US 20190199817A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2019/0199817 A1**

Smith et al. (43) **Pub. Date: Jun. 27, 2019**

(54) **SYSTEM AND METHOD FOR DISTRIBUTED CACHING**

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(21) Appl. No.: **15/921,568**

(22) Filed: **Mar. 14, 2018**

Related U.S. Application Data

(60) Provisional application No. 62/610,036, filed on Dec. 22, 2017, provisional application No. 62/609,948, filed on Dec. 22, 2017.

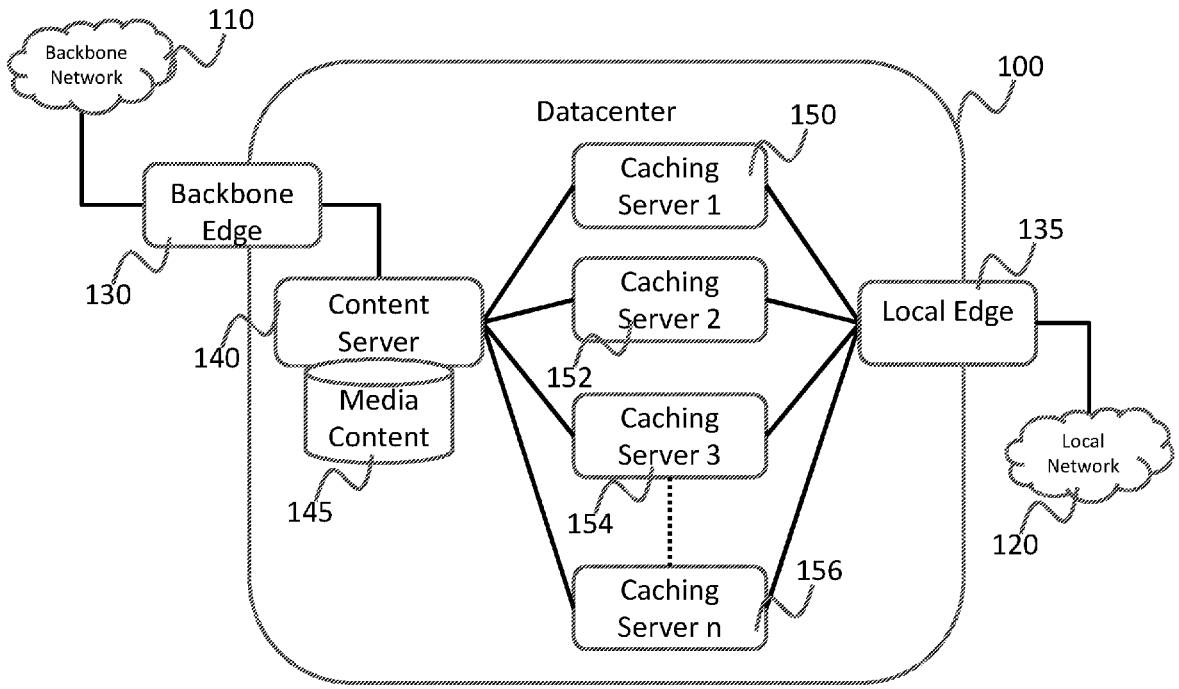
Publication Classification

(51) **Int. Cl.**
H04L 29/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 67/2842*** (2013.01); ***H04L 67/26*** (2013.01); ***H04L 67/1097*** (2013.01)

(57) **ABSTRACT**

A system and method for distributed caching, the system having at least one network-connected storage device, a content server, and a control server. The control server is configured to discover the at least one network-connected storage device, collect device information from the at least one network-connected storage device, where the device information comprises a device location, assign each of the at least one network-connected storage device to a device domain based on each device location, and provide the content server with the device information for the one or more network-connected storage.



