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Proactive content placement for low latency mobile access

Abstract

The described technology is generally directed towards proactive content placement for low latency mobile access. Digital content requested by a mobile device can be sent to network nodes proactively, so that the network nodes have the digital content before it is requested by the mobile device. Mobile device travel predictions can be made to predict future locations of the mobile device. The future locations can be used to determine network nodes for proactive digital content delivery. The digital content for delivery to a network node can also be predicted based on current digital content in use at the mobile device and estimated arrival times of the mobile device into service areas of next network nodes.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
9582603	12/2016	Acharya	N/A	G06F 16/9574
10037231	12/2017	Jakhetiya	N/A	G06F 9/5072
2015/0350590	12/2014	Micewicz	386/230	H04N 5/775
2017/0064066	12/2016	Das	N/A	H04W 4/023
2019/0278631	12/2018	Guim Bernat et al.	N/A	N/A
2019/0319868	12/2018	Svennebring	N/A	H04W 24/08
2020/0145699	12/2019	Hong	N/A	H04N 21/251
2020/0163042	12/2019	Cho et al.	N/A	N/A
2020/0204603	12/2019	Upadhyaya et al.	N/A	N/A
2020/0259878	12/2019	Yang	N/A	H04L 65/1016
2020/0366732	12/2019	Trang	N/A	H04W 4/02
2022/0303331	12/2021	Svennebring	N/A	H04N 21/44209

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
109362064	12/2018	CN	N/A
2642393	12/2018	EP	G06F 11/1456

OTHER PUBLICATIONS

Non Final Office Action received for U.S. Appl. No. 16/876,648 dated Mar. 17, 2022, 123 pages. cited by applicant

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Background/Summary

RELATED APPLICATION (1) The subject patent application is a continuation of, and claims priority to, U.S. patent application Ser. No. 16/876,648, filed May 18, 2020, and entitled "PROACTIVE CONTENT PLACEMENT FOR LOW LATENCY MOBILE ACCESS," the entirety of which priority application is hereby incorporated by reference herein.

TECHNICAL FIELD
(1) The subject application is related to fifth generation (5G) and subsequent generation cellular communication systems.
BACKGROUND
(2) 5G wireless technologies will improve the performance and throughput of wireless networks. These wireless network enhancements will enable a new generation of mobile services characterized by low latencies, very high bandwidth, spectrum efficiency, operations automation, and the like.
(3) Enhancements associated with 5G radio access network (RAN) technologies create challenges and opportunities for other systems involved in delivery of end-to-end service. If other systems do not also step up their performance, then the benefits of 5G RAN technologies will hampered.
(4) For example, augmented reality (AR) and virtual reality (VR) technologies are expected to benefit from the low latency and high throughput associated with 5G technologies. AR and VR have promising applications in a variety of areas such as games, advertising, training, education, field-work, etc. Some of these applications will require delivery of digital content to mobile user equipment (UE) devices. In such use cases, an entire end-to-end service may have demands to deliver digital content to a mobile UE at or near the speeds achievable via the 5G RAN.
(5) The above-described background is merely intended to provide a contextual overview of some current issues, and is not intended to be exhaustive. Other contextual information may become further apparent upon review of the following detailed description.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) Non-limiting and non-exhaustive embodiments of the subject disclosure are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.
(2) FIG. **1** illustrates an example wireless communication system, in accordance with various aspects and embodiments of the subject disclosure.
(3) FIG. **2** illustrates an example a wireless communication system arranged for proactive content placement for low latency mobile access, in accordance with various aspects and embodiments of the subject disclosure.
(4) FIG. **3** illustrates an example predictive content mobilization module, in accordance with various aspects and embodiments of the subject disclosure.
(5) FIG. **4** illustrates an example content delivery network (CDN) server, in accordance with various aspects and embodiments of the subject disclosure.
(6) FIG. **5** illustrates an example network node, in accordance with various aspects and

embodiments of the subject disclosure.
(7) FIG. **6** illustrates several example multi-access edge computing options, in accordance with various aspects and embodiments of the subject disclosure.
(8) FIG. **7** is a flow diagram representing example operations of a communication service provider network device comprising a predictive content mobilization module, in accordance with various aspects and embodiments of the subject disclosure.
(9) FIG. **8** is a flow diagram representing example operations of a CDN server, in accordance with various aspects and embodiments of the subject disclosure.
(10) FIG. **9** is a flow diagram representing example operations of an edge computing device, in accordance with various aspects and embodiments of the subject disclosure.
(11) FIG. **10** is a block diagram of an example computer that can be operable to execute processes and methods in accordance with various aspects and embodiments of the subject disclosure.

DETAILED DESCRIPTION

(12) One or more embodiments are now described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the various embodiments. It is evident, however, that the various embodiments can be practiced without these specific details, and without applying to any particular networked environment or standard.
(13) One or more aspects of the technology described herein are generally directed towards proactive content placement for low latency mobile access. Digital content requested by a mobile device can be sent to network nodes proactively, so that the network nodes have the digital content before it is requested by the mobile device. Mobile device travel predictions can be made to predict future locations of the mobile device. The future locations can be used to determine network nodes for proactive digital content delivery. The digital content for delivery to a network node can also be predicted, e.g., based on current digital content in use at the mobile device and an estimated arrival time of the mobile device into a service area of a next network node.
(14) Examples of digital content include media such as images, videos, audio content, and three dimensional (3D) objects. Digital content can also include experiences such as AR interactions and overlays, and gaming and work instructions. Maps, including two dimensional (2D) maps, 3D maps, and point clouds are also digital content. This disclosure is not limited to any particular form of digital content.
(15) As used in this disclosure, in some embodiments, the terms “component,” “system” and the like are intended to refer to, or comprise, a computer-related entity or an entity related to an operational apparatus with one or more specific functionalities, wherein the entity can be either hardware, a combination of hardware and software, software, or software in execution. As an example, a component can be, but is not limited to being, a process running on a processor, a processor, an object, an executable, a thread of execution, computer-executable instructions, a program, and/or a computer. By way of illustration and not limitation, an application running on a server, the application or other media residing on the server, and the server can be a component.
(16) One or more components can reside within a process and/or thread of execution and a component can be localized on one computer and/or distributed between two or more computers. In addition, these components can execute from various computer readable media having various data structures stored thereon. The components can communicate via local and/or remote processes such as in accordance with a signal having one or more data packets (e.g., data from one component interacting with another component in a local system, distributed system, and/or across a network such as the internet with other systems via the signal). As another example, a component can be an apparatus with specific functionality provided by mechanical parts operated by electric or electronic circuitry, which is operated by a software application or firmware application executed by a processor, wherein the processor can be internal or external to the apparatus and executes at

least a part of the software or firmware application. As yet another example, a component can be an apparatus that provides specific functionality through electronic components without mechanical parts, the electronic components can comprise a processor therein to execute software or firmware that confers at least in part the functionality of the electronic components. While various components have been illustrated as separate components, it will be appreciated that multiple components can be implemented as a single component, or a single component can be implemented as multiple components, without departing from example embodiments.

