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### Hierarchical aggregation of select network traffic statistics

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#### Abstract

Disclosed herein are systems and methods for the collection, aggregation, and processing of network traffic statistics for a plurality of network appliances in a wide area network. Select network traffic statistics can be collected and associated with a hierarchical string, and aggregated over time. In this way, only information that is likely to be relevant is gathered and maintained, allowing for the maintenance of select network traffic statistics for large-scale operations.

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## Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) The present application is a Divisional of, and claims the priority benefit of, U.S. patent application Ser. No. 16/581,637 filed on 24 Sep. 2019, which is a Continuation of, and claims the priority benefit of, U.S. patent application Ser. No. 15/180,981 filed on 13 Jun. 2016. The disclosure of the above-referenced applications are incorporated herein by reference in their entirety for all purposes.

### TECHNICAL FIELD

(1) This disclosure relates generally to the collection, aggregation, and processing of network traffic statistics for a plurality of network appliances.

### BACKGROUND

(2) The approaches described in this section could be pursued, but are not necessarily approaches that have previously been conceived or pursued. Therefore, unless otherwise indicated, it should not be assumed that any of the approaches described in this section qualify as prior art merely by virtue of their inclusion in this section.

(3) An increasing number of network appliances, physical and virtual, are deployed in communication networks such as wide area networks (WAN). For each network appliance, it may be desirable to monitor attributes and statistics of the data traffic handled by the device. For example, information can be collected regarding source IP addresses, destination IP addresses, traffic type, port numbers, etc. for the traffic that passes through the network appliance. Typically this information is collected for each data flow using industry standards such as NetFlow and IPFIX. The collected data is transported across the network to a collection engine, stored in a database, and can be utilized for running queries and generating reports regarding the network.

(4) Since there can be any number of data flows processed by a network appliance each minute (hundreds, thousands, or even millions), this results in a large volume of data that is collected each minute, for each network appliance. As the number of network appliances in a communication network increases, the amount of data generated can quickly become unmanageable. Moreover, transporting all of this data across the network from each network appliance to the collection engine can be a significant burden, as well as storing and maintaining a database with all of the data. Further, it may take longer to run a query and generate a report since the amount of data to be processed and analyzed is so large.

(5) Thus, there is a need for a more efficient mechanism for collecting and storing network traffic statistics for a large number of network appliances in a communication network.

### SUMMARY

(6) This summary is provided to introduce a selection of concepts in a simplified form that are further described in the Detailed Description below. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

(7) In various exemplary methods of the present disclosure, a system for aggregating select network traffic statistics is disclosed. The system comprises a plurality of network appliances in a communication network configured to collect a plurality of flow attributes for network traffic through each network appliance, build a plurality of hierarchical strings of network traffic flow attributes with extracted attribute values of those flow attributes, extract at least one network metric for at least one network characteristic associated with each of the plurality of hierarchical strings,



and aggregate the at least one network metric for the at least one network characteristic over the plurality of flows, and transmit the aggregated information to a network information collector in communication with each network appliance; and the network information collector configured to receive the information from each network appliance, and provide the information to a user on a graphical user display in response to the user running a query on the received information.

(8) In other embodiments, a method for aggregating select network traffic statistics for each of a plurality of network appliances connected in a communication network is disclosed. The method for each flow from a network appliance, extracting an attribute value of a first flow attribute; for each flow from the network appliance, extracting an attribute value of a second flow attribute; building at least one hierarchical string with the extracted attribute values; extracting at least one network metric for at least one network characteristic associated with the at least one hierarchical string; aggregating the at least one network metric for the at least one network characteristic over a plurality of flows; and transmitting the at least one hierarchical string and associated aggregated network metrics to a network information collector in communication with the network appliance.

(9) Other features, examples, and embodiments are described below.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) Embodiments are illustrated by way of example and not by limitation in the figures of the accompanying drawings, in which like references indicate similar elements.

(2) FIG. 1A depicts an exemplary system of the prior art.

(3) FIG. 1B depicts an exemplary system within which the present disclosure can be implemented.

(4) FIG. 2 illustrates a block diagram of a network appliance, in an exemplary implementation of the disclosure.

(5) FIG. 3 depicts an exemplary flow table at a network appliance.