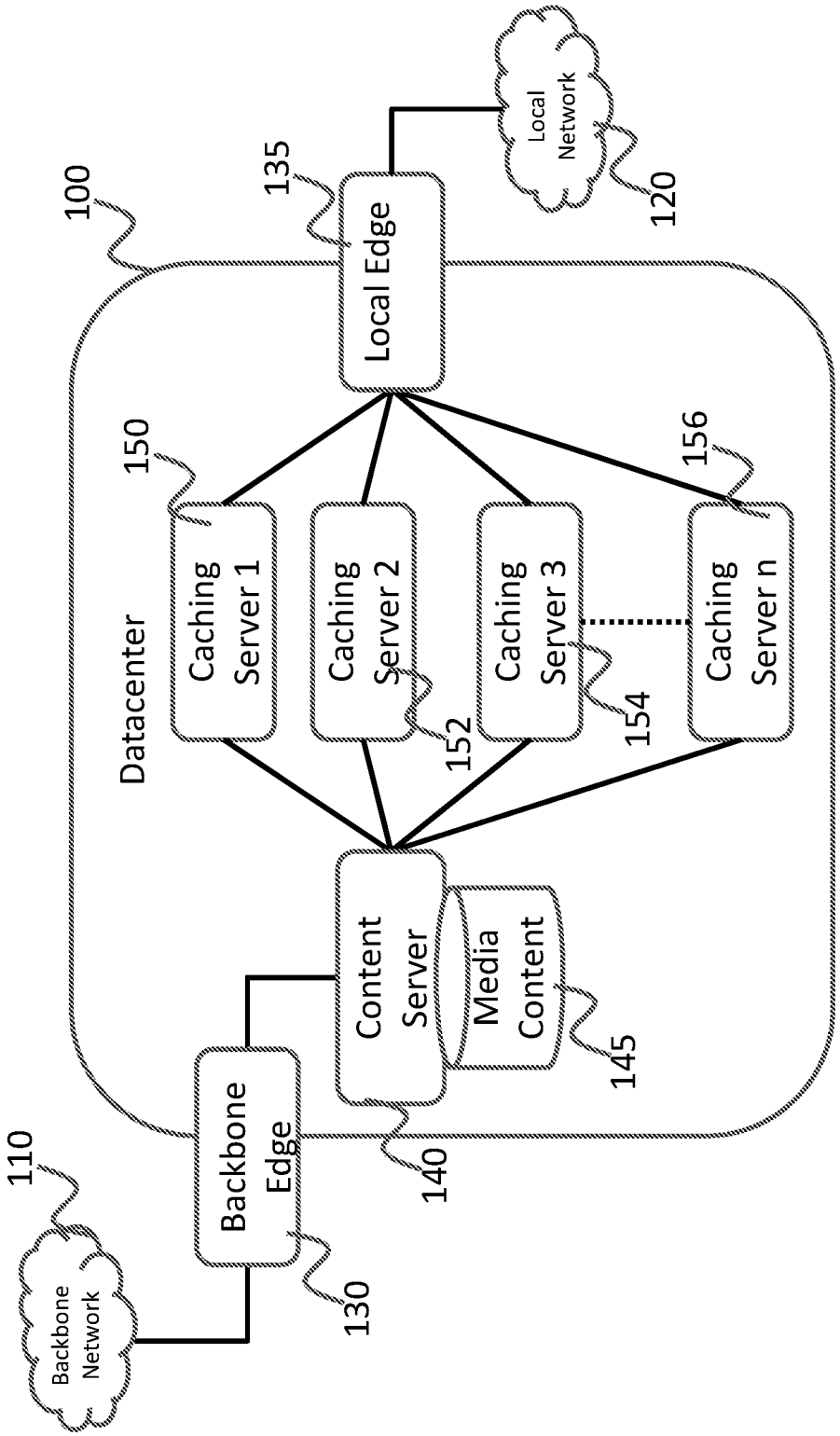


FIG. 1

Related Art

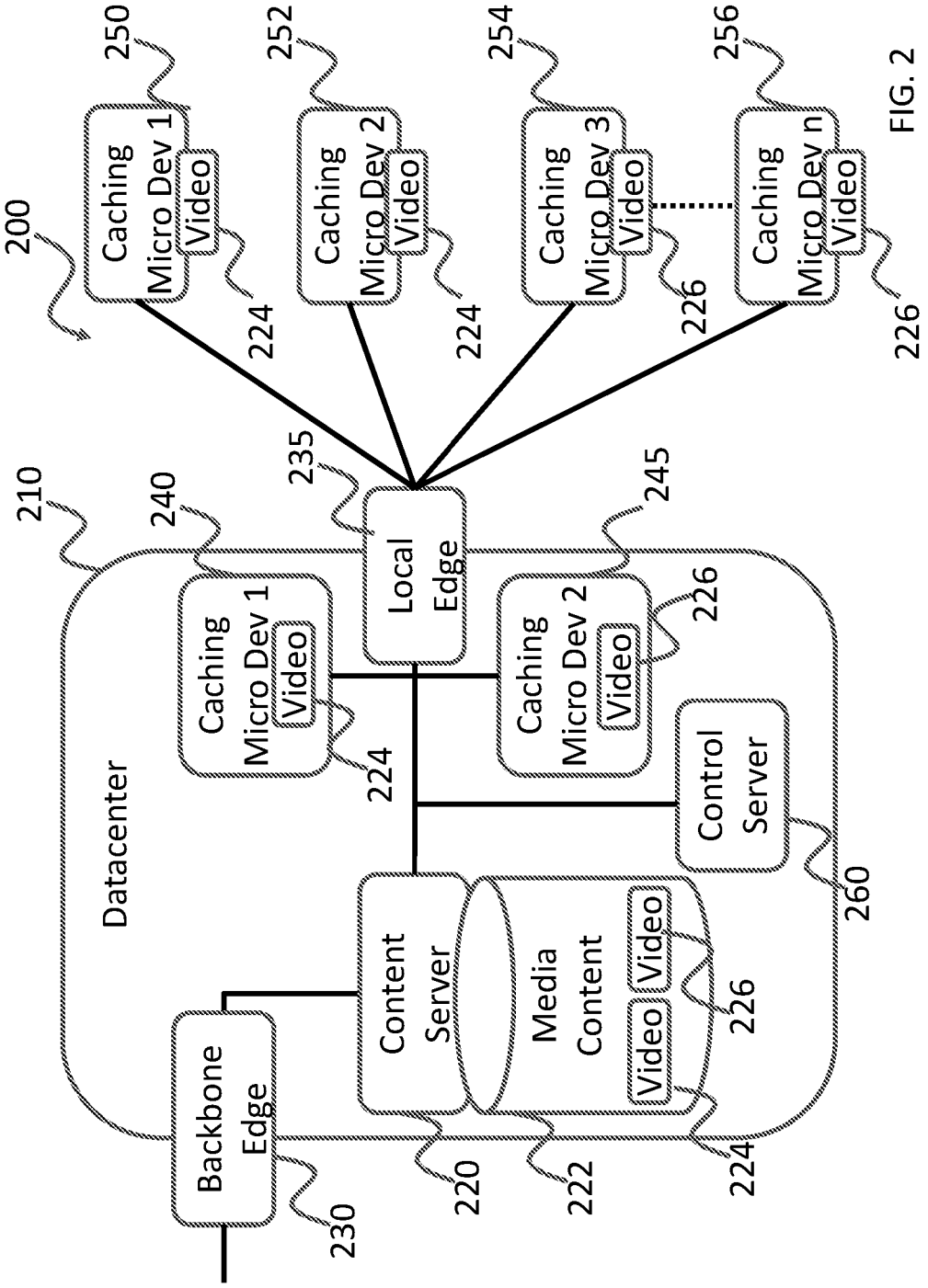

200
250
Caching Micro Dev 1
Video
224
252
Caching Micro Dev 2
Video
224
254
Caching Micro Dev 3
Video
226
256
Caching Micro Dev n
Video
226
235
Local Edge
210
Datacenter
240
Caching Micro Dev 1
Video
224
245
Caching Micro Dev 2
Video
226
Control Server
260
Content Server
Media Content
Video
Video
226
Backbone Edge
230
220
222
224

FIG. 2

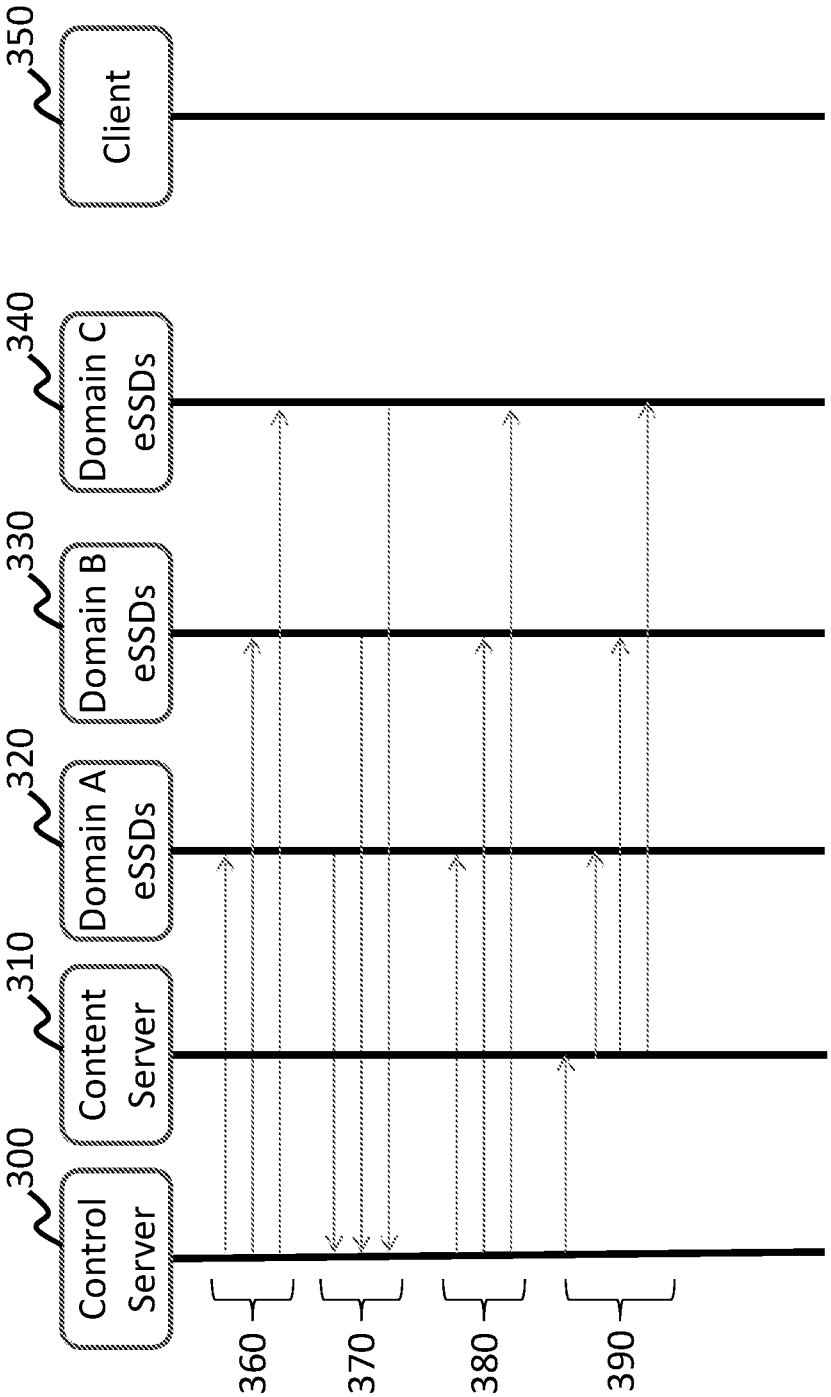

300
Control Server
310
Content Server
320
Domain A eSSDs
330
Domain B eSSDs
340
Domain C eSSDs
350
Client
360
370
380
390

FIG. 3

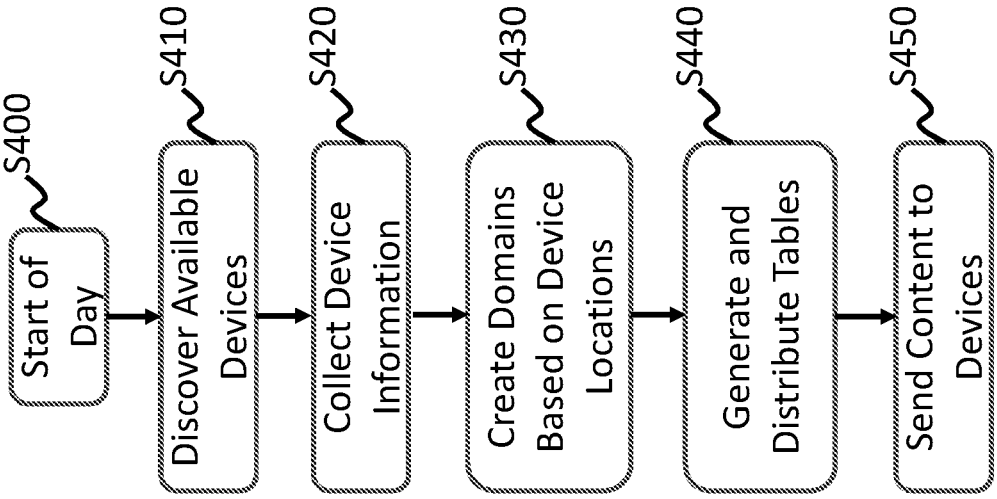

S400
Start of Day
S410
Discover Available Devices
S420
Collect Device Information
S430
Create Domains Based on Device Locations
S440
Generate and Distribute Tables
S450
Send Content to Devices