(17) The term “facilitate” as used herein is in the context of a system, device or component “facilitating” one or more actions or operations, in respect of the nature of complex computing environments in which multiple components and/or multiple devices can be involved in some computing operations. Non-limiting examples of actions that may or may not involve multiple components and/or multiple devices comprise transmitting or receiving data, establishing a connection between devices, determining intermediate results toward obtaining a result, etc. In this regard, a computing device or component can facilitate an operation by playing any part in accomplishing the operation. When operations of a component are described herein, it is thus to be understood that where the operations are described as facilitated by the component, the operations can be optionally completed with the cooperation of one or more other computing devices or components, such as, but not limited to, sensors, antennae, audio and/or visual output devices, other devices, etc.

(18) Further, the various embodiments can be implemented as a method, apparatus or article of manufacture using standard programming and/or engineering techniques to produce software, firmware, hardware or any combination thereof to control a computer to implement the disclosed subject matter. The term “article of manufacture” as used herein is intended to encompass a computer program accessible from any computer-readable (or machine-readable) device or computer-readable (or machine-readable) storage/communications media. For example, computer readable storage media can comprise, but are not limited to, magnetic storage devices (e.g., hard disk, floppy disk, magnetic strips), optical disks (e.g., compact disk (CD), digital versatile disk (DVD)), smart cards, and flash memory devices (e.g., card, stick, key drive). Of course, those skilled in the art will recognize many modifications can be made to this configuration without departing from the scope or spirit of the various embodiments.

(19) Moreover, terms such as “mobile device equipment,” “mobile station,” “mobile,” subscriber station,” “access terminal,” “terminal,” “handset,” “communication device,” “mobile device” (and/or terms representing similar terminology) can refer to a wireless device utilized by a subscriber or mobile device of a wireless communication service to receive or convey data, control, voice, video, sound, gaming or substantially any data-stream or signaling-stream. The foregoing terms are utilized interchangeably herein and with reference to the related drawings. Likewise, the terms “access point (AP),” “Base Station (BS),” BS transceiver, BS device, cell site, cell site device, “gNode B (gNB),” “evolved Node B (eNode B),” “home Node B (HNB)” and the like, are utilized interchangeably in the application, and refer to a wireless network component or appliance that transmits and/or receives data, control, voice, video, sound, gaming or substantially any data-stream or signaling-stream from one or more subscriber stations. Data and signaling streams can be packetized or frame-based flows.

(20) Furthermore, the terms “device,” “communication device,” “mobile device,” “subscriber,” “customer entity,” “consumer,” “customer entity,” “entity” and the like are employed interchangeably throughout, unless context warrants particular distinctions among the terms. It should be appreciated that such terms can refer to human entities, computational components, or automated components supported through artificial intelligence (e.g., a capacity to make inference based on complex mathematical formalisms), which can provide simulated vision, sound recognition and so forth.

(21) Embodiments described herein can be exploited in substantially any wireless communication

technology, comprising, but not limited to, wireless fidelity (Wi-Fi), global system for mobile communications (GSM), universal mobile telecommunications system (UMTS), worldwide interoperability for microwave access (WiMAX), enhanced general packet radio service (enhanced GPRS), third generation partnership project (3GPP) long term evolution (LTE), third generation partnership project 2 (3GPP2) ultra-mobile broadband (UMB), fifth generation core (5G Core), fifth generation option 3x (5G Option 3x), high speed packet access (HSPA), Z-Wave, Zigbee and other 802.XX wireless technologies and/or legacy telecommunication technologies.

(22) FIG. **1** illustrates a non-limiting example of a wireless communication system **100** which can be used in connection with at least some embodiments of the subject disclosure. In one or more embodiments, system **100** can comprise one or more user equipment UEs **102**.sub.1, **102**.sub.2, referred to collectively as UEs **102**, a network node **104**, and communication service provider network(s) **106**.

(23) The non-limiting term "user equipment" can refer to any type of device that can communicate with a network node **104** in a cellular or mobile communication system **100**. UEs **102** can have one or more antenna panels having vertical and horizontal elements. Examples of UEs **102** comprise target devices, device to device (D2D) UEs, machine type UEs or UEs capable of machine to machine (M2M) communications, personal digital assistants (PDAs), tablets, mobile terminals, smart phones, laptop mounted equipment (LME), universal serial bus (USB) dongles enabled for mobile communications, computers having mobile capabilities, mobile devices such as cellular phones, laptops having laptop embedded equipment (LEE, such as a mobile broadband adapter), tablet computers having mobile broadband adapters, wearable devices, virtual reality (VR) devices, heads-up display (HUD) devices, smart cars, machine-type communication (MTC) devices, augmented reality head mounted displays, and the like. UEs **102** can also comprise IOT devices that communicate wirelessly.

(24) In various embodiments, system **100** comprises communication service provider network(s) **106** serviced by one or more wireless communication network providers. Communication service provider network(s) **106** can comprise a "core network". In example embodiments, UEs **102** can be communicatively coupled to the communication service provider network(s) **106** via network node **104**. The network node **104** (e.g., network node device) can communicate with UEs **102**, thus providing connectivity between the UEs **102** and the wider cellular network. The UEs **102** can send transmission type recommendation data to the network node **104**. The transmission type recommendation data can comprise a recommendation to transmit data via a closed loop MIMO mode and/or a rank-1 precoder mode.

(25) A network node **104** can have a cabinet and other protected enclosures, computing devices, an antenna mast, and multiple antennas for performing various transmission operations (e.g., MIMO operations) and for directing/steering signal beams. Network node **104** can comprise one or more base station devices which implement features of the network node **104**. Network nodes can serve one or several cells, also called sectors or service areas, depending on the configuration and type of antenna. In example embodiments, when UEs **102** are within service area **110**, UEs **102** can send and/or receive communication data via a wireless link to the network node **104**. The dashed arrow lines from the network node **104** to the UEs **102** represent downlink (DL) communications and the solid arrow lines from the UEs **102** to the network node **104** represents an uplink (UL) communications.