(6) FIG. 4A depicts an exemplary accumulating map at a network appliance.

(7) FIG. 4B depicts exemplary information from a row of an accumulating map.

(8) FIG. 5A depicts an exemplary sorting via bins for an accumulating map.

(9) FIG. 5B depicts an exemplary eviction policy for an accumulating map.

(10) FIG. 6 depicts an exemplary method for building a hierarchical string.

### DETAILED DESCRIPTION

(11) The following detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show illustrations, in accordance with exemplary embodiments. These exemplary embodiments, which are also referred to herein as “examples,” are described in enough detail to enable those skilled in the art to practice the present subject matter. The embodiments can be combined, other embodiments can be utilized, or structural, logical, and electrical changes can be made without departing from the scope of what is claimed. The following detailed description is therefore not to be taken in a limiting sense, and the scope is defined by the appended claims and their equivalents. In this document, the terms “a” and “an” are used, as is common in patent documents, to include one or more than one. In this document, the term “or” is used to refer to a nonexclusive “or,” such that “A or B” includes “A but not B,” “B but not A,” and “A and B,” unless otherwise indicated.

(12) The embodiments disclosed herein may be implemented using a variety of technologies. For example, the methods described herein may be implemented in software executing on a computer system containing one or more computers, or in hardware utilizing either a combination of microprocessors or other specially designed application-specific integrated circuits (ASICs), programmable logic devices, or various combinations thereof. In particular, the methods described herein may be implemented by a series of computer-executable instructions residing on a storage

medium, such as a disk drive, or computer-readable medium.

(13) The embodiments described herein relate to the collection, aggregation, and processing of network traffic statistics for a plurality of network appliances.

(14) FIG. 1A depicts an exemplary system **100** within which embodiments of the prior art are implemented. The system comprises a plurality of network appliances **110** in communication with a flow information collector **120** over one or more wired or wireless communication network(s) **160**. The flow information collector **120** is further in communication with one or more flow database(s) **125**, which in turn is in communication with a reporting engine **140** that is accessible by a user **150**.

(15) Network appliance **110** collects information about network flows that are processed through the appliance and maintains flow records **112**. These flow records are transmitted to the flow information collector **120** and maintained in flow database **125**. User **150** can access information from these flow records **112** via reporting engine **140**.

(16) FIG. 1B depicts an exemplary system **170** within which the present disclosure can be implemented. The system comprises a plurality of network appliances **110** in communication with a network information collector **180** over one or more wired or wireless communication network(s) **160**. The network information collector **180** is further in communication with one or more database(s) **130**, which in turn is in communication with a reporting engine **140** that is accessible by a user **150**. While network information collector **180**, database(s) **130**, and reporting engine **140** are depicted in the figure as separate, one or more of these engines can be part of the same computing machine or distributed across many computers.

(17) In a wide area network, there can be multiple network appliances deployed in one or more geographic locations. Each network appliance **110** comprises hardware and/or software elements configured to receive data and optionally perform any type of processing, including but not limited to, WAN optimization techniques to the data, before transmitting to another appliance. In various embodiments, the network appliance **110** can be configured as an additional router or gateway. If a network appliance has multiple interfaces, it can be transparent on some interfaces, and act like a router/bridge on others. Alternatively, the network appliance can be transparent on all interfaces, or appear as a router/bridge on all interfaces. In some embodiments, network traffic can be intercepted by another device and mirrored (copied) onto network appliance **110**. The network appliance **110** may further be either physical or virtual. A virtual network appliance can be in a virtual private cloud (not shown), managed by a cloud service provider, such as Amazon Web Services, or others.

(18) Network appliance **110** collects information about network flows that are processed through the appliance in flow records **112**. From these flow records **112**, network appliance **110** further generates an accumulating map **114** containing select information from many flow records **112** aggregated over a certain time period. The flow records **112** and accumulating map **114** generated at network appliance **110** are discussed in further detail below with respect to FIGS. 3 and 4.

(19) At certain time intervals, network appliance **110** transmits information from the accumulating map **114** (and not flow records **112**) to network information collector **180** and maintains this information in one or more database(s) **130**. User **150** can access information from these accumulating maps via reporting engine **140**, or in some instances user **150** can access information from these accumulating maps directly from a network appliance **110**.