FIG. 4

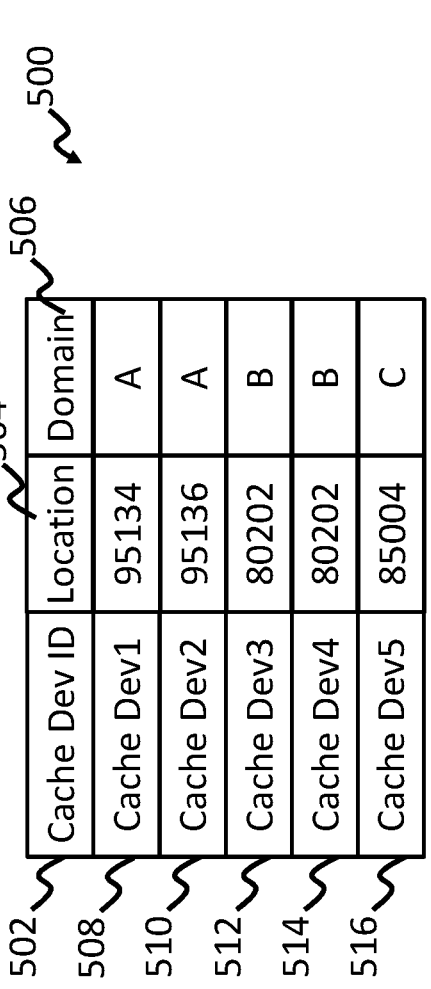

500
504
506
Cache Dev ID
Location
Domain
Cache Dev1
95134
A
Cache Dev2
95136
A
Cache Dev3
80202
B
Cache Dev4
80202
B
Cache Dev5
85004
C
502
508
510
512
514
516

FIG. 5A

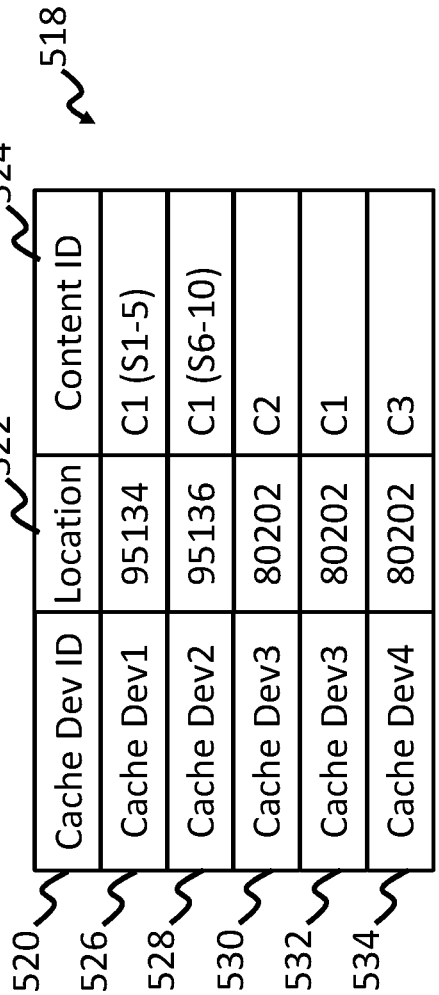

518
522
524
Cache Dev ID
Location
Content ID
Cache Dev1
95134
C1 (S1-5)
Cache Dev2
95136
C1 (S6-10)
Cache Dev3
80202
C2
Cache Dev3
80202
C1
Cache Dev4
80202
C3
520
526
528
530
532
534

FIG. 5B

536
542
540
538
Client ID
Content ID
Caching Dev ID
User 1
Content 1
Cache Dev3

FIG. 5C

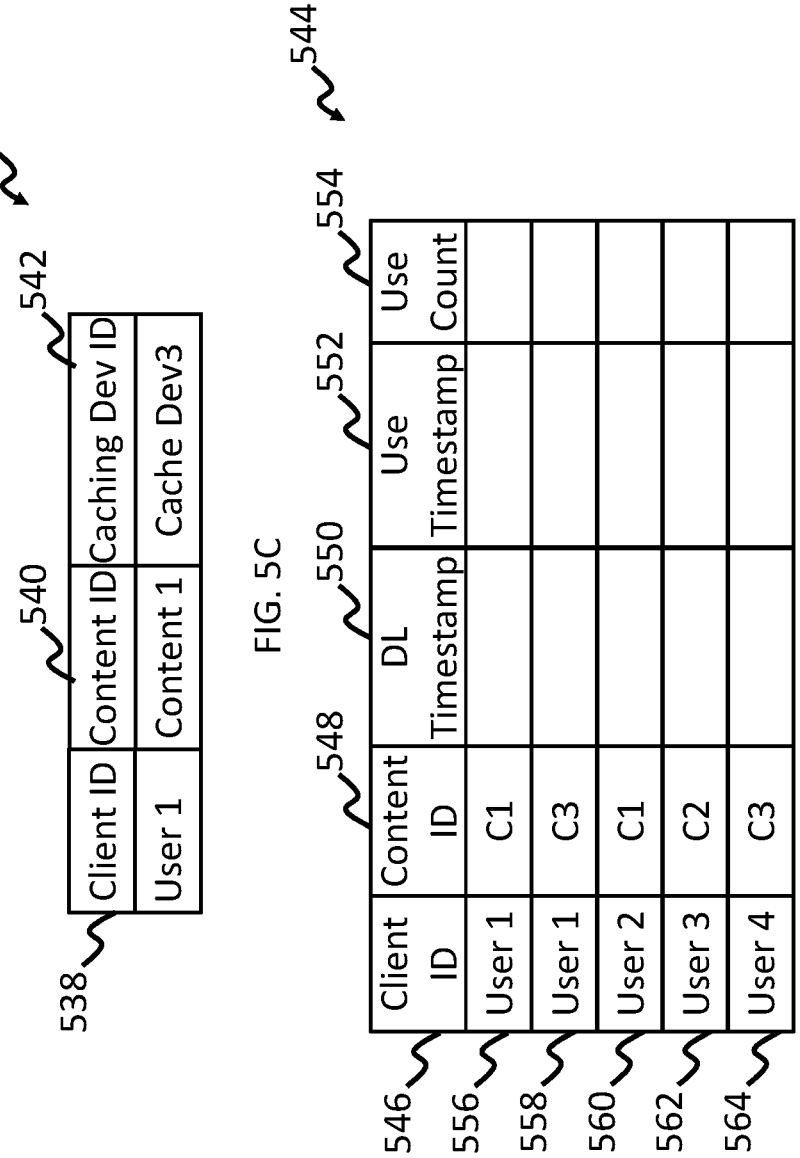

544
554
552
550
548
546
556
558
560
562
564
Client ID
Content ID
DL Timestamp
Use Timestamp
Use Count
User 1
C1
User 1
C3
User 2
C1
User 3
C2
User 4
C3