(26) Communication service provider networks **106** can facilitate providing wireless communication services to UEs **102** via the network node **104** and/or various additional network devices (not shown) included in the one or more communication service provider networks **106**. The one or more communication service provider networks **106** can comprise various types of disparate networks, including but not limited to: cellular networks, femto networks, picocell networks, microcell networks, internet protocol (IP) networks Wi-Fi service networks, broadband service network, enterprise networks, cloud based networks, millimeter wave networks and the

like. For example, in at least one implementation, system **100** can be or comprise a large scale wireless communication network that spans various geographic areas. According to this implementation, the one or more communication service provider networks **106** can be or comprise the wireless communication network and/or various additional devices and components of the wireless communication network (e.g., additional network devices and cell, additional UEs, network server devices, etc.).

(27) The network node **104** can be connected to the one or more communication service provider networks **106** via one or more backhaul links **108**. For example, the one or more backhaul links **108** can comprise wired link components, such as a T1/E1 phone line, a digital subscriber line (DSL) (e.g., either synchronous or asynchronous), an asymmetric DSL (ADSL), an optical fiber backbone, a coaxial cable, and the like. The one or more backhaul links **108** can also comprise wireless link components, such as but not limited to, line-of-sight (LOS) or non-LOS links which can comprise terrestrial air-interfaces or deep space links (e.g., satellite communication links for navigation). In an embodiment, network node **104** can be part of an integrated access and backhaul network. This may allow easier deployment of a dense network of self-backhauled 5G cells in a more integrated manner by building upon many of the control and data channels/procedures defined for providing access to UEs.

(28) Wireless communication system **100** can employ various cellular systems, technologies, and modulation modes to facilitate wireless radio communications between devices (e.g., the UE **102** and the network node **104**). While example embodiments might be described for 5G new radio (NR) systems, the embodiments can be applicable to any radio access technology (RAT) or multi-RAT system where the UE operates using multiple carriers e.g., LTE FDD/TDD, GSM/GERAN, CDMA2000 etc.

(29) For example, system **100** can operate in accordance with global system for mobile communications (GSM), universal mobile telecommunications service (UMTS), long term evolution (LTE), LTE frequency division duplexing (LTE FDD, LTE time division duplexing (TDD), high speed packet access (HSPA), code division multiple access (CDMA), wideband CDMA (WCMDA), CDMA2000, time division multiple access (TDMA), frequency division multiple access (FDMA), multi-carrier code division multiple access (MC-CDMA), single-carrier code division multiple access (SC-CDMA), single-carrier FDMA (SC-FDMA), orthogonal frequency division multiplexing (OFDM), discrete Fourier transform spread OFDM (DFT-spread OFDM) single carrier FDMA (SC-FDMA), Filter bank based multi-carrier (FBMC), zero tail DFT-spread-OFDM (ZT DFT-s-OFDM), generalized frequency division multiplexing (GFDM), fixed mobile convergence (FMC), universal fixed mobile convergence (UFMC), unique word OFDM (UW-OFDM), unique word DFT-spread OFDM (UW DFT-Spread-OFDM), cyclic prefix OFDM CP-OFDM, resource-block-filtered OFDM, Wi Fi, WLAN, WiMax, and the like. However, various features and functionalities of system **100** are particularly described wherein the devices (e.g., the UEs **102** and the network device **104**) of system **100** are configured to communicate wireless signals using one or more multi carrier modulation schemes, wherein data symbols can be transmitted simultaneously over multiple frequency subcarriers (e.g., OFDM, CP-OFDM, DFT-spread OFMD, UFMC, FMBC, etc.). The embodiments are applicable to single carrier as well as to multicarrier (MC) or carrier aggregation (CA) operation of the UE. The term carrier aggregation (CA) is also called (e.g., interchangeably called) “multi-carrier system”, “multi-cell operation”, “multi-carrier operation”, “multi-carrier” transmission and/or reception. Note that some embodiments are also applicable for Multi RAB (radio bearers) on some carriers (that is data plus speech is simultaneously scheduled).

(30) In various embodiments, system **100** can be configured to provide and employ 5G or subsequent generation wireless networking features and functionalities. 5G wireless communication networks are expected to fulfill the demand of exponentially increasing data traffic and to allow people and machines to enjoy gigabit data rates with virtually zero (e.g., single digit

millisecond) latency. Compared to 4G, 5G supports more diverse traffic scenarios. For example, in addition to the various types of data communication between conventional UEs (e.g., phones, smartphones, tablets, PCs, televisions, internet enabled televisions, AR/VR head mounted displays (HMDs), etc.) supported by 4G networks, 5G networks can be employed to support data communication between smart cars in association with driverless car environments, as well as machine type communications (MTCs). Considering the drastic different communication demands of these different traffic scenarios, the ability to dynamically configure waveform parameters based on traffic scenarios while retaining the benefits of multi carrier modulation schemes (e.g., OFDM and related schemes) can provide a significant contribution to the high speed/capacity and low latency demands of 5G networks. With waveforms that split the bandwidth into several sub-bands, different types of services can be accommodated in different sub-bands with the most suitable waveform and numerology, leading to an improved spectrum utilization for 5G networks.

(31) To meet the demand for data centric applications, features of proposed 5G networks can comprise: increased peak bit rate (e.g., 20 Gbps), larger data volume per unit area (e.g., high system spectral efficiency—for example about 3.5 times that of spectral efficiency of long term evolution (LTE) systems), high capacity that allows more device connectivity both concurrently and instantaneously, lower battery/power consumption (which reduces energy and consumption costs), better connectivity regardless of the geographic region in which a user is located, a larger numbers of devices, lower infrastructural development costs, and higher reliability of the communications. Thus, 5G networks can allow for: data rates of several tens of megabits per second should be supported for tens of thousands of users, 1 gigabit per second to be offered simultaneously to tens of workers on the same office floor, for example; several hundreds of thousands of simultaneous connections to be supported for massive sensor deployments; improved coverage, enhanced signaling efficiency; reduced latency compared to LTE.

(32) The upcoming 5G access network can utilize higher frequencies (e.g., >6 GHz) to aid in increasing capacity. Currently, much of the millimeter wave (mmWave) spectrum, the band of spectrum between 30 GHz and 300 GHz is underutilized. The millimeter waves have shorter wavelengths that range from 10 millimeters to 1 millimeter, and these mmWave signals experience severe path loss, penetration loss, and fading. However, the shorter wavelength at mmWave frequencies also allows more antennas to be packed in the same physical dimension, which allows for large-scale spatial multiplexing and highly directional beamforming.