(20) FIG. 2 illustrates a block diagram of a network appliance **110**, in an exemplary implementation of the disclosure. The network appliance **110** includes a processor **210**, a memory **220**, a WAN communication interface **230**, a LAN communication interface **240**, and a database **250**. A system bus **280** links the processor **210**, the memory **220**, the WAN communication interface **230**, the LAN communication interface **240**, and the database **250**. Line **260** links the WAN communication interface **230** to another device, such as another appliance, router, or gateway, and line **270** links the LAN communication interface **240** to a user computing device, or other networking device. While network appliance **110** is depicted in FIG. 2 as having these exemplary components, the appliance may have additional or fewer components.

(21) The database **250** comprises hardware and/or software elements configured to store data in an organized format to allow the processor **210** to create, modify, and retrieve the data. The hardware and/or software elements of the database **250** may include storage devices, such as RAM, hard drives, optical drives, flash memory, and magnetic tape.

(22) In some embodiments, some network appliances comprise identical hardware and/or software elements. Alternatively, in other embodiments, some network appliances may include hardware and/or software elements providing additional processing, communication, and storage capacity.

(23) Each network appliance **110** can be in communication with at least one other network appliance **110**, whether in the same geographic location, different geographic location, private cloud network, customer datacenter, or any other location. As understood by persons of ordinary skill in the art, any type of network topology may be used. There can be one or more secure tunnels between one or more network appliances. The secure tunnel may be utilized with encryption (e.g., IPsec), access control lists (ACLs), compression (such as header and payload compression), fragmentation/coalescing optimizations and/or error detection and correction provided by an appliance.

(24) A network appliance **110** can further have a software program operating in the background that tracks its activity and performance. For example, information about data flows that are processed by the network appliance **110** can be collected. Any type of information about a flow can be collected, such as header information (source port, destination port, source address, destination address, protocol, etc.), packet count, byte count, timestamp, traffic type, or any other flow attribute. This information can be stored in a flow table **300** at the network appliance **110**. Flow tables will be discussed in further detail below, with respect to FIG. 3.

(25) In exemplary embodiments, select information from flow table **300** is aggregated and populated into an accumulating map, which is discussed in further detail below with respect to FIG. 4. Information from the accumulating map is transmitted by network appliance **110** across communication networks(s) **160** to network information collector **180**. In this way, the information regarding flows processed by network appliance **110** is not transmitted directly to network information collector **180**, but rather a condensed and aggregated version of selected flow information is transmitted across the network, creating less network traffic.

(26) After a flow table **300** is used to populate an accumulating map, or on a certain periodic basis or activation of a condition, flow table **300** may be discarded by network appliance **110** and a new flow table is started. Similarly, after an accumulating map **400** is received by network information collector **180**, or on a certain periodic basis or activation of a condition, accumulating map **400** may be discarded by network appliance **110** and a new accumulating map is started.

(27) Returning to FIG. 1B, network information collector **180** comprises hardware and/or software elements, including at least one processor, for receiving data from network appliance **110** and processing it. Network information collector **180** may process data received from network appliance **110** and store the data in database(s) **130**. In various embodiments, database(s) **130** is a relational database that stores the information from accumulating map **400**. The information can be stored directly into database(s) **130** or separated into columns and then stored in database(s) **130**.

(28) Database(s) **130** is further in communication with reporting engine **140**. Reporting engine **140** comprises hardware and/or software elements, including at least one processor, for querying data in database(s) **130**, processing it, and presenting it to user **150** via a graphical user interface. In this way, user **150** can run any type of query on the stored data. For example, a user can run a query requesting information on the most visited websites, or a “top talkers” report, as discussed in further detail below.

(29) FIG. 3 depicts an exemplary flow table **300** at network appliance **110** for flows **1** through **N**, with **N** representing any number. The flow table contains one or more rows of information for each flow that is processed through network appliance **110**. Data packets transmitted and received between a single user and a single website that the user is browsing can be parsed into multiple

flows. Thus, one browsing session for a user on a website may comprise many flows. Typically a TCP flow begins with a SYN packet and ends with a FIN packet. Other methods can be used for determining the start and end of non-TCP flows. The attributes of each of these flows, while they may be identical or substantially similar, are by convention stored in different rows of flow table **300** since they are technically different flows.