FIG. 5D

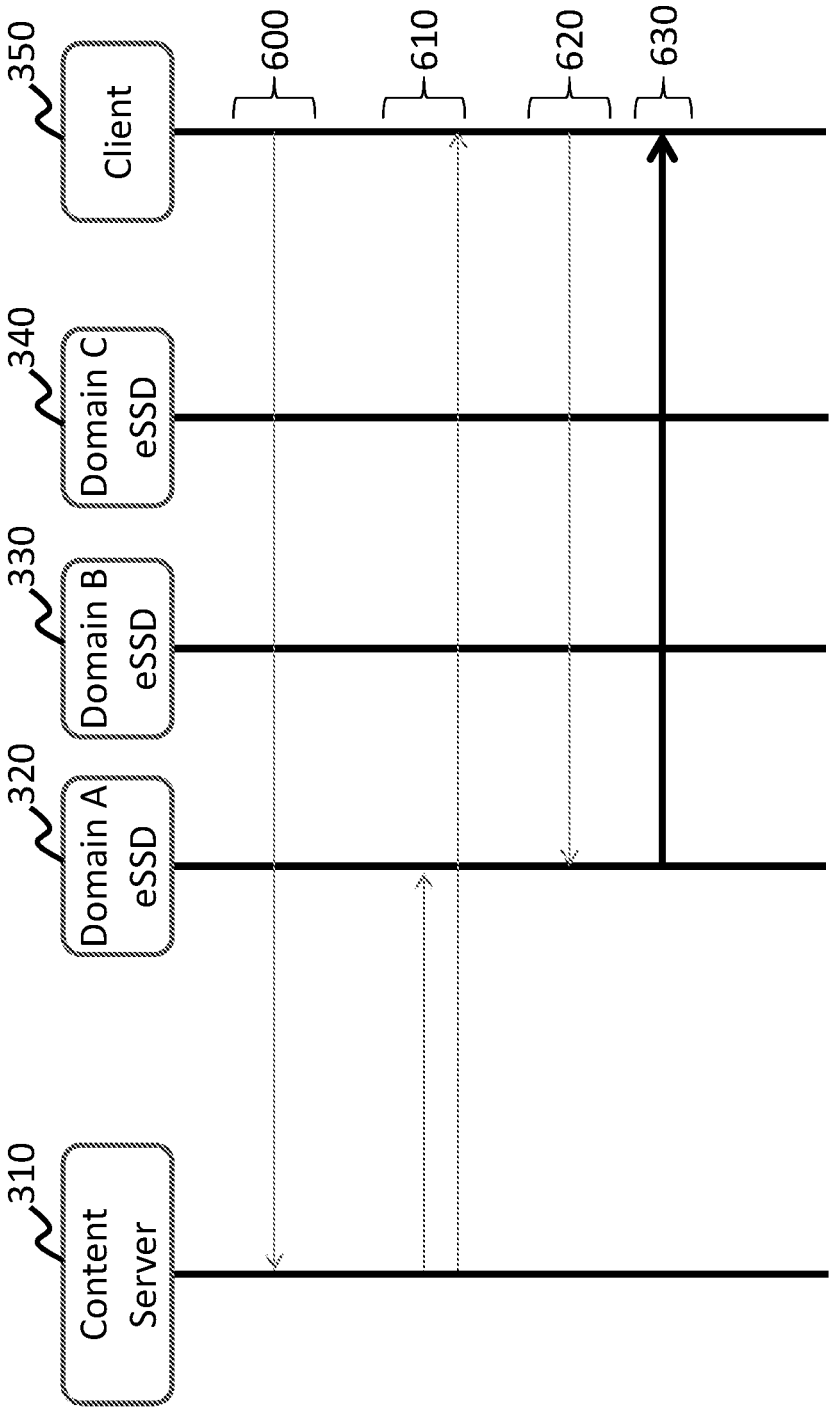

350
Client
340
Domain C eSSD
330
Domain B eSSD
320
Domain A eSSD
310
Content Server
600
610
620
630

FIG. 6

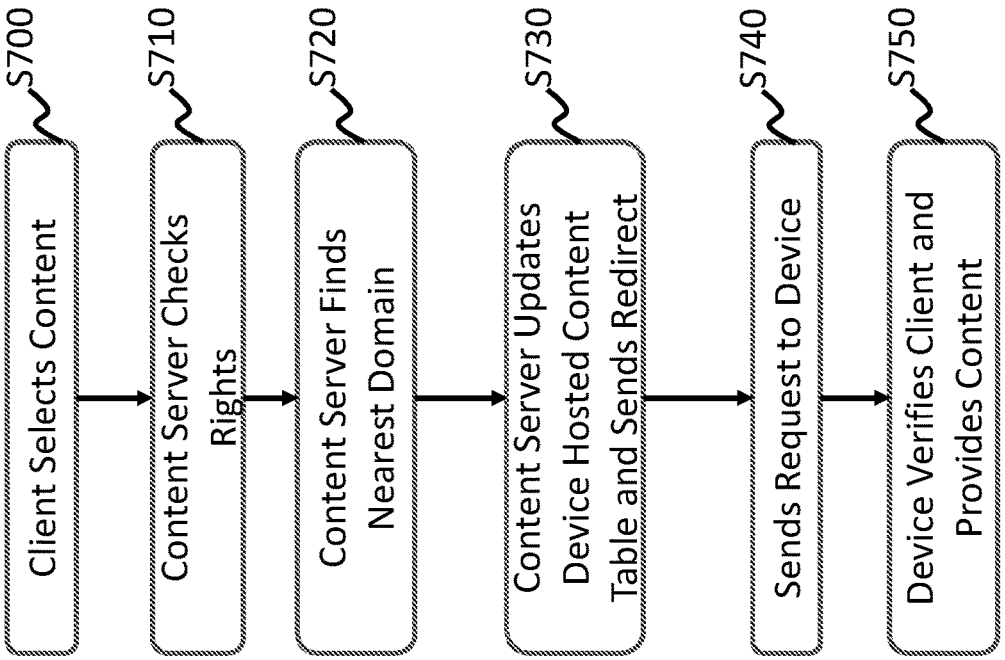

S700
Client Selects Content
S710
Content Server Checks Rights
S720
Content Server Finds Nearest Domain
S730
Content Server Updates Device Hosted Content Table and Sends Redirect
S740
Sends Request to Device
S750
Device Verifies Client and Provides Content

FIG. 7

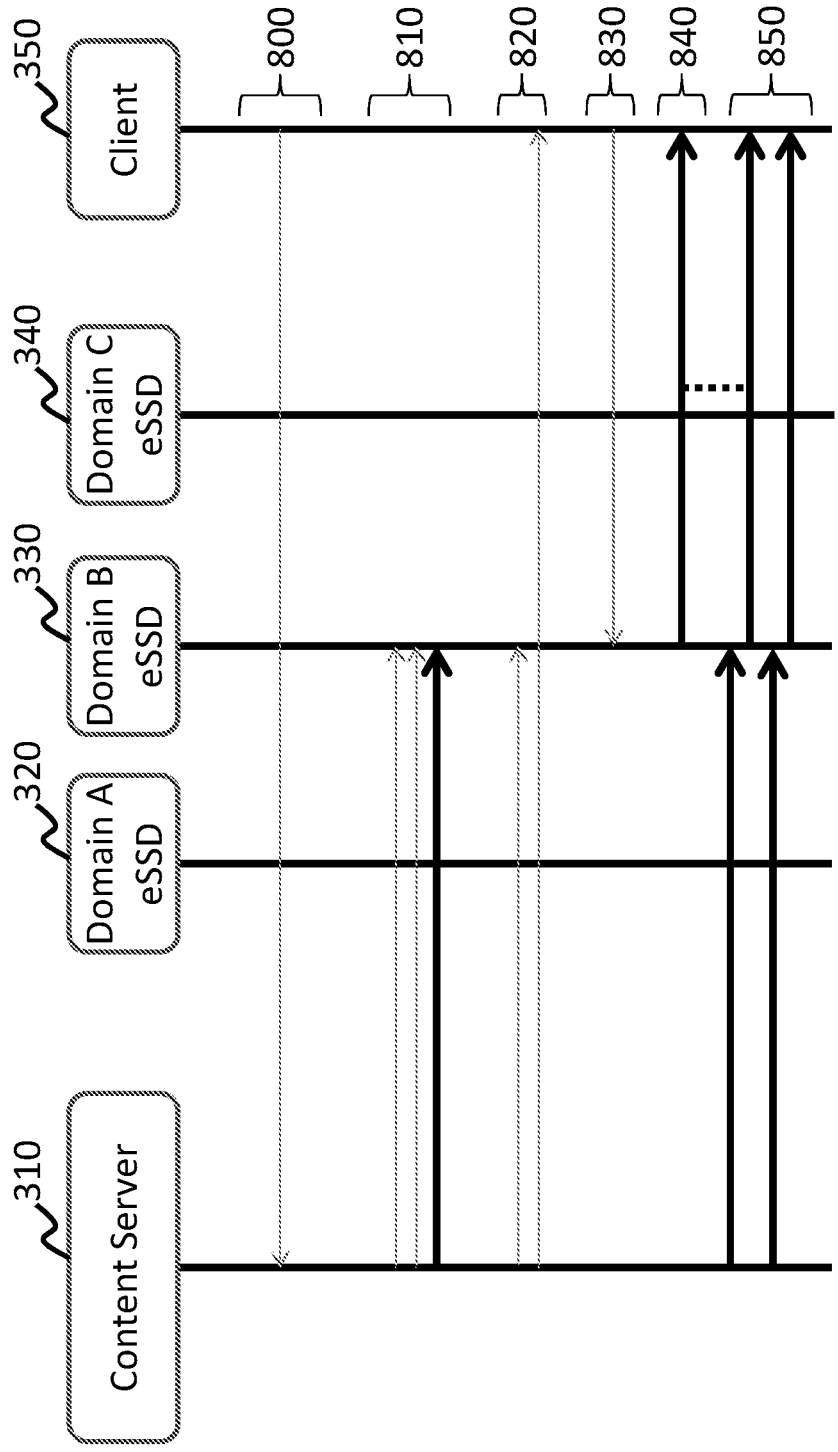

350
Client
340
Domain C eSSD
330
Domain B eSSD
320
Domain A eSSD
310
Content Server
800
810
820
830
840
850

FIG. 8

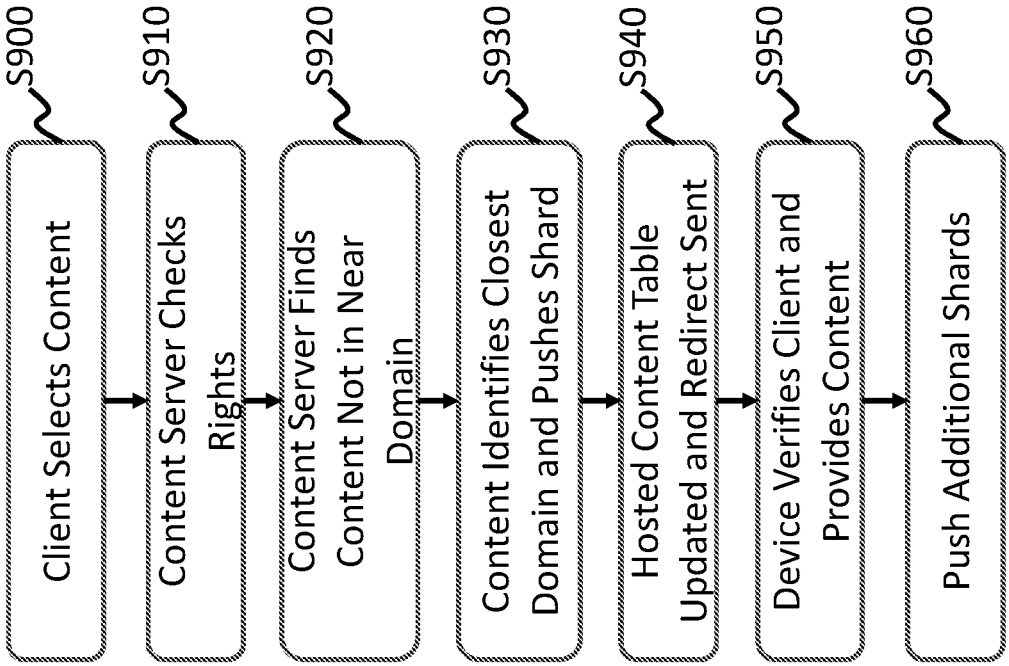

S900
Client Selects Content
S910
Content Server Checks Rights
S920
Content Server Finds Content Not in Near Domain
S930
Content Identifies Closest Domain and Pushes Shard
S940
Hosted Content Table Updated and Redirect Sent
S950
Device Verifies Client and Provides Content
S960
Push Additional Shards

FIG. 9

SYSTEM AND METHOD FOR DISTRIBUTED CACHING

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] The present application claims priority to, and the benefit of, U.S. Provisional Patent Application No. 62/610,036, filed on Dec. 22, 2017, and U.S. Provisional Patent Application No. 62/609,948, filed on Dec. 22, 2017, the contents of which are incorporated herein by reference in its entirety.