(33) Performance can be improved if both the transmitter and the receiver are equipped with multiple antennas. Multi-antenna techniques can significantly increase the data rates and reliability of a wireless communication system. The use of multiple input multiple output (MIMO) techniques, which was introduced in the 3GPP and has been in use (including with LTE), is a multi-antenna technique that can improve the spectral efficiency of transmissions, thereby significantly boosting the overall data carrying capacity of wireless systems. The use of MIMO techniques can improve mmWave communications and has been widely recognized a potentially important component for access networks operating in higher frequencies. MIMO can be used for achieving diversity gain, spatial multiplexing gain and beamforming gain. For these reasons, MIMO systems are an important part of the 3rd and 4th generation wireless systems and are planned for use in 5G systems.

(34) FIG. **2** illustrates an example a wireless communication system arranged for proactive content placement for low latency mobile access, in accordance with various aspects and embodiments of the subject disclosure. FIG. **2** includes multiple example network nodes **201**, **202**, **203**, and **204**, a UE **250**, communication service provider network(s) **106**, a content delivery network (CDN) **220**, and a CDN content store **222**. The communication service provider network(s) **106** are introduced in FIG. **1**, however, in FIG. **2**, the communication service provider network(s) **106** further comprise a predictive content mobilization module **210**. The example network nodes **201**, **202**, **203**, and **204** can comprise instances of network node **104** introduced in FIG. **1**, and the UE **250** can comprise an

instance of UEs **102** introduced in FIG. **1**.

(35) Each of the network nodes **201**, **202**, **203**, and **204** can include, inter alia, a network node device, an edge content object store, and a radio unit. Thus, network node **201** comprises network node device **201**A, edge content object store **201**B, and radio unit **201**C. Network node **202** comprises network node device **202**A, edge content object store **202**B, and radio unit **202**C. Network node **203** comprises network node device **203**A, edge content object store **203**B, and radio unit **203**C. Network node **204** comprises network node device **204**A, edge content object store **204**B, and radio unit **204**C.

(36) In an alternative arrangement, the edge content object stores **201**B, **202**B, **203**B, and **204**B can be physically near the network nodes **201**, **202**, **203**, and **204**, e.g., rather than incorporated within the network nodes **201**, **202**, **203**, and **204**. The term "proximally coupled" is used herein to refer to incorporating the edge content object stores **201**B, **202**B, **203**B, and **204**B within the network nodes **201**, **202**, **203**, and **204**, or otherwise coupling the edge content object stores **201**B, **202**B, **203**B, and **204**B within a defined proximal distance of the network nodes **201**, **202**, **203**, and **204**. The defined proximal distance can be, e.g., 1 kilometer, 500 meters, 250 meters, or 100 meters, depending properties of desired embodiments. The defined proximal distance can also be defined, e.g., as any distance equal to or less than a distance to a nearest neighbor network node, or any distance equal to or less than a fraction (such as one half) of the distance to the nearest neighbor node. For some implementations, the defined proximal distance can be defined as an average, mean, or median distance between network nodes in a geographical area, or a fraction (such as one half) of the average, mean, or median distance between network nodes in a geographical area.

(37) In general, with regard to FIG. **2**, the network nodes **201**, **202**, **203**, and **204** can be spread over a geographic area, such as a city or a rural area. Each of the network nodes **201**, **202**, **203**, and **204** can support wireless communications of UEs, such as UE **250**, when the UE **250** is within its service area. Example service area **212** is supported by network node **202**, and example service area **214** is supported by network node **204**. The network nodes **201**, **202**, **203**, and **204** can each be coupled with the communication service provider network(s) **106**, also referred to herein as a core network, via one or more backhaul links **108** such as illustrated in FIG. **1**.

(38) The UE **250** can travel among the various service areas supported by network nodes **201**, **202**, **203**, and **204**. For example, the UE **250** is illustrated proximal to network node **201**, and within the service area of network node **201**, while UE **250** has a direction of travel **252** in the direction of network nodes **202** and **204**. Future location **254**A and future location **254**B indicate predicted future locations of UE **250**. Future location **254**A is within service area **212**, and future location **254**B is within service area **214**.

(39) The CDN **220** can be configured to serve digital content to the UE **250**. For example, when the UE **250** is replaying a movie, the CDN **220** can retrieve movie segments from the CDN content store **222**, and the CDN **220** can send the movie segments to the UE **250**. In some embodiments, the CDN **220** can send digital content to the UE **250** via the communication service provider network(s) **106**. The communication service provider network(s) **106** can receive digital content from the CDN **220** and the communication service provider network(s) **106** can send received digital content to UE **250** via the network nodes **201**, **202**, **203**, and **204**. In other embodiments, the CDN **220** can be arranged to communicate directly with devices at the network nodes **201**, **202**, **203**, and **204**. For example, the CDN **220** can send movie segments directly edge computing devices that host the edge content object stores **201**B, **202**B, **203**B, and **204**B.

(40) The CDN **220** can likewise be configured to serve other forms of digital content, such as AR or VR content, to the UE **250**. For example, when the UE **250** provides an AR display for electric utility inspection and troubleshooting, the CDN **220** can retrieve digital content such as status, performance and technical information of various electric utility components such as transformers, taps, fuses, drops, insulators, grounds, guy wires etc. from the CDN content store **222**, and the CDN **220** can send such digital content to the UE **250**, as described above.

(41) The communication service provider network(s) **106** can be configured to support network communications of the UE **250**. When the UE **250** is connected to network node **201** as illustrated in FIG. **2**, the communication service provider network(s) **106** can engage in network communications **264** between communication service provider network(s) **106** and network node **201**. The network node **201** can in turn engage in network communications **262** between network node **201** and UE **250**.

(42) Network communications **264** and **262** can comprise, inter alia, information that can be used to estimate UE **250** location and direction of travel **252**. A variety of UE location and movement detection technologies are currently in use in today's wireless communication networks, and this disclosure is not limited to any particular approach. Network communications **264** and **262** can furthermore comprise initial digital content from CDN **220**. In some embodiments, CDN **220** can support an ongoing digital content experience at UE **250**, for example by sending initial digital content to edge content object store **201**B for transmission to the UE **250** when requested. Network communications **264** and **262** can furthermore comprise digital content state information, for example, an identification of a movie segment that is currently being replayed at UE **250**.

