are described below with reference to computing device **210**, other suitable components for execution of methods **400**, **450** will be apparent to those of skill in the art. Methods **400**, **450** may be implemented in the form of executable instructions stored on a machine-readable storage medium and/or in the form of electronic circuitry.

[0047] FIG. **4**A is a block diagram of an example method **400** for detection of elephant flows based on monitoring of an amount or rate of data provided to a socket. Method **400** may start in block **402** and proceed to block **405**, where computing device **210** may detect provision of data to a socket opened by an application in which a particular flow originates. For example, a shim layer **213** included in an operating system **212** of computing device **210** may detect the provision of data from the application to the socket. As detailed above, in some implementations, computing device **210** may monitor a socket buffer used to queue data provided to the socket by the application.

[0048] Upon detection of the provision of data to the socket, method **400** may then proceed to block **410**, where computing device **210** may determine the amount of data provided to the socket as, for example, a number of bytes. Computing device **210** may then add the determined number of bytes to a running total, which may track a total amount of data provided to the socket since it was opened. Alternatively, the total may track a total amount of data provided to the socket in a given period of time. In such implementations, computing device **210** may determine a rate at which data is provided to the socket by dividing the total amount of data for the time period by the duration of the time period.

[0049] After computing device **210** determines the total amount of data or a corresponding rate, method **400** may proceed to block **415**, where computing device **210** may determine whether the amount of data or the determined rate is greater than or equal to a threshold level. The threshold level may vary based, for example, on the characteristics of the network used for transmission of the flow, such that the threshold is higher in networks with a greater amount of bandwidth.

[0050] When computing device **210** determines that the amount of data or the rate is greater than or equal to the threshold, method **400** may proceed to block **420**. In block **420**, computing device **210** may determine whether a minimal amount of time has elapsed since the elephant flow was last tagged. In other words, to ensure that a central controller **230** or other node **240** is not overly burdened with elephant flow signals, computing device **210** may only send out a signal once every t seconds, where t may vary by implementation.

[0051] When computing device **210** determines that the tagging period has elapsed, method **400** may continue to block **425**, where computing device **210** may generate the signaling packet. For example, computing device **210** may either set the header of the next packet to a predetermined pattern or generate a dedicated signaling packet. In block **430**, computing device **210** may transmit the signaling packet to the next hop in the network, which may be, for example, an OpenFlow node **225** or another network node **240**.

[0052] Method **400** may then proceed to block **435**. Alternatively, if computing device **210** determines in block **415** that the amount or rate is less than the threshold or determines in block **420** that the tagging period has not elapsed, method **400** may skip directly to block **435**. In block **435**, computing device **210** may determine whether the socket corresponding to the particular flow has been closed. If not, method **400** may return to block **405**, where computing device **210** may continue monitoring the socket for provision of data. Otherwise, method **400** may proceed to block **437**, where method **400** may stop.

[0053] FIG. 4B is a block diagram of an example method **450** for detection of elephant flows based on monitoring of a fill level of a socket buffer. Method **450** may start in block **452** and proceed to block **455**, where computing device **210** may configure the size of the socket buffer based on flow characteristics of the target network. For example, in a high-bandwidth network, such as a data center, a typical flow is relatively large, so computing device **210** may set the buffer to a large size (e.g., 1 megabyte). In contrast, in a lower-bandwidth network, such as a cellular or wireless network, where typical flows are much smaller, computing device **210** may set the buffer to a smaller size (e.g., 64 kilobytes).

[0054] Method **450** may then proceed to block **460**, where computing device **210** may detect insertion of data into the socket buffer corresponding to a flow. For example, a shim layer **213** in the operating system **212** of computing device **210** may detect insertion of data into the socket buffer by the application in which the flow originates.

[0055] After detection of the insertion of data into the socket buffer, method **450** may proceed to block **465**, where computing device **210** may determine the current fill level of the buffer. For example, computing device **210** may determine the total number of bytes of data queued in the buffer or, alternatively, may determine the percentage of the buffer that is occupied.