BACKGROUND

1. Field

[0002] Some embodiments of the present disclosure relate generally to content caching using network-attached storage devices.

2. Description of the Related Art

[0003] Storage servers are utilized for a variety of data storage applications. In some applications a storage server may provide data storage to a number of remote clients. For example a storage server may store a database, media content, backup storage, etc. Media content delivery typically use storage servers located in datacenters spread around the world.

[0004] FIG. **1** depicts an example related art content delivery system.

[0005] Referring to FIG. **1**, a datacenter **100** may be positioned with a connection to a backbone network **110** and a local network **120**. Backbone networks are typically long-haul networks that span great distances and connect datacenters, servers, and user across cities, states, countries, and the world. The local network **120** usually span shorter distances, for example, connecting end users to data centers and the backbone networks **110**. A datacenter **100** includes edge routers **130/135** which are used by the datacenter's servers to connect to both networks **110/120**. For content delivery systems, a datacenter may include a content server **140** storing multimedia content **145** and a plurality of caching servers **150-156** for quickly distributing the content to end-user devices. For example, the content server **140** may store all of a content provider's content and may receive updates using the backbone network **110**. The content server **140** may then distribute portions of the multimedia content to the caching servers **150-156**. An end-user device may request the content via the local network **120** and retrieves the content from the appropriate caching server **150-156**.

[0006] Current content delivery systems present multiple issues. They require lots of expensive hardware and consume high amounts of power and cooling. Furthermore, utilizing relatively few caching devices results in a performance bottleneck and leaves the system more vulnerable to hacking. Thus, a new system is desired.

[0007] The above information is only for enhancement of understanding of the background of embodiments of the present disclosure, and therefore may contain information that does not form the prior art.

SUMMARY

[0008] Some embodiments of the present disclosure provide a system and method for distributed caching. In various embodiments, the system includes at least one network-connected storage device, a content server, and a control server. In various embodiments, the control server is configured to discover the at least one network-connected storage device, collect device information from the at least one network-connected storage device, where the device information comprises a device location, assign each of the at least one network-connected storage device to a device domain based on each device location, and provide the content server with the device information for the one or more network-connected storage.

[0009] In various embodiments, the at least one network connected storage device comprises an Ethernet solid state drive (eSSD).

[0010] In various embodiments, the control server is further configured to generate a device table, wherein the device table comprises an entry for each of the discovered at least one network-connected storage device, the entry comprising: a cache device identifier, the device location, and the assigned device domain.

[0011] In various embodiments, the cache device identifier is an IP address.

[0012] In various embodiments, the content server is configured to push a content to each of the at least one network-connected storage device based on each device location.

[0013] In various embodiments, the content server has a cached content table, the cached content table having a content entry for each content stored on the at least one network-connected storage devices, wherein the content entry includes a cache device identifier and a content identifier.

[0014] In various embodiments, each of the at least one network-connected storage devices includes a hosted content table. In various embodiments, the hosted content table has an authorization entry for verifying a client device's access rights to each content stored on the network-connected storage device.

[0015] In various embodiments, a distributed caching system may include a plurality of network-connected storage devices. In various embodiments, the network-connected storage devices each include at least one content and a domain based on a device location. In various embodiments, the distributed caching system also includes a content server having a memory and a processor, wherein the processor is configured to execute instructions from the memory that, when executed by the processor, cause the processor to: verify an access right of a client to access a requested content; identify a location of the client; match the location of the client to a proximate domain; update a hosted content table of a device within the nearest domain to include an authorization entry for the client; deliver a redirect message to the client, wherein the redirect message comprises a caching device identifier.

[0016] In various embodiments, the at least one network connected storage device comprises an Ethernet solid state drive (eSSD).

[0017] In various embodiments, the instructions further cause the content server to verify the storage of the content within the nearest domain.

[0018] In various embodiments, the instructions further cause the content server to push a first shard of the requested content to a network-connected storage device in the nearest domain.

[0019] In various embodiments, the instructions further cause the content server to push an additional shard of the requested content to the network-connected storage device in the nearest domain.

[0020] In various embodiments, the device location is a physical location.

[0021] In various embodiments, the distributed caching system includes a plurality of Ethernet solid state drives (eSSDs) each having an IP address, a content server, and a control server. In various embodiments, the control server has a first memory and a first processor, wherein the first processor is configured to execute first instructions from the first memory that, when executed by the first processor, cause the first processor to: discover the each of the plurality of eSSDs; collect device information from each eSSD of the plurality of eSSDs, wherein the device information comprises a device location based on the IP address; and provide the content server with a list of the eSSDs and each corresponding device location.

[0022] In various embodiments, the instructions further cause the control server to generate a device table, having an entry for each of the plurality of eSSDs. In various embodiments, each entry has a cache device identifier, the device location, and the assigned device domain.

[0023] In various embodiments, the content server is configured to push a content to each of the at least one network-connected storage device based on each device location.

[0024] In various embodiments, the content server has a cached content table, the cached content table having a content entry for each content stored on the at least one network-connected storage devices. In various embodiments, the content entry has a cache device identifier and a content identifier.

[0025] In various embodiments, each of the at least one network-connected storage devices has a hosted content table. In various embodiments, the hosted content table includes an authorization entry for verifying a client device's access rights to each content stored on the network-connected storage device.

[0026] In various embodiments, the content server has a second memory and a second processor. In various embodiments, the second processor is configured to execute second instructions from the second memory that, when executed by the second processor, cause the second processor to: verify an access right of a client to access a requested content; identify a location of the client; match the location of the client to a nearest domain; update a hosted content table of an eSSD within the nearest domain to include an authorization entry for the client; deliver a redirect message to the client, wherein the redirect message comprises a caching device identifier.

[0027] In various embodiments, the second instructions further cause the content server to: verify the storage of the content within the nearest domain; and push the requested content to an eSSD in the nearest domain.

[0028] In various embodiments, a network-connected storage device has a network connection, a persistent memory storing at least one multimedia content, and a storage controller. In various embodiments, the storage controller has a memory storing a hosted content table that includes an authorization entry for the at least one multimedia content, and a processor, configured to execute instructions from the memory that, when executed by the processor, cause the processor to: verify an access right of a client to the a requested multimedia content according to the hosted content table; and deliver the requested multimedia content to the client via the network connection.

[0029] In various embodiments, the authorization entry includes a client ID, a content ID, a download timestamp, a use timestamp, and a use count.

[0030] In various embodiments, the at least one multimedia content is a first shard of a multimedia content.

[0031] In various embodiments, the network-connected storage device may request a second shard of the multimedia content from a content server according to the delivery of the first shard of the multimedia content.

[0032] In various embodiments, the network-connected storage device may notify a content server according to the delivery of the first shard of the multimedia content.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] Some embodiments can be understood in more detail from the following description taken in conjunction with the accompanying drawings, in which:

[0034] FIG. **1** depicts an example related art content delivery system;

[0035] FIG. **2** depicts a distributed caching system in accordance with various embodiments of the present invention;

[0036] FIG. **3** depicts a communications chart for initializing the distributed caching system according to various embodiments of the present invention;

[0037] FIG. **4** depicts a method for system initialization according to various embodiments of the present invention;

[0038] FIG. **5**A depicts a Device Table for use on a control server in accordance with various embodiments;

[0039] FIG. **5**B depicts a Cached Content Table for use by a content server in accordance with various embodiments;

[0040] FIG. **5**C depicts a Redirect message that may be sent by the content server to a client device in accordance with various embodiments;

[0041] FIG. **5**D depicts a Content Table for use on a network-connected storage device in accordance with various embodiments;

[0042] FIG. **6** depicts a communications chart for utilizing the distributed caching system to download a content according to various embodiments of the present invention;

[0043] FIG. **7** depicts a method for downloading a content utilizing the distributed caching system according to various embodiments of the present invention;

[0044] FIG. **8** depicts a communications chart for utilizing the distributed caching system to download a content when the content is not currently available on a local caching device according to various embodiments of the present invention;

[0045] FIG. **9** depicts a method for downloading a content utilizing the distributed caching system when the content is not currently available on a local caching device according to various embodiments of the present invention.