(43) The predictive content mobilization module **210** can be configured to use information included in network communications **264** to predict future locations of the UE **250**. For example, the predictive content mobilization module **210** can predict the future location **254**A and the future location **254**B as likely future locations of UE **250**. Various example techniques to predict future locations **254**A, **254**B are disclosed herein. The predictive content mobilization module **210** can use the predicted future locations **254**A, **254**B to identify network nodes **202**, **204** corresponding to the predicted future locations **254**A and **254**B. In some embodiments, the predictive content mobilization module **210** can furthermore estimate arrival times for UE **250** arrival at the predicted future locations **254**A, **254**B, and probabilities that the UE **250** will arrive at the predicted future locations **254**A, **254**B.

(44) In an example embodiment, the predictive content mobilization module **210** can be configured to send prediction information **266** to the CDN **220**. The prediction information **266** can comprise, e.g., current digital content state information retrieved from UE **250**, as well as identifications of network nodes **202**, **204** corresponding to the predicted future locations **254**A, **254**B of UE **250**, and estimated arrival times of UE **250** arrival at the predicted future locations **254**A, **254**B.

(45) In such an example embodiment, the CDN **220** can be configured to retrieve digital content **260** from the CDN content store **222**, wherein digital content **260** comprises digital content that is predicted to be consumed at UE **250** when UE **250** arrives at either of future locations **254**A or **254**B. For example, if the UE **250** is predicted to arrive at future location **254**A in 5 minutes, the CDN **220** can retrieve from CDN content store **222** movie segments that are about 5 minutes ahead of a currently replayed segment identified in digital content state information. If the UE **250** is predicted to arrive at future location **254**B in 10 minutes, the CDN **220** can retrieve from CDN content store **222** movie segments that are about 10 minutes ahead of a currently replayed segment identified in digital content state information. The CDN **220** can then send the digital content **260** to edge content object stores **202**B, **202**C of network nodes **202**, **204** identified in the prediction information **266**.

(46) In some scenarios, prediction information **266** can identify different estimated arrival times for different predicted future locations **254**A and **254**B. The CDN **220** can be configured to send different digital content **260** to different network nodes **202**, **204** having different estimated arrival times.

(47) While the example of digital content **260** comprising movie segments is useful for its simplicity, other types of digital content is also contemplated for deployment in connection with embodiments of this disclosure. In particular, AR and VR digital content can have high bandwidth and low latency demands, and so AR and VR digital content is usefully deployed according to the techniques described herein. Digital content state information associated with AR and VR content

can comprise, e.g., types of AR and VR objects associated with a current user session, states of AR or VR objects within a session, or AR and VR objects associated with a particular game or experience. AR and VR content can also comprise digital content that is localized to a particular geographic area, for example, a service area such as **212** or **214**. Therefore, the AR and VR content sent from CDN **220** to different network nodes **202**, **204** can comprise different sets of localized AR and VR objects.

(48) As described further in connection with FIG. **3**, example approaches to predict future locations **254**A, **254**B comprise estimations based on map information, speed and direction of travel, estimations based on travel pattern probabilities, and estimations based on navigation data entered at UE **250**, e.g., a destination entered in a map application at the UE **250**.

(49) While FIG. **2** illustrates an embodiment wherein communication service provider network(s) **106** send prediction information **266** to CDN **220**, and the CDN **220** subsequently delivers digital content **260** to network nodes **202**, **204** associated with future locations **254**A and **254**B, other arrangements are feasible and within the scope of this disclosure. For example, in another arrangement, digital content **260** can be provided to communication service provider network(s) **106**, and the communication service provider network(s) **106** can determine subsets of digital content **260** to send to different network nodes **202**, **204** associated with predicted future locations **254**A, **254**B. The subsets of digital content **260** can be based on estimated arrival times as described herein.

(50) In some embodiments, the predictive content mobilization module **210** can require a threshold probability that UE **250** will enter a service area, such as service area **212** or **214**, prior to identifying the service area **212** or **214** in prediction information **266**. Network bandwidth is not unlimited and therefore it is preferably used to supply digital content **260** to network nodes **202**, **204** associated with high probabilities, e.g., fifty percent or higher, of eventually serving the digital content **260** to the UE **250**. Similarly, prediction information **266** can be limited by estimated arrival times. Network nodes having short estimated arrival times, e.g., within 10 minutes or less, are associated with higher probabilities that any proactively placed digital content **260** will be consumed by UE **250**. Longer arrival times are associated with lower consumption probabilities and therefore delivery of digital content **260** to network nodes associated with longer estimated arrival times can be delayed to preserve network bandwidth.

(51) FIG. **3** illustrates an example predictive content mobilization module, in accordance with various aspects and embodiments of the subject disclosure. The example predictive content mobilization module **310** provides an example instance of the predictive content mobilization module **210** illustrated in FIG. **2**. The example predictive content mobilization module **310** is implemented at a server **300** which can be included in communication service provider network(s) **106**. The example predictive content mobilization module **310** comprises a future UE location/network node predictor **312**, a location/travel pattern catalog **314**, a trajectory calculator **316**, a navigation system interface **318**, and a digital content (DC) state information relay **320**. The predictive content mobilization module **310** can furthermore comprise or operate in conjunction with RAN/edge topology **322**, AI/ML travel pattern identifier **332** and historical UE location/travel data **334**, and map data **336**. Various other elements introduced in FIG. **2** are also included in FIG. **3**, namely CDN content store **222**, CDN network **220**, network node **204** comprising network node device **204**A, edge content object store **204**B, and radio unit **204**C, and UE **250**.

(52) The predictive content mobilization module **310** can be configured to receive information from UE **250**, comprising for example UE location **352**, UE travel info **354**, and digital content (DC) state information **356**. In an embodiment, the illustrated information received from UE **250** can be included in, or calculated based on, network communications **264** illustrated in FIG. **2**.

(53) The predictive content mobilization module **310** can be configured to use the information received from UE **250** to predict future UE **250** locations and corresponding network nodes. In the illustrated configuration, a future UE location/network node predictor **312** can use any of several

supporting modules to make predictions. The example supporting modules comprise a location/travel prediction catalog **314**, a trajectory calculator **316**, and a navigation system interface **318**.

(54) In an embodiment, the navigation system interface **318** can receive navigation information included in the UE travel information **354** received from the UE **250**. For example, a map application at the UE **250** can have UE **250** destination information as well as route information. The UE **250** destination and route information can be provided to navigation system interface **318**, and this information can be provided to the future UE location/network node predictor **312**. The future UE location/network node predictor **312** can use the UE **250** destination and route information to make a direct and high probability prediction of future UE **250** locations.