(30) In exemplary embodiments, flow table **300** may collect certain information about the flow, such as header information **310**, network information **320**, and other information **330**. As would be understood by a person of ordinary skill in the art, flow table **300** can comprise fewer or additional fields than depicted in FIG. 3. Moreover, even though header information **310** is depicted as having three entries in exemplary flow table **300**, there can be fewer or additional entries for header information. Similarly, there can be fewer or additional entries for network information **320** and for other information **330** than the number of entries depicted in exemplary flow table **300**.

(31) Header information **310** can comprise any type of information found in a packet header, for example, source port, destination port, source address (such as IP address), destination address, protocol. Network information **320** can comprise any type of information regarding the network, such as a number of bytes received or a number of bytes transmitted during that flow. Further, network information **320** can contain information regarding other characteristics such as loss, latency, jitter, reordering, etc. Flow table **300** may store a sum of the number of packets or bytes of each characteristic, or a mathematical operator other than the sum, such as maximum, minimum, mean, median, average, etc. Other information **330** can comprise any other type of information regarding the flow, such as traffic type or domain name (instead of address).

(32) In an example embodiment, entry **340** of flow N is the source port for the flow, entry **345** is the destination port for the flow, and entry **350** is the destination IP address for the flow. Entry **355** is the domain name for the website that flow N originates from or is directed to, entry **360** denotes that the flow is for a voice traffic type, and entry **365** is an application name (for example from deep packet inspection (DPI)). Entry **370** contains the number of packets in the flow and entry **375** contains a number of bytes in the flow.

(33) The flow information regarding every flow is collected by the network appliance **110** at all times, in the background. A network appliance **110** could have one million flows every minute, in which case a flow table for one minute of data for network appliance **110** would have one million rows. Over time, this amount of data becomes cumbersome to process, synthesize, and manipulate. Conventional systems may transport a flow table directly to a flow information collector, or to reduce the amount of data, retain only a fraction of the records from the flow table as a sample. In contrast, embodiments of the present disclosure reduce the amount of data to be processed regarding flows, with minimal information loss, by synthesizing selected information from flow table **300** into an accumulating map. This synthesis can occur on a periodic basis (such as every minute, every 5 minutes, every hour, etc.), or upon the meeting of a condition, such as number of flows recorded in the flow table **300**, network status, or any other condition.

(34) FIG. 4A depicts exemplary accumulating maps that are constructed from information from flow table **300**. A string of information is built in a hierarchical manner from information in flow table **300**. A network administrator can determine one or more strings of information to be gathered. For example, a network administrator may determine that information should be collected regarding a domain name, user computing device, and user computer's port number that is accessing that domain. A user computing device can identify different computing devices utilized by the same user (such as a laptop, smartphone, desktop, tablet, smartwatch, etc.). The user computing device can be identified in any manner, such as by host name, MAC address, user ID, etc.

(35) Exemplary table **400** has rows **1** through F, with F being any number, for the hierarchical string “/domain name/computer/port” that is built from this information. Since the accumulating map **400** is an aggregation of flow information, F will be a much smaller value than N, the total

number of flows from flow table **300**.

(36) Exemplary table **450** shows data being collected for a string of source IP address and destination IP address combinations. Thus, information regarding which IP addresses are communicating with each other is accumulated. Network appliance **110** can populate an accumulating map for any number of strings of information from flow table **300**. In an exemplary embodiment, network appliance **110** populates multiple accumulating maps, each for a different string hierarchy of information from flow table **300**. While FIG. **4A** depicts only two string hierarchies, there can be fewer or additional strings of information collected in accumulating maps. (37) Row **410** in exemplary accumulating map **400** shows that during the time interval represented, sampledomain1 was accessed by computer1 from port 1. All of the flows where sampledomain1 was accessed by computer1 from port1 in flow table **300** are aggregated into a single row, row **410**, in accumulating map **400**. The network information **320** may be aggregated for the flows to depict a total number of bytes received and a total number of packets received from sampledomain1 accessed by computer1 via port1 during the time interval of flow table **300**. In this way, a large number of flows may be condensed into a single row in accumulating map **400**.