DETAILED DESCRIPTION

[0046] Features of the inventive concept and methods of accomplishing the same may be understood more readily by reference to the following detailed description of embodiments and the accompanying drawings. Hereinafter, embodiments will be described in more detail with reference

to the accompanying drawings, in which like reference numbers refer to like elements throughout. The present invention, however, may be embodied in various different forms, and should not be construed as being limited to only the illustrated embodiments herein. Rather, these embodiments are provided as examples so that this disclosure will be thorough and complete, and will fully convey the aspects and features of the present invention to those skilled in the art. Accordingly, processes, elements, and techniques that are not necessary to those having ordinary skill in the art for a complete understanding of the aspects and features of the present invention may not be described. Unless otherwise noted, like reference numerals denote like elements throughout the attached drawings and the written description, and thus, descriptions thereof will not be repeated. In the drawings, the relative sizes of elements, layers, and regions may be exaggerated for clarity.

[0047] In the following description, for the purposes of explanation, numerous specific details are set forth to provide a thorough understanding of various embodiments. It is apparent, however, that various embodiments may be practiced without these specific details or with one or more equivalent arrangements. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring various embodiments.

[0048] It will be understood that when an element, layer, region, or component is referred to as being "on," "connected to," or "coupled to" another element, layer, region, or component, it can be directly on, connected to, or coupled to the other element, layer, region, or component, or one or more intervening elements, layers, regions, or components may be present. However, "directly connected/directly coupled" refers to one component directly connecting or coupling another component without an intermediate component. Meanwhile, other expressions describing relationships between components such as "between," "immediately between" or "adjacent to" and "directly adjacent to" may be construed similarly. In addition, it will also be understood that when an element or layer is referred to as being "between" two elements or layers, it can be the only element or layer between the two elements or layers, or one or more intervening elements or layers may also be present.

[0049] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present invention. As used herein, the singular forms "a" and "an" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "have," "having," "includes," and "including," when used in this specification, specify the presence of the stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0050] As used herein, the term "substantially," "about," "approximately," and similar terms are used as terms of approximation and not as terms of degree, and are intended to account for the inherent deviations in measured or calculated values that would be recognized by those of ordinary skill in the art. "About" or "approximately," as used herein, is inclusive of the stated value and means within an acceptable range of deviation for the particular value as determined by one of ordinary skill in the art, considering the measurement in question and the error associated with measurement of the particular quantity (i.e., the limitations of the measurement system). For example, "about" may mean within one or more standard deviations, or within ±30%, 20%, 10%, 5% of the stated value. Further, the use of "may" when describing embodiments of the present invention refers to "one or more embodiments of the present invention." As used herein, the terms "use," "using," and "used" may be considered synonymous with the terms "utilize," "utilizing," and "utilized," respectively. Also, the term "exemplary" is intended to refer to an example or illustration.

[0051] When a certain embodiment may be implemented differently, a specific process order may be performed differently from the described order. For example, two consecutively described processes may be performed substantially at the same time or performed in an order opposite to the described order.

[0052] Various embodiments are described herein with reference to sectional illustrations that are schematic illustrations of embodiments and/or intermediate structures. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Further, specific structural or functional descriptions disclosed herein are merely illustrative for the purpose of describing embodiments according to the concept of the present disclosure. Thus, embodiments disclosed herein should not be construed as limited to the particular illustrated shapes of regions, but are to include deviations in shapes that result from, for instance, manufacturing. For example, an implanted region illustrated as a rectangle will, typically, have rounded or curved features and/or a gradient of implant concentration at its edges rather than a binary change from implanted to non-implanted region. Likewise, a buried region formed by implantation may result in some implantation in the region between the buried region and the surface through which the implantation takes place. Thus, the regions illustrated in the drawings are schematic in nature and their shapes are not intended to illustrate the actual shape of a region of a device and are not intended to be limiting.

[0053] The electronic or electric devices and/or any other relevant devices or components according to embodiments of the present invention described herein may be implemented utilizing any suitable hardware, firmware (e.g. an application-specific integrated circuit), software, or a combination of software, firmware, and hardware. For example, the various components of these devices may be formed on one integrated circuit (IC) chip or on separate IC chips. Further, the various components of these devices may be implemented on a flexible printed circuit film, a tape carrier package (TCP), a printed circuit board (PCB), or formed on one substrate. Further, the various components of these devices may be a process or thread, running on one or more processors, in one or more computing devices, executing computer program instructions and interacting with other system components for performing the various functionalities described herein. The computer program instructions are stored in a memory which may be implemented in a computing device using a standard memory device, such as, for example, a random access memory (RAM). The computer program instructions may also be stored in other

non-transitory computer readable media such as, for example, a CD-ROM, flash drive, or the like. Also, a person of skill in the art should recognize that the functionality of various computing devices may be combined or integrated into a single computing device, or the functionality of a particular computing device may be distributed across one or more other computing devices without departing from the spirit and scope of the exemplary embodiments of the present invention.

[0054] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which the present invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and/or the present specification, and should not be interpreted in an idealized or overly formal sense, unless expressly so defined herein.

[0055] Embodiments of the present invention include a system and method for distributed caching using network-attached storage devices. In various embodiments, the system includes one or more network-attached storage devices such as Ethernet SSDs (eSSDs) or other network-attached micro devices. The network-attached storage devices may be distributed in a datacenter or throughout a local network. A control server is utilized to configure the network-attached storage devices as caching devices. The caching devices may then be used as part of a multimedia content delivery system, where the caching devices operate in conjunction with a content server to server multimedia or other content to users.

[0056] FIG. **2** depicts a distributed caching system in accordance with various embodiments of the present invention.

[0057] Referring, to FIG. **2**, in various embodiments, the distributed caching system **200** may be configured to provide storage services using a plurality of caching network-connected storage devices. For example, the distributed caching system **200** may include various components located in a datacenter **210**. The datacenter **210** may be connected to a backbone network via a backbone edge router **230** and be connected to a local network via a network edge router **235**. In various embodiments, the datacenter **210** includes a content server **220** configured to store multimedia content **222**. The multimedia content **222** may include, for example, video, audio, and other multimedia files. For example, in various embodiments, the multimedia content **222** may include a first video **224** and a second video **226**. In various embodiments, the datacenter **210** includes one or more datacenter caching network-connected storage devices **240**, **245**. Similarly, in various embodiments, one or more local caching network-connected storage devices **250-256** may be located on a local network. In various embodiments, the caching network-connected storage devices may include micro devices such as eSSDs. For example, in various embodiments, the eSSDs include a storage controller having a processor, memory (e.g. DRAM), persistent memory (e.g. firmware) and a network connection, and persistent memory (e.g. flash memory). The eSSDs are configured to perform Input/Output operations with remote hosts via the network connection. In various embodiments, the caching network-connected storage devices may be configured to store a portion of the media content **222** and provide access to their stored media content to one or more client devices.

[0058] For example, in various embodiments, the first video **224** may be stored on the datacenter caching network connected storage device **240** and the second video **226** may be stored on the datacenter caching network connected storage device **245**. Client devices may retrieve the first and second videos **224**, **226** from the datacenter caching network-connected storage devices **240**, **245**. In some embodiments, all or a portion of the media content **240**, **245** may be stored in the local caching network-connected storage devices **250-256**. For example, in various embodiments the first video **224** may be stored on the local caching network-connected storage devices **250** and **252**, while the second video **226** may be stored on the local caching network-connected storage devices **254** and **256**. In various embodiments, the datacenter and local caching network-connected storage devices may store a portion of the first and second videos **224**,**226**. For example, the local caching network-connected storage device **250** may store a first portion of the first video **224**, the local caching network-connected storage device **252** may store a second portion of the first video **224**, and the datacenter caching network-connected storage device **250** may store a third portion of the first video **224**. As will be discussed below, the multimedia content **222** may be stored in a variety of ways across multiple caching network-attached storage devices.

[0059] In various embodiments, a control server **260** may be configured for performing administrative functions on the various caching network-connected devices **240**, **245**, **250-256**. For example, the control server **260** may be located in the datacenter **210** and able to communicate with each of the caching network-connected devices, while in other embodiments, the control server **260** may be located on the local network or connected to the backbone network. In various embodiments, the administrative functions may include an initialization of the caching network-connected devices (as will be described in detail below) and subsequent modifications to that setup.

[0060] FIG. **3** depicts a communications chart for initializing the distributed caching system according to various embodiments of the present invention. FIG. **4** depicts a method for system initialization according to various embodiments of the present invention.

[0061] Referring to FIGS. **3** and **4**, in various embodiments, the control server **300** may configure the attached caching network-connected devices **320**, **330**, **340** for use with the content server **310** for the distribution of multimedia content to client devices **350**. In various embodiments, the initialization may begin at a "Start of Day" (S**400**). In various embodiments, a "Start of Day" may occur when the distributed caching system is initially setup or when new caching network-connected storage devices **320**, **330**, **340** are added to the distributed caching system.