(55) The trajectory calculator **316** can be configured to calculate a trajectory of UE **250** based on a current UE location **352**, a direction and speed of UE movement (determined from UE travel info **354** or using previous UE locations), and map data **336**. The trajectory can also be influenced by other factors such as traffic, time of day, and previous or routine trajectories of the UE **250**. The trajectory of the UE **250** can be provided to the future UE location/network node predictor **312** to enable the future UE location/network node predictor **312** to predict future UE **250** locations.

(56) The location/travel pattern catalog **314** can comprise a catalog of locations and corresponding probable future UE travel patterns. In an embodiment, the location/travel pattern catalog **314** can be generated and updated by the artificial intelligence (AI)/machine learning (ML) travel pattern identifier **332**, using historical UE location/travel data **334**. The historical UE location/travel data **334** can comprise historical UE location and movement data for multiple UEs. The AI/ML travel pattern identifier **332** can analyze the historical UE location/travel data **334** to build the location/travel pattern catalog **314**, comprising a catalog of probable future UE movements, indexed by UE location information. The future UE location/network node predictor **312** can look up UE location **352** in the location/travel pattern catalog **314** to predict future UE **250** locations.

(57) The future location prediction techniques disclosed herein are intended as a non-exhaustive set of example techniques, and this disclosure is not limited to any particular future location prediction technique or set of techniques. The disclosed future location prediction techniques can be modified, combined, and/or supplemented with other future location prediction techniques.

(58) When the future UE location/network node predictor **312** has predicted future locations of UE **250**, the future UE location/network node predictor **312** can look up network nodes corresponding to the predicted future locations of UE **250** in the RAN/edge topology **322**. The RAN/edge topology **322** can provide RAN network nodes and/or corresponding edge computing devices associated with their respective geographical service areas. The future UE location/network node predictor **312** can identify service areas that overlap with predicted future locations of UE **250**, and the future UE location/network node predictor **312** can identify network nodes that serve the identified service areas.

(59) In an embodiment, the digital content (DC) state info relay **320** can be configured to receive any DC state information **356** from the UE **250**, and include the received DC state information **356** in prediction information **266**. The future UE location/network node predictor **312** can furthermore comprise identified future network nodes in prediction information **266**. In some embodiments, the future UE location/network node predictor **312** can also comprise, in prediction information **266**, arrival probabilities and estimated arrival time information associated with identified future network nodes.

(60) As described in connection with FIG. **2**, the CDN network **220** can be configured to use the prediction information **266** to identify future digital content **260** to proactively place at future network nodes, such as network node **204**. The CDN network **220** can retrieve the digital content **260** from CDN content store **222** and send it to the network nodes identified in the prediction information **266**, e.g., to network node **204**. In an embodiment, the CDN network **220** can employ edge content object stores at network nodes or proximally coupled with network nodes, however, in

other embodiments the CDN network **220** can send digital content **260** to any appropriately configured device at a network node **204**.
(61) FIG. **4** illustrates an example content delivery network (CDN) server, in accordance with various aspects and embodiments of the subject disclosure. The example CDN server **420** can comprise an instance of a server in a CDN network **220** such as illustrated in FIGS. **2** and **3**. The CDN server **420** comprises a digital content prefetch and delivery service **422**. The digital content prefetch and delivery service **422** comprises a content predictor **424**. FIG. **4** furthermore illustrates the CDN content store **222**, introduced in FIG. **2**, and edge content object store(s) **404**, which can comprise instances of edge content object stores **201**B, **202**B, **203**B, and **204**B, illustrated in FIG. **2**.
(62) In FIG. **4**, the CDN server **420** can be configured to receive prediction information **266**. In response to prediction information **266**, the CDN server **420** can identify digital content **260** to send to edge content object store(s) **404**, retrieve the digital content **260** from the CDN content store **222**, and send the digital content **260** to the edge content object store(s) **404**.
(63) The content predictor **424** can be configured to use DC state information **356** included in the prediction information **266**, along with estimated arrival times at edge content object store(s) **404** and any other information, such as locations of edge content object store(s) **404**, to identify digital content **260** to be sent to the edge content object store(s) **404**. Different digital content can optionally be identified for different edge content object store(s) **404**.
(64) The digital content prefetch and delivery service **422** can be configured to fetch digital content **260** identified by the content predictor **424** from the CDN content store **222**. The digital content prefetch and delivery service **422** can send the digital content **260** to each of the edge content object store(s) **404** identified in the prediction information **266**.
(65) The CDN server **420** can also be configured to provide ongoing delivery of digital content to any of the edge content object store(s) **404**. For example, should UE **250** remain within a service area of a single network node for an extended period of time while UE **250** continues to consume additional digital content, beyond digital content **260**, the CDN server **420** can retrieve and deliver the additional digital content to an edge content object store associated with the network node serving the UE **250**.
(66) FIG. **5** illustrates an example network node, in accordance with various aspects and embodiments of the subject disclosure. The example network node **504** can implement any of the network nodes **201**, **202**, **203**, and **204** illustrated in FIG. **2**. The example network node **504** comprises network node device(s) **504**A and radio unit **504**C. The network node device(s) **504**A comprise a UE detection component **520** and a digital content (DC) server **510**. The DC server **510** comprises a DC state retriever **512** and an edge content object store **504**B. The network node device(s) **504**A illustrated in FIG. **5** can implement, e.g., any of network node devices **201**A, **202**A, **203**A, and **204**A, illustrated in FIG. **2**, and the edge content object store **504**B can implement any of the edge content object stores **201**B, **202**B, **203**B, and **204**B, illustrated in FIG. **2**. FIG. **5** furthermore illustrates UE **250**, also introduced in FIG. **2**.
(67) The network node device(s) **504**A can be configured to receive digital content **260** prior to establishing communications with UE **250**. The received digital content **260** can comprise an identifier of an associated UE **250**. The DC server **510** can store received digital content **260** and the UE identifier in the edge content object store **504**B. Meanwhile, the UE detection component **520** can detect new connections from UEs, and provide new UE identifiers to DC server **510**. If a new UE identifier (e.g., associated with UE **250**) matches digital content (e.g., digital content **260**) stored in the edge content object store **504**B, then the DC state retriever **512** can optionally retrieve current DC state information from UE **250**, via network communications **262**, and the DC server **260** can begin sending appropriate portions of digital content **260** to UE **250**, also via network communications **262**.
(68) Should UE **250** request additional digital content, beyond the digital content **260**, then

additional digital content **562** can be delivered to UE **250** via network node **504**. Furthermore, DC state retriever **512** can send occasional DC state information requests to UE **250**. DC state information **356** reported by UE **250** can be sent to the CDN network **220** and/or the predictive content mobilization module **310**, illustrated in FIG. **3**.