(38) As would be understood by a person of ordinary skill in the art, while accumulating map **400** depicts a total number of bytes received and a total number of packets received (also referred to herein as a network characteristic), any attribute can be collected and aggregated into accumulating map **400**. For example, instead of a sum of bytes received, accumulating map **400** can track a maximum value, minimum value, median, percentile, or other numeric attribute for a string. Additionally, the network characteristic can be other characteristics besides number of packets or number of bytes. Loss, latency, re-ordering, and other characteristics can be tracked for a string in addition to, or instead of, packets and bytes, such as number of flows that are aggregated into the row. For example, packet loss and packet jitter can be measured by time stamps and serial numbers from the flow table. Additional information on measurement of network characteristics can be found in commonly owned U.S. Pat. No. 9,143,455 issued on Sep. 22, 2015 and entitled “Quality of Service Using Multiple Flows”, which is hereby incorporated herein in its entirety.

(39) Row **430** shows that the same computer (computer1) accessed the same domain name (sampledomain1), but from a different port (port2). Thus, all of the flows in flow table **300** from port2 of computer1 to sampledomain1 are aggregated into row **430**. Similarly, accumulating map **400** can be populated with information from flow table **300** for any number of domains accessed by any number of computers from any number of ports, as shown in row **440**.

(40) Flow table **300** may comprise data for one time interval while accumulating map **400** can comprise data for a different time interval. For example, flow table **300** can comprise data for all flows through network appliance **110** over the course of a minute, while data from 60 minutes can all be aggregated into one accumulating map. Thus, if a user returns to the same website from the same computer from the same port within the same hour, even though this network traffic is on a different flow, the data can be combined with the previous flow information for the same parameters into the accumulating map. This significantly reduces the number of records that are maintained. All activity between a computer and a domain from a certain port is aggregated together as one record in the accumulating map, instead of multiple records per flow. This provides information in a compact manner for further processing, while also foregoing the maintenance of all details about more specific activities.

(41) Exemplary accumulating map **450** depicts flow information for another string—source IP address and destination IP address combinations. In IPv4 addressing alone, there are four billion possibilities for source IP addresses and four billion possibilities for destination IP addresses. To maintain a table of all possible IP address combinations between these would be an unwieldy table of information to collect. Further, most combinations for a particular network appliance **110** would be zero. Thus, to maintain large volumes of data in a scalable way, the accumulating map **450** only collects information regarding IP addresses actually used as a source or destination, instead of

every possible combination of IP addresses.

(42) The accumulating map **450** can be indexed in different indexing structures, as would be understood by a person of ordinary skill in the art. For example, a hash table can be used where the key is the string and a hash of the string is computed to find a hash bin. In that bin is a list of strings and their associated values. Furthermore, there can be additional indexing to make operations (like finding smallest value) fast, as discussed herein. An accumulating map may comprise the contents of the table, such as that depicted in **400** and **450**, and additionally one or more indexing structures and additional information related to the table. In some embodiments, only the table itself from the accumulating map may be transmitted to network information collector **180**. In other embodiments, some or all of the additional information, such as indexing information, may be transmitted with the table.

(43) The information from an accumulating map can be collected from the network appliances and then stored in database(s) **130**, which may be a relational database. The scheme can use raw aggregated strings and corresponding values in columns of the database(s) **130**, or separate columns can be used for each flow attribute of the string and its corresponding values. For example, port, computer, and domain name can all be separate columns in a relational database, rather than stored as one column for the string.

(44) The reporting engine **140** allows a user **150** or network administrator to run a query and generate a report from information in accumulating maps that was stored in database(s) **130**. For example, a user **150** can query which websites were visited by searching “/domain/\*”. A user **150** can query the top traffic types by searching “\*/traffic type”. Multi-dimensional searches can also be run on data in database(s) **130**. For example, who are they top talkers and which websites are they visiting? For the top destinations, who is going there? For the top websites, what are the top traffic types? A network administrator can configure the system to aggregate selected flow information based specifically on the most common types of queries that are run on network data. Further, multi-dimensional queries can be run on this aggregated information, even though the data is not stored in a multi-dimensional format (such as a cube).