[0056] In block **470**, computing device **210** may determine whether the fill level of the socket buffer has reached a threshold level. The threshold may be, for example, a percentage (e.g., 75% full) or an amount of data (e.g., 64 kilobytes, 1 megabyte, etc.). If the socket buffer has reached the fill level, method **450** may continue to block **475**, where, as with block **420** of FIG. **4**A, computing device **210** may determine whether a tagging period has elapsed. If so, method **450** may proceed to blocks **480** and **485**, where computing device **210** may generate and transmit a signaling packet, as described above in connection with blocks **425** and **430** of FIG. **4**A.

[0057] Method **450** may then proceed to block **490**. Alternatively, if computing device **210** determines in block **470** that the fill level is lower than the threshold or determines in block **475** that the tagging period has not elapsed, method **450** may skip directly to block **490**. In block **490**, computing device **210** may determine whether the socket corresponding to the particular flow has been closed. If not, method **450** may return to block **460**, where computing device **210** may continue monitoring the socket buffer for insertion of data. Otherwise, method **450** may proceed to block **492**, where method **400** may stop.

[0058] FIG. **5** is a block diagram of an example operation flow **500** illustrating the processing of example packets by a computing device **510**. As illustrated, computing device **510** includes an application **512** that provides data to a socket buffer **514** that temporarily stores data for a particular flow. A shim layer **516** included in the operating system of computing device **510** monitors the fill level of socket buffer **514** to determine whether the flow associated with application **512** is an elephant flow.

[0059] It should be noted that, although operation flow **500** is described below with reference to a shim layer **516** that monitors the fill level of a socket buffer **514**, operation flow **500** is equally applicable to implementations in which a buffer is not utilized (e.g., when device **510** transmits a UDP flow). Furthermore, although described in connection with a network that complies with the OpenFlow specification, operation flow **500** is applicable to any network.

[0060] Referring now to block **1**A of operation flow **500**, application **512** initially generates a first data packet, P**1**, and provides the packet to socket buffer **514** using, for example, an API provided by the operating system of computing device **510**. As shown by block **1**B, packet P**1** is inserted into the socket buffer. Shim layer **516** detects this insertion, but takes no action, as the fill level of socket buffer **514** has not reached the predetermined threshold (illustrated by the dotted line). In block **2**A, application **512** generates a second data packet, P**2**, and inserts the packet into buffer **514**, as shown by block **2**B. Again, shim layer **516** detects this insertion, but takes no action.

[0061] Next, in block **3**A, application **512** generates a third data packet, P**3**, and inserts P**3** into buffer **514**. As illustrated by block **3**B, the fill level of buffer **514** has now exceeded the threshold. Accordingly, shim layer **516** detects this condition and, in block **3**C, generates a header for P**3** that includes a marking indicating that the flow is an elephant flow.

[0062] In block **4**, computing device **510** begins emptying socket buffer **514** and, in the process, transmits packets P**1**, P**2**, and P**3** to the next hop, OpenFlow node **520**. Upon receipt of the unmarked packets, P**1** and P**2**, node **520** forwards the packets along path **1**, as illustrated by block **5**.

[0063] Upon receipt of P**3**, however, node **520** detects the modified header with the elephant flow marking and therefore forwards P**3** to central controller **530**, as shown by block **6**A. In response, central controller **530** determines the most efficient path for the flow (here, Path **2**) and, as shown by block **6**B, transmits a forwarding table entry to node **520**. In response, node **520** updates its forwarding table and, as shown by block **7**, begins transmitting packets belonging to the elephant flow over Path **2**, starting with packet P**3**.

[0064] According to the foregoing, example embodiments disclosed herein allow for fast detection of elephant flows in a manner that minimizes bandwidth usage in the network. Furthermore, because the flow detection process may be implemented in the operating system of the source of a flow, example embodiments minimize or eliminate the need to modify individual applications. Additional advantages of embodiments disclosed herein will be apparent based on the foregoing description.