(69) In some embodiments, the edge content object store **504**B can be configured to delete or otherwise expunge received digital content **260** from the edge content object store **504**B. For example, digital content **260** that has been sent to UE **250** can be deleted from the edge content object store **504**B. Also, the digital content **260** can expire and the edge content object store **504**B can be configured to delete expired digital content. The digital content **260** can expire, for example, within a determined time interval after an estimated arrival time of UE **250** within the service area of network node **504**.

(70) Further example operations of network node **504** can comprise, e.g., processing network communications **262** between the network node **504** and the UE **250**, and processing network communications **264** between the network node **504** and the core network. Network communications **264** and **262** can comprise, e.g., UE location information, voice calls, text messages and other data transmitted on behalf of UE **250**. In some embodiments, network communications **264** can comprise digital content **260**, DC state information **356**, and digital content **562**. In other embodiments, the digital content **260**, DC state information **356**, and/or digital content **562** can be included in communications with a CDN network **220**, separate from network communications **264**.

(71) FIG. **6** illustrates several example multi-access edge computing options, in accordance with various aspects and embodiments of the subject disclosure. FIG. **6** comprises UE **250**, a radio unit **604**, and a multi-access edge computing (MEC) virtual network function (VNF) **620**.

(72) A first example configuration can be used with network nodes distributed over a wide geographic area such as a city. In such a scenario, the MEC VNF **620** can connect with network edge compute (NEC) devices **630**, and the NEC devices **630** can comprise aspects of this disclosure, e.g., an edge content object store (ECOS) **632** and/or a predictive content mobilization module (PCM) **634**. All user data **612** and control data **614** can be routed to NEC devices **630**. A second example configuration can be used with network nodes in a particular location, such as within a building. In such a scenario, the MEC VNF **620** can connect with MEC server devices **640**, and the MEC server devices **640** can comprise aspects of this disclosure, e.g., an ECOS **642** and/or a PCM **644**. All user data **612** and control data **614** can be routed to MEC server devices **640**. In either of the above configurations, a CDN network **220** can connect with applicable edge devices and CDN network **220** can deliver digital content **260** to the edge devices.

(73) While the discussion of FIG. **2**-FIG. **6** has used a single UE **250** as an example, it should be emphasized that embodiments can involve multiple UEs. Furthermore, in scenarios involving multiple UEs, embodiments can proactively place digital content for future use by multiple UEs. For example, when many UEs are predicted to request digital content from a predicted future location, such as a sports stadium scheduled to host a sporting event, the technologies disclosed herein can be used to predict the future location of multiple UEs, as well as to predict digital content likely to be requested by the multiple UEs while at the predicted future location. The content can be predicted based on the nature of the event and location rather than current digital content being displayed at a particular UE. Predicted digital content can be proactively placed at predicted future network nodes in advance of UE arrival at the predicted future location.

(74) FIG. **7** is a flow diagram representing example operations of a communication service provider network device comprising a predictive content mobilization module, in accordance with various aspects and embodiments of the subject disclosure. The illustrated blocks can represent actions performed in a method, functional components of a computing device, or instructions implemented in a machine-readable storage medium executable by a processor. While the operations are illustrated in an example sequence, the operations can be eliminated, combined, or

re-ordered in some embodiments.

(75) The operations illustrated in FIG. **7** can be performed, for example, by a server **300** equipped with a predictive content mobilization module **310**, as illustrated in FIG. **3**. The server **300** can be included in communication service provider network(s) **106** such as illustrated in FIG. **2**. The operations of FIG. **7** are therefore described with reference to FIG. **2** and FIG. **3**. Example operations comprise operation **702**, which represents facilitating, by a device **300** comprising a processor, delivery of initial digital content to an initial edge content object store. For example, as illustrated in FIG. **2**, initial digital content can be delivered to the initial edge content object store **201**B which is proximally coupled with an initial network node device **201**A that provides wireless service in an initial service area (a service area of network node **201**) in order to wirelessly serve the initial digital content to the mobile device **250** while the mobile device **250** is in the initial service area. Facilitating delivery of initial digital content can comprise facilitating delivery by CDN **220** or facilitating delivery by communication service provider network(s) **106**, or combinations thereof.

(76) At operation **704**, the device **300** can predict a future location **254**A or **254**B of a mobile device **250**. For example, a future UE location/network node predictor **312** can predict a future UE **250** location **254**A or **254**B, e.g., as described in connection with FIG. **3**. Predicting the future location **254**A or **254**B of the mobile device **250** can comprise using a location and a direction of travel of the mobile device **250** to predict the future location **254**A or **254**B, using a navigation route for the mobile device **250** to predict the future location **254**A or **254**B, and/or determining a future location **254**A or **254**B probability for the mobile device **250** based on historical mobile device location data.

(77) At operation **706**, the device **300** can determine a network node device, e.g., a network node device at network node **202** or at network node **204**, which provides wireless service in a service area **212** or **214** comprising the future location **254**A or **254**B of the mobile device **250**.

(78) At operation **708**, the device **300** can facilitate determining future digital content **260** based on the initial digital content delivered pursuant to operation **702**. For example, the device **300** can include, in prediction information **266**, DC state information **356** and/or calculated arrival time(s) of UE **250** at future locations **254**A or **254**B. The future digital content **260** can comprise, e.g., AR content, VR content, video content, or any other digital content. In the case of video content, future digital content **260** can comprise, e.g., a future segment of a video for display at the mobile device **250**, wherein the future segment of the video can be determined based on a current segment of the video displayed at the mobile device **250** as well as on estimated arrival time(s) of the mobile device **250** at future location(s) **254**A or **254**B.

(79) At operation **710**, the device **300** can facilitate delivery, in advance of arrival of the mobile device **250** in the service area **212** or **214**, delivery of future digital content **260** to an edge content object store **202**B or **204**B that is proximally coupled with the network node device (of network node **202** or **204**) in order to wirelessly serve the future digital content **260** to the mobile device **250** after the mobile device **250** arrives in the service area **212** or **214**. Facilitating delivery of future digital content **260** can comprise, e.g., facilitating delivery by CDN **220** or facilitating delivery by communication service provider network(s) **106**, or combinations thereof. For example, facilitating the delivery of the future digital content **260** to the edge content object store **202**B can comprise sending an instruction, such as prediction information **266**, to a content delivery network device such as CDN **420**.