(45) Further, by collecting flow information for a certain time interval in flow table **300** (e.g., once a minute), and aggregating selected flow information into one or more accumulating maps for a set time interval (e.g., once an hour) at the network appliance **110**, only relevant flow information is gathered by network information collector **180** and maintained in database(s) **130**. This allows for efficient scalability of a large number of network appliances in a WAN, since the amount of information collected and stored is significantly reduced, compared to simply collecting and storing all information about all flows through every network appliance for all time. Through an accumulating map, information can be aggregated by time, appliance, traffic type, IP address, website/domain, or any other attribute associated with a flow.

(46) While the strings of an accumulating map are depicted herein with slashes, the information can be stored in an accumulating map in any format, such as other symbols or even no symbol at all. A string can be composed of binary records joined together to make a string, or normal ASCII text, Unicode text, or concatenations thereof. For example, row **410** can be represented as “sampledomain1, computer1, port1” or in any number of ways. Further, instead of delimiting a string by characters, it can be delimited by links and values. Information can also be sorted lexicographically.

(47) FIG. **4B** depicts exemplary information from a row of an accumulating map. A string is composed of an attribute value **412** (such as 1.2.3.4) of a first attribute **411** (such as source IP address), and an attribute value **414** (such as 5.6.7.8) of a second attribute **413** (such as destination IP address). For each string of information, there is an associated network characteristic **415** (such as number of bytes received) and its corresponding network metric **416** (such as 54) and there can optionally be a second network characteristic **417** (number of packets received) and its corresponding network metric **418** (such as 13). While two network characteristics are depicted

here, there can be only one network characteristic or three or more network characteristics. Similarly, there can be fewer or additional attributes in a string. This information can also be stored as a binary key string **419** as depicted in the figure.

(48) Furthermore, while data is discussed herein as being applicable to a particular flow, a similar mechanism can be utilized to gather data for a tunnel, instead of just a flow. For example, a string of information comprising “/tunnelname/application/website” can be gathered in an accumulating map. In this way, information regarding which tunnel a flow goes into and which application is using that tunnel can be collected and stored. Data packets can be encapsulated into tunnel packets, and a single string may collect information regarding each of these packets as a way of tracking tunnel performance.

(49) In various embodiments, an accumulating map, such as map **400**, can have a maximum or target number of rows or records that can be maintained. Since one purpose of the accumulating map is to reduce the amount of flow information that is collected, transmitted, and stored, it can be advantageous to limit the size of the accumulating map. Once a defined number of records is reached, then an eviction policy can be applied to determine how new entries are processed. The eviction policy can be triggered upon reaching a maximum number of records, or upon reaching a lower target number of records.

(50) In one eviction policy, any new strings of flow information that are not already in the accumulating map will simply be discarded for that time interval, until a new accumulating map is started for the next time interval.

(51) In a second eviction policy, the strings of information that constitute overflow are summarized into a log file, called an eviction log. The eviction log can be postprocessed and transmitted to the network information collector **180** at substantially the same time as information from the accumulating map. Alternatively, the eviction log may be consulted only at a later time when further detail is required.

(52) In a third eviction policy, when a new string needs to be added to an accumulating map, then an existing record can be moved from the accumulating map into an eviction log to make space for the new string which is then added to the accumulating map. The determination of which existing record to purge from the accumulating map can be based on a metric. For example, the existing entry with the least number of bytes received can be evicted. In various embodiments there can also be a time parameter for this so that new strings have a chance to aggregate and build up before automatically being evicted for having the lowest number of bytes. That is, to avoid a situation where the newest entry is constantly evicted, a time parameter can be imposed to allow for any desired aggregation of flows for the string.

(53) In some embodiments, to find the existing entry with the least number of bytes to be evicted, the whole accumulating map can be scanned. In other embodiments, the accumulating map is already indexed (such as via a hash table) so it is already sorted and the lowest value can be easily found.

(54) In further embodiments, information from an accumulating map can be stored in bins such as those depicted in FIG. 5A. In the exemplary embodiment of FIG. 5A, aggregated network metric values of a network characteristic are displayed, and bins are labeled with various numeric ranges, such as 0-10, 11-40 and 41-100. Each network metric is associated with the bin of its numeric range. Thus strings and their corresponding aggregated values can be placed in an indexing structure for the accumulating map in accordance with the metric value of their corresponding network characteristic. As a network metric increases (for example from new flows being aggregated into the string), or as a network metric decreases (for example from some strings being evicted), then the entry can be moved to a different bin in accordance with its new numeric range. In an exemplary embodiment, the table of an accumulating map is a first data structure, a bin is a second data structure, and sorting operations can be conducted in a third data structure.