[0062] In various embodiments, at the "Start of Day" the control server **300** will discover each available caching network-connected storage device **320-340**. For example, in various embodiments, the control server **300** sends discovery packets (**360**) to IP addresses potentially having a caching network-connected storage device. For example, the control server **300** may ping the IP addresses of the network-connected storage devices. In various embodiments, the

network-connected storage devices **320**, **330**, **340** may respond to the control server **300** when they are available (**370**).

[0063] In various embodiments, the responses by the network-connected storage devices **320**, **330**, **340** may include device information (S**420**). For example, the device information may include the network-connected storage device's identifier (e.g. an IP or MAC address), a device's physical location (e.g. a geographic location), and the device's performance characteristics (e.g. available storage space, total storage space, network bandwidth, etc.).

[0064] In various embodiments, the control server **300** may utilize the device information to create caching domains (S**430**). For example, in various embodiments, the control server **300** may create caching domains that include devices in relatively close geographic locations. For example, the network-connected storage device **320** may be representative of multiple network-connected storage devices all located in the relative same geographic area (e.g. the same city). Similarly, the network-connected storage devices **330** and **340** may each be representative of multiple network-connected storage devices all located in the relative same geographic areas.

[0065] In various embodiments, the control server **300** may generate a device table (e.g. the device table depicted in FIG. **5**A which will be described below) that includes each of the discovered network-connected storage devices **320**, **330**, **340** and updates **380** each of the network-connected storage devices' content tables (e.g. the content table depicted in FIG. **5**D which will be described below) to include the control server **300** (S**440**). In various embodiments, the control server **300** may provide a table that includes the available network-connected storage devices (e.g. the cached content table depicted in FIG. **5**B which will be described below) to the content server **310** and the content server **310** may start distributing content to the network-connected storage devices **320**, **330**, **340** (**390**) (S**450**).

[0066] FIG. **5**A depicts a Device Table for use on a control server in accordance with various embodiments. FIG. **5**B depicts a Cached Content Table for use by a content server in accordance with various embodiments. FIG. **5**C depicts a Redirect message that may be sent by the content server to a client device in accordance with various embodiments. FIG. **5**D depicts a Content Table for use on a network-connected storage device in accordance with various embodiments.

[0067] Referring to FIG. **5**A, in various embodiments, the control server may generate and maintain a device table **500**. In various embodiments, the device table **500** is configured to list each of the caching devices that are usable by the caching system and includes their locations and a domain. The device table **500** may be initially generated upon a "Start of Day" (e.g. system initialization) and may also be updated by the control server as caching network-connected storage devices are added and removed from the caching system. In various embodiments, the device table **500** includes a caching device identification **502**, a device location **504**, and a domain **506**. In various embodiments, the device identification may include a unique identifier for a caching network-connected storage device. For example, in various embodiments, the device identification may include an IP address for the device. In various embodiments, the device location **504** identifies the actual geographic location of the device. For example, in various embodiments, the device location **504** may include a postal zip code. In other embodiments, the device location **504** may include a longitude and latitude of the device. In various embodiments, the device domain **506** is a group that the control server has added the device to. For example, devices having the same or similar device locations may be grouped in the same domain. In various embodiments, the device table **500** includes a device entry **508**-**516** for each device under the control of the control server.

[0068] Referring to FIG. **5**B, in various embodiments, the content server may be configured with a cached content table **518**. In various embodiments, the cached content table **518** is configured to provide the content server with a list of the caching network-connected storage devices, their locations, and a listing of what content is stored on each device. For example, in various embodiments, the cached content table **518** may include a cache device identifier **520**, a location **522**, and a content identifier **524**. The cache device identifier **520** and location **522** may correspond to the cache device identifier **502** and device location **504** described above. In various embodiments, the content identifier **522** includes a unique identifier of a content (e.g. a multimedia content). For example, the content identifier **524** may include a movie title. In various embodiments, the cache device may store only a portion of a complete content (e.g. a portion of a video) and the content identifier **524** may also identify which portion of the content is stored in the caching device. For example, the cache content table **518** includes device entries **526**-**534**. In this example, a first caching device **526** is located in zip code 95134 (e.g. San Jose, Calif., USA), and is storing shards 1 through 5 of content 1 (e.g. the first five portions of content 1). A second caching device **528** is located in zip code 95136 (e.g. San Jose, Calif., USA), and is storing shards 6 through 10 of content 1 (e.g. the final five portions of content 1). In various embodiments, the cached content table **518** may include an entry for each content (e.g. each device may have multiple listings if the device stores more than one content, such as device 3 which includes entries **530** and **532**). In various other embodiments, the cached content table **518** may include a single entry for each caching device and list all of the content stored on the device in the content ID **524**.

[0069] In various embodiments, the cached content table **518** may be generated and maintained by the content server in conjunction with the control server. For example, in various embodiments, the control server may generate the cached content table and populate it with each of the devices being used for caching. In other embodiments, the content server may generate the cached content table **516** and may receive, from the control server, a list of the devices.

[0070] Referring to FIG. **5**C, in various embodiments, a redirect message **536** may be sent by the content server to a client to direct the client to a device storing a requested data. For example, in various embodiments, the redirect message **536** includes a client identifier **538**, a content identifier **540**, and a caching device identifier **542**. In various embodiments, the client identifier **538** is a unique identifier for the client. For example, the client identifier **538** may be an IP address. In other examples, the client identifier **538** may include a client username or a security token associated with the client. In various embodiments, the content identifier **540** includes a unique identifier of a content and may correspond to the content identifier **524**. In various embodiments, the

caching device identifier **542** may correspond to the cache device identifier **502** and **520**. For example, as stated above, the caching device identifiers **502**, **520**, **542** may include an IP address for a caching device.

[0071] Referring to FIG. **5**D, in various embodiments, each of the caching network-connected storage devices may include a hosted content table **544**. In various embodiments, the hosted content table **544** is stored on the network-connected storage device in persistent memory, such as in a device controller in a firmware or in main storage (e.g. flash). In various embodiments, the hosted content table **544** includes an authorization entry for each client that has or has previously downloaded content from the device (entries **556-564**). For example, the hosted content table **544** may include entries having a client identifier **546**, a content identifier **548**, a download timestamp **550**, a use timestamp **552**, and use count **554**. In various embodiments, the client identifier **546** may correspond to the client identifier **538** described above. In various embodiments, the content identifier **548** may be the same content identifier as the content identifier **524** and **540**. In various embodiments, the download timestamp **550** may be a timestamp for when the content was downloaded from a content server. For example, in some embodiments, the device may be configured to remove a content after it has become older than a predefined threshold. In various embodiments, the use timestamp **552** includes a timestamp when the client downloaded the content. In various embodiments, the use count **554** may include a total number of views of the content by the client.

[0072] FIG. **6** depicts a communications chart for utilizing the distributed caching system to download a content according to various embodiments of the present invention. FIG. **7** depicts a method for downloading a content utilizing the distributed caching system according to various embodiments of the present invention.

[0073] Referring to FIGS. **6** and **7**, in various embodiments, the distributed caching system may distribute content utilizing the content server in conjunction with the caching network-connected storage devices and without further intervention from the control server. In various embodiments, the caching network-connected storage devices include a first group of one or more eSSDs **320** located in a first location and assigned to "Domain A", a second group of one or more SSDs **330** located in a second location and assigned to "Domain B", and a third group of one or more eSSDs **340** located in a first location and assigned to "Domain C".

[0074] In various embodiments, a client **350** may send a request **600** to access a content from the content server **310** (S**700**). In various embodiments, the content server **310** may check the client's access rights to the content (S**710**). For example, the request may include a username and password for the client (or other user account identifying information) to verify the identity of the user and compare the user's identity to access rights to the content. In various embodiments, the content server **310** may identify the location of the client device **350** and identify a domain having caching devices that are relatively near the client device **350** (S**720**). For example, the content server **310** may use the client's **350** IP address to identify the location of the client **350** and then match the client **350** to the closest caching devices using the cache content table to identify which devices have the requested content and where those devices are located.

[0075] In various embodiments, the content server **310** may provide an authorization update **610** the caching device **320** and the client **350** so that the client **350** may access the requested content from the caching device **320**. For example, in various embodiments, the content server **310** may provide the identified caching device **320** with an update to the device's hosted content table (e.g. the hosted content table of FIG. **5**D) to allow for the client device **350** to access the caching device **320** and may send the client device **350** a redirect message (e.g. the redirect message of FIG. **5**C) (S**730**).

[0076] In various embodiments, the client **350** receives the redirect message from the content server **310** and uses the information provided in the redirect message to request **620** the content from the caching device **320** (S**740**). In various embodiments, the caching device **320** will receive the request from the client **350** and the caching device will verify that the client **350** has authority to access the content by checking the device's hosted content table (e.g. the hosted content table of FIG. **5**D). Once the client **350** has been verified the caching device **320** provides the content **630** (S**750**).

[0077] FIG. **8** depicts a communications chart for utilizing the distributed caching system to download a content when the content is not currently available on a local caching device according to various embodiments of the present invention. FIG. **9** depicts a method for downloading a content utilizing the distributed caching system when the content is not currently available on a local caching device according to various embodiments of the present invention.