1. A source computing device for detection of elephant flows, the source computing device comprising:
- a processor to:
- monitor outgoing data provided from an application to a socket provided by an operating system (OS) of the source computing device, the outgoing data associated with a particular flow originating in the application,
- determine, at the source computing device, based on the monitoring of the outgoing data provided to the socket, whether the particular flow is an elephant flow, and
- send a signal into a network that transmits the particular flow, the signal indicating that the particular flow is an elephant flow.

2. The source computing device of claim **1**, wherein, to monitor, determine, and send, the processor executes logic included in a shim layer of the OS of the computing device.

3. The source computing device of claim **1**, wherein:
- the processor monitors an amount of data provided to the socket during a given period of time,
- the processor determines a rate at which the data was provided to the socket based on the amount of data and a duration of the given period of time, and
- the processor determines that the particular flow is an elephant flow when the determined rate exceeds a given value.

4. The source computing device of claim **1**, wherein:
- the processor monitors a total amount of data provided to the socket since the socket was opened for the particular flow, and
- the processor determines that the particular flow is an elephant flow when the total amount of data provided to the socket exceeds a given value.

5. The source computing device of claim **1**, wherein:
- the processor monitors a current fill level of a socket buffer corresponding to the socket, and
- the processor determines that the particular flow is an elephant flow when the current fill level of the socket buffer reaches a given level.

6. The source computing device of claim **5**, wherein the processor is further configured to size the socket buffer based on characteristics of a plurality of flows in the network used for transmission of the particular flow.

7. The source computing device of claim **1**, wherein the signal sent by the processor comprises one of:
- a packet belonging to the particular flow in which the processor sets at least one bit in a header of the packet, the at least one bit indicating that the particular flow is an elephant flow, and
- a separate signaling packet indicating that the particular flow is an elephant flow.

8. The source computing device of claim **1**, wherein:
- in sending the signal into the network, the processor tags a signaling packet for transmission to a central controller in the network.

9. A non-transitory machine-readable storage medium encoded with instructions executable by a processor of a source computing device for detection of elephant flows, the machine-readable storage medium comprising:
- instructions for monitoring data provided from an application in which a particular flow originates to a socket provided in an operating system hosting the application in the source computing device;
- instructions for determining, at the source computing device, based on an amount of data provided to the socket by the application determined from the monitoring, whether the particular flow is an elephant flow; and
- instructions for signaling a network used for transmission of the particular flow when it is determined that the particular flow is an elephant flow.

10. The non-transitory machine-readable storage medium of claim **9**, wherein the instructions for monitoring, the instructions for determining, and the instructions for signaling are included in instructions of an operating system (OS) of the source computing device.

11. The non-transitory machine-readable storage medium of claim **10**, wherein the instructions for monitoring monitor a socket buffer provided by the OS of the source computing device to queue the data provided to the socket by the application.

12. The non-transitory machine-readable storage medium of claim **9**, wherein the instructions for monitoring comprise one of:
- instructions for monitoring a rate at which data is provided to the socket,
- instructions for monitoring a total amount of data provided to the socket, and
- instructions for monitoring a current fill level of a socket buffer provided to queue the data provided to the socket.

13. A method for detection of elephant flows in a source computing device, the method comprising:
- monitoring, by a shim layer included in an operating system (OS) of the source computing device, an amount of data provided from an application in which a particular flow originates to a socket in the operating system;
- determining, at the source computing device, that the particular flow is an elephant flow when the amount of data provided to the operating system exceeds a given threshold; and
- transmitting a signal indicating that the particular flow is an elephant flow when it is determined that the particular flow is an elephant flow.

14. The method of claim **13**, wherein the monitoring comprises one of:
- monitoring the amount of data as a rate at which data is added to a socket buffer provided by the operating system;

monitoring the amount of data as a total amount of data added to the socket buffer since the particular originated; and

monitoring the amount of data as a current fill level of the socket buffer.

15. The method of claim **14**, wherein the socket buffer is a Transmission Control Protocol (TCP) buffer provided by the operating system for transmission of the particular flow.

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