(55) Placing data from accumulating map **400** in bins allows for eviction to occur from the lowest

value bin with data. Any record can be evicted from the lowest value bin with data, or the lowest value bin can be scanned to find the entry with the lowest network metric for eviction.

(56) The bins can also be arranged in powers of two to cover bigger ranges of values. For example, bins can have ranges of 0-1, 2-3, 4-7, 8-15, 16-31, 32-63, 64-127 and so on. In this way, the information from accumulating map doesn't need to be kept perfectly sorted by network metric, which can require a significant amount of indexing.

(57) In another exemplary embodiment, space can be freed up in an accumulating map by combining multiple records that have common attributes. For example, in the accumulating map of FIG. 5B, there are two entries with the same domain and computer, but different port numbers. The data from these entries can be combined by keeping the domain and computer in the string, but removing the port numbers. In this way, two or more records in the accumulating map with common flow attributes can be aggregated into one record by removing the uncommon attributes from the record. The bytes received and packets received for the new condensed record is an aggregation of the previous separate records. In this way, some information may be lost from the accumulating map (through loss of some granularity), but by least importance as defined by the combination of attributes in the string (by removing a lower level but keeping a higher level of information in the string). Alternatively, of the two entries with the same domain and computer but different port numbers, the record with the lowest number of bytes may simply be evicted from the accumulating map and added to the eviction log. There can also be a time interval allotted to the record before it is evicted to allow flow data to be aggregated for that string before eviction.

(58) In a fourth eviction policy, a batch eviction can be conducted on the accumulating map to free up space. For example, a determination may be made of which records are the least useful and then those are evicted from the accumulating map and logged in the eviction log. In an exemplary embodiment, an accumulating map may be capable of having 10,000 records. A batch eviction may remove 1,000 records at a time. However, any number of records can be moved in a batch eviction process, and an accumulating map size can be set to any number of records. A batch eviction can also remove one or more bins of information.

(59) FIG. 6 depicts an exemplary method for building a hierarchical string and aggregating the associated values, as discussed herein. In step **610**, information about network traffic flows is collected at a network appliance. In step **620**, an attribute value of a first attribute (or flow attributes) is extracted when the flow ends, or on a periodic basis. For example, if a flow attribute is source IP address, then the attribute value of the source IP address (such as 1.2.3.4) is extracted. An attribute value of a second flow attribute can also be extracted. There can be any number of flow attributes extracted from flow information. In step **630**, at least one hierarchical string is built with the extracted attribute values. For example, source IP may be a part of only one, or multiple different hierarchical strings. Network metric(s) for the associated network characteristic(s) of the hierarchical string(s) are extracted in step **640**, and the network metrics are aggregated for the different flows into an accumulating map record for each hierarchical string in step **650**. For example, a string of “/source IP/destination IP” can be built from the various source and destination IP address combinations with the aggregated network metrics of the network characteristic of number of bytes exchanged between each source IP and destination IP combination.

(60) The aggregated information may be sent from each network device to the network information collector **180** as discussed herein. The information can be transmitted as raw data, or may be subjected to processing such as encryption, compression, or other type of processing. The network information collector **180** may initiate a request for the data from each network appliance, or the network appliance may send it automatically, such as on a periodic basis after the passage of a certain amount of time (for example, every minute, every 5 minutes, every hour, etc.).

(61) While the method has been described in these discrete steps, various steps may occur in a different order, or concurrently. Further, this method may be practiced for each incoming flow or outgoing flow of a network appliance.