[0078] Referring to FIGS. **8** and **9**, in various embodiments, the distributed caching system may distribute content utilizing the content server in conjunction with the caching network-connected storage devices and without further intervention from the control server even when a local caching device does not have the content stored on the device.

[0079] In various embodiments, a client **350** may send a request **800** to access a content from the content server **310** (S**900**). In various embodiments, the content server **310** may check the client's access rights to the content (S**910**). As described above, in various embodiments, the request may include a username and password for the client (or other user account identifying information) to verify the identity of the user and compare the user's identity to access rights to the content. In various embodiments, the content server **310** may identify the location of the client device **350** and identify a domain having caching devices that are relatively near the client device **350** (e.g. physically or logically). In some instances, the closest domain (e.g. a proximate domain) may not include any devices that are hosting the requested content (S**920**). For example, the caching devices **330** in "Domain B" may be the closest caching devices to the client **350**, but may not currently include the requested content. In various embodiments, the content server **310** identifies the closest domain to the client **350** and pushes **810** the content or a first shard of the content to a caching device in the identified domain (S**930**). In various embodiments, the cached content table (e.g. the cached content table of FIG. **5**B) may be updated to reflect the newly cached content. In various embodiments, the content server **310** may provide the identified caching device **330** with an update to the device's hosted content table (e.g. add an authorization entry to the hosted content table of FIG. **5**D) to allow for the client

device **350** to access the caching device **330** and may send the client device **350** a redirect message (e.g. the redirect message of FIG. **5**C) **820** (S**940**).

[0080] For example, the content server **310** may use the client's **350** IP address to identify the location of the client **350** and then match the client **350** to the closest caching devices (e.g. a proximate caching device)using the cache content table to identify which devices have the requested content and where those devices are located. In various embodiments, the client **350** receives the redirect message from the content server **310** and uses the information provided in the redirect message to request **830** the content from the caching device **320** and, after verifying that the client **350** has authority to access the content by checking the device's hosted content table (e.g. the hosted content table of FIG. **5**D), the caching device **330** provides the content **840** (S**950**).

[0081] In various embodiments, the content server **310** may send **850** the caching devices **330** with shards as the client device **350** requires them (S**960**). For example, in various embodiments the requested content may include a video file. The video file may be split into a plurality of shards. The plurality of shards may be of a uniform or non-uniform size. For example, a first shard may include the first 3 minutes of a video and each subsequent shard may include the next 10 minutes of video. In various embodiments, as the client plays the video, the caching devices **330** may notify the content server **310** when additional shards are needed (e.g. when the client will soon complete the download of the current shard) and the content server **310** may push additional shards **850** to the caching device(s) **330** being utilized (and update the cached content table as necessary). In various embodiments, the shards may be pushed to different caching devices within the same domain. In these cases, the content server **310** may be configured to send redirect messages as necessary to properly direct the client device to the caching devices with the requested content. Additionally, the content server **310** may also update the hosted content tables of the caching devices so that the client will be able to access their stored content.

[0082] Accordingly, the above described embodiments of the present disclosure provide a system and method for a distributed caching system.

[0083] The foregoing is illustrative of example embodiments, and is not to be construed as limiting thereof. Although a few example embodiments have been described, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from the novel teachings and advantages of example embodiments. Accordingly, all such modifications are intended to be included within the scope of example embodiments as defined in the claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures. Therefore, it is to be understood that the foregoing is illustrative of example embodiments and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed example embodiments, as well as other example embodiments, are intended to be included within the scope of the appended claims. The inventive concept is defined by the following claims, with equivalents of the claims to be included therein.

What is claimed is:

1. A distributed caching system comprising:

at least one network-connected storage device;

a content server; and

a control server, the control server comprising:

a memory; and

a processor, wherein the processor is configured to execute instructions from the memory that, when executed by the processor, cause the processor to:

discover the at least one network-connected storage device;

collect device information from the at least one network-connected storage device, wherein the device information comprises a device location;

assign each of the at least one network-connected storage device to a device domain based on each device location; and

provide the content server with the device information for the one or more network-connected storage.

2. The distributed caching system of claim **1**, wherein the at least one network connected storage device comprises an Ethernet solid state drive (eSSD).

3. The distributed caching system of claim **1**, the instructions further comprising generating a device table, wherein the device table comprises an entry for each of the discovered at least one network-connected storage device, the entry comprising: a cache device identifier, the device location, and the assigned device domain.

4. The distributed caching system of claim **3**, wherein the cache device identifier comprises an IP address.

5. The distributed caching system of claim **1**, wherein the content server is configured to push a content to each of the at least one network-connected storage device based on each device location.

6. The distributed caching system of claim **5**, wherein the content server comprises a cached content table, the cached content table comprising a content entry for each content stored on the at least one network-connected storage devices, wherein the content entry comprises: a cache device identifier and a content identifier.

7. The distributed caching system of claim **6**, wherein each of the at least one network-connected storage devices comprises a hosted content table, wherein the hosted content table comprises an authorization entry for verifying a client device's access rights to each content stored on the network-connected storage device.

8. A distributed caching system comprising:

a plurality of network-connected storage devices, wherein each of the network-connected storage devices comprises at least one content and a domain based on a device location; and

a content server, the content server comprising:

a memory; and

a processor, wherein the processor is configured to execute instructions from the memory that, when executed by the processor, cause the processor to:

verify an access right of a client to access a requested content;

identify a location of the client;

match the location of the client to a proximate domain;

update a hosted content table of a device within the nearest domain to include an authorization entry for the client; and

deliver a redirect message to the client, wherein the redirect message comprises a caching device identifier.

9. The distributed caching system of claim **8**, wherein the at least one network connected storage device comprises an Ethernet solid state drive (eSSD).

10. The distributed caching system of claim **8**, the instructions further comprising:

verifying the storage of the content within the nearest domain.

11. The distributed caching system of claim **10**, the instructions further comprising:

push a first shard of the requested content to a network-connected storage device in the nearest domain.

12. The distributed caching system of claim **11**, the instructions further comprising:

push an additional shard of the requested content to the network-connected storage device in the nearest domain.

13. The distributed caching system of claim **8**, wherein the device location comprises a physical location.

14. A distributed caching system comprising:

a plurality of Ethernet solid state drives (eSSDs), wherein each of the plurality of eSSDs comprises an IP address;

a content server; and

a control server, the control server comprising:

a first memory; and

a first processor, wherein the first processor is configured to execute first instructions from the first memory that, when executed by the first processor, cause the first processor to:

discover the each of the plurality of eSSDs;

collect device information from each eSSD of the plurality of eSSDs, wherein the device information comprises a device location based on the IP address; and

provide the content server with a list of the eSSDs and each corresponding device location.

15. The distributed caching system of claim **14**, the instructions further comprising generating a device table, wherein the device table comprises an entry for each of the plurality of eSSDs, the entry comprising: a cache device identifier, the device location, and the assigned device domain.

16. The distributed caching system of claim **15**, wherein the content server is configured to push a content to each of the at least one network-connected storage device based on each device location.

17. The distributed caching system of claim **16**, wherein the content server comprises a cached content table, the cached content table comprising a content entry for each content stored on the at least one network-connected storage devices, wherein the content entry comprises: a cache device identifier and a content identifier.

18. The distributed caching system of claim **17** wherein each of the at least one network-connected storage devices comprises a hosted content table, wherein the hosted content table comprises an authorization entry for verifying a client device's access rights to each content stored on the network-connected storage device.

19. The distributed caching system of claim **14**, wherein the content server comprises:

a second memory; and

a second processor, wherein the second processor is configured to execute second instructions from the second memory that, when executed by the second processor, cause the second processor to:

verify an access right of a client to access a requested content;

identify a location of the client;

match the location of the client to a nearest domain;

update a hosted content table of an eSSD within the nearest domain to include an authorization entry for the client; and

deliver a redirect message to the client, wherein the redirect message comprises a caching device identifier.

20. The distributed caching system of claim **19**, the second instructions further comprising:

verify the storage of the content within the nearest domain; and

push the requested content to an eSSD in the nearest domain.

21. A network-connected storage device comprising:

a network connection;

a persistent memory storing at least one multimedia content; and

a storage controller comprising:

a memory storing a hosted content table, wherein the hosted content table comprises an authorization entry for the at least one multimedia content; and

a processor, wherein the processor is configured to execute instructions from the memory that, when executed by the processor, cause the processor to:

verify an access right of a client to the a requested multimedia content according to the hosted content table; and

deliver the requested multimedia content to the client via the network connection.

22. The network-connected storage device of claim **21**, wherein the authorization entry comprises a client ID, a content ID, a download timestamp, a use timestamp, and a use count.

23. The network-connected storage device of claim **21**, wherein the at least one multimedia content comprises a first shard of a multimedia content.

24. The network-connected storage device of claim **23**, wherein the instructions further cause the processor to:

request a second shard of the multimedia content from a content server according to the delivery of the first shard of the multimedia content.

25. The network-connected storage device of claim **23**, wherein the instructions further cause the processor to:

notify a content server according to the delivery of the first shard of the multimedia content.

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