(62) Thus, methods and systems for aggregated select network traffic statistics are disclosed. Although embodiments have been described with reference to specific examples, it will be evident that various modifications and changes can be made to these example embodiments without departing from the broader spirit and scope of the present application. Therefore, these and other variations upon the exemplary embodiments are intended to be covered by the present disclosure. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

## Claims

1. A network information collector, comprising: a processor; and a memory including instructions that, when executed by the processor, cause the network information collector to: periodically receive, from a plurality of network appliances connected in a communication network, a respective plurality of accumulating maps, wherein: each accumulating map includes entries organized hierarchically according to a set of flow attributes, and each entry represents one or more flows in a flow table of a respective network appliance of the plurality of network appliances; aggregate each of the received respective plurality of accumulating maps into a global accumulating map; and remove, from the global accumulating map, entries according to a lowest number of bytes eviction policy that evicts an entry having a lowest number of bytes among entries of the global accumulating map, wherein the entry having the lowest number of bytes is the entry that includes a first network metric of a bytes received count that is lowest of any entry in the global accumulating map.
2. The network information collector of claim 1, wherein the instructions further cause the network information collector to forward information from the global accumulating map to a network administrator via a graphical user interface such that the network administrator can generate a report based on the forwarded information and a search query.
3. The network information collector of claim 1, wherein the accumulating maps are periodically received after a pre-determined time interval.
4. The network information collector of claim 3, wherein each successive accumulating map received from a network appliance includes entries for flows during the pre-determined time interval.
5. The network information collector of claim 1, wherein entries removed from the global accumulating map are recorded in an eviction log.
6. The network information collector of claim 1, wherein a first attribute of the set of flow attributes is related to and more specific than a second attribute of the set of flow attributes.
7. A method, comprising: receiving, at a network information collector and from a plurality of network appliances, a plurality of respective accumulating maps, wherein: each accumulating map includes entries organized hierarchically according to a set of flow attributes, a first attribute of the set of flow attributes is related to and more specific than a second attribute of the set of flow attributes, and each entry represents one or more flows in a flow table of a respective network appliance of the plurality of network appliances; aggregating, at the network information collector, each of the received plurality of respective accumulating maps into a global accumulating map, wherein the aggregating comprises: for each entry of each received accumulating map, identifying a corresponding entry of the global accumulating map; updating each identified corresponding entry to incorporate information from the respective received accumulating map entry; and removing entries according to a lowest number of bytes eviction policy that evicts an entry having a lowest number of bytes among entries of the global accumulating map, wherein the entry having the lowest number of bytes is the entry that includes a first network metric of a bytes received count that is lowest of any entry in the global accumulating map.
8. The method of claim 7, wherein each successive accumulating map received from a network

appliance includes entries for flows during a pre-determined time interval.

9. The method of claim 7, wherein entries removed from the global accumulating map are recorded in an eviction log.

10. The method of claim 7, wherein each entry includes a network metric extracted from associated flows.

11. The method of claim 7, wherein the network appliances are connected in a communication network and each network appliance gathers information on flows passing through itself.

12. The method of claim 7, further comprising forwarding information from the global accumulating map to a network administrator via a graphical user interface such that the network administrator can generate a report based on the forwarded information and a search query.

13. A system, comprising: a plurality of network appliances each comprising a respective processor and a memory including instructions that, when executed by the respective processor, cause each respective network appliance of the plurality of network appliances to: insert details of a plurality flows into a flow table; generate one or more entries according to a set of flow attributes of the plurality of flows, wherein each of the one or more entries may be associated with one or more of the plurality of flows; insert the one or more entries into an accumulating map such that the entries are organized hierarchically according to a set of related flow attributes, wherein a first attribute of the set of flow attributes is related to and more specific than a second attribute of the set of flow attributes; and periodically transmit the accumulating map to a network information collector; and the network information collector comprising a processor and a memory including instructions that, when executed by the processor, cause the network information collector to: receive an accumulating map from a network appliance; aggregate the received accumulating map into a global accumulating map; remove, from the global accumulating map, entries according to, a lowest number of bytes eviction policy that evicts an entry having a lowest number of bytes among entries of the global accumulating map, wherein the entry having the lowest number of bytes is the entry that includes a first network metric of a bytes received count that is lowest of any entry in the global accumulating map; and forward information from the global accumulating map to a network administrator via a graphical user interface such that the network administrator can generate a report based on the forwarded information and a search query.

14. The system of claim 13, wherein each entry includes a network metric extracted from associated flows.

15. The system of claim 14, wherein upon removing an entry, the network metric of the removed entry is combined with a network metric of another entry associated with the removed entry.

16. The system of claim 13, wherein each successive accumulating map received from a network appliance includes entries for flows during a pre-determined time interval.

17. The system of claim 13, wherein entries removed from the global accumulating map are recorded in an eviction log.

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