(80) In some embodiments, predicting the future location of the mobile device **250** at operation **704** can comprise predicting multiple potential future locations **254**A and **254**B of the mobile device **250**. Operation **706** can comprise determining multiple potential network node devices (of network nodes **202** and **204**) that provide wireless service in multiple potential service areas **212**, **214** comprising the multiple potential future locations **254**A and **254**B of the mobile device **250**. Operation **710** can comprise facilitating the delivery of the future digital content **260** to multiple

potential edge content object stores **202**B, **204**B proximally coupled with the multiple potential network node devices (of network nodes **202** and **204**).
(81) In some embodiments, the future location **254**A or **245**B of the mobile device **250** can comprises a future location of multiple mobile devices. The future digital content **260** can comprise digital content predicted to be requested by the multiple mobile devices at the future location **254**A or **245**B of the multiple mobile devices.
(82) FIG. **8** is a flow diagram representing example operations of a CDN server, in accordance with various aspects and embodiments of the subject disclosure. The illustrated blocks can represent actions performed in a method, functional components of a computing device, or instructions implemented in a machine-readable storage medium executable by a processor. While the operations are illustrated in an example sequence, the operations can be eliminated, combined, or re-ordered in some embodiments.
(83) The operations illustrated in FIG. **8** can be performed, for example, by a CDN server **420** as illustrated in FIG. **4**. The CDN server **420** can be included in CDN **220** such as illustrated in FIG. **2**. The operations of FIG. **8** are therefore described with reference to FIG. **2** and FIG. **4**. Example operations comprise operation **802**, which represents receiving a first instruction to deliver digital content to a first edge content object store. For example, prior to receiving prediction information **266**, CDN server **420** can receive a first instruction from communication service provider network(s) **106** to deliver initial digital content to first edge content object store **201**B. The first edge content object store **201**B can be proximally coupled with a first network equipment, namely, first network node device **201**A that provides wireless service in a first service area (the service area of network node **201**, not shown in FIG. **2**). The wireless service provided by network node **201** is able to wirelessly serve the initial digital content to a mobile device **250** while the mobile device **250** is in the first service area (the service area of network node **201**, not shown in FIG. **2**). At operation **804**, the CDN server **420** can deliver, in response to the receiving the first instruction at operation **802**, the initial digital content to the first edge content object store **201**B.
(84) At operation **806**, after receiving the first instruction at operation **802**, the CDN server **420** can receive a second instruction, in the form of prediction information **266**, to deliver future digital content **260** to a second edge content object store, e.g., second edge content object store **202**B. The second edge content object store **202**B can be proximally coupled with a second network equipment, namely second network node device **202**A to wirelessly serve the future digital content **260** to the mobile device **250** in a second service area **212** while the mobile device **250** is in the second service area **212**.
(85) At operation **808**, the CDN server **420** can determine, based on the digital content delivered pursuant to operations **802** and **804**, the future digital content **260** to serve to the mobile device **250** at operation **810**. The second instruction/prediction information **266** at operation **806** need not specify exactly the content to include in the future digital content **260**. Instead, the prediction information **266** can comprise DC state information **356** and estimated arrival time, as described herein, and the CDN server **420** can determine the future digital content **260**. The digital content and the future digital content **260** can comprise, e.g., AR or VR content based on applicable service areas, e.g., based on the second service area **212**, or different portions of a video, or any other digital content.
(86) At operation **810**, the CDN server **420** can deliver, in response to the receiving the second instruction/prediction information **266**, and in advance of arrival of the mobile device **250** in the second service area **212**, the future digital content **260** to the second edge content object store **202**B. In some embodiments, the second instruction/prediction information **266** to deliver the future digital content **260** to the second edge content object store **202**B can comprise instructions to deliver the future digital content **260** to multiple potential second edge content object stores **202**B, **204**B proximally coupled with multiple potential second network node devices **202**A, **204**A, and operation **810** can comprise delivering the future digital content **260** to the multiple potential

second edge content object stores **202**A, **204**A.

(87) FIG. **9** is a flow diagram representing example operations of an edge computing device, in accordance with various aspects and embodiments of the subject disclosure. The illustrated blocks can represent actions performed in a method, functional components of a computing device, or instructions implemented in a machine-readable storage medium executable by a processor. While the operations are illustrated in an example sequence, the operations can be eliminated, combined, or re-ordered in some embodiments.

(88) The operations illustrated in FIG. **9** can be performed, for example, by an edge computing device such as DC server **510** illustrated in FIG. **5**. The DC server **510** can be included in, or proximally coupled to, network node device(s) **504**A, which can in turn be included in a network node such as network node **504** or network node **202**, illustrated in FIG. **2**. The operations of FIG. **9** are therefore described with reference to FIG. **2** and FIG. **5**. Example operations comprise operation **902**, which represents receiving, in advance of arrival of a mobile device **250** in a service area **212** of a network equipment comprising network node device **202**A proximally coupled with the edge computing device (e.g., the edge computing device comprising edge content object store **202**B), future digital content **260** for the mobile device **250**. At operation **904**, the edge computing device associated with edge content object store **202**B can store the future digital content **260** in the edge content object store **202**B.

(89) At operation **906**, the edge computing device associated with edge content object store **202**B can determine digital content state information. For example, upon entry of UE **250** in the service area **212** associated with edge content object store **202**B, the devices of network node **202** can determine digital content state information at UE **250**, in order to select content from digital content **260** for delivery to the UE **250**. Delivering the future digital content **260** to the mobile device at operation **908** can thereby be performed according to the digital content state information gathered at operation **906**.

(90) Operation **908** represents delivering, in response to the arrival of the mobile device **250** in the service area **212** of the network equipment comprising network node device **202**A proximally coupled with the edge computing device (associated with edge content object store **202**B), the future digital content **260** to the mobile device **250** via the network node device **202**A. For example, with reference to FIG. **5**, network communications **262** can be used to deliver the future digital content **260** to the mobile device **250**.

(91) Operation **910** represents removing, in response to a departure of the mobile device **250** from the service area **212** of the network equipment comprising network node device **202**A, the future digital content **260** from the edge content object store **202**B. In some embodiments, the future digital content **260** is no longer needed in the edge content object store **202**B after the mobile device **250** departs from the service area **212**. In other embodiments, operation **910** can be eliminated, e.g., where other mobile devices are likely to make further use of future digital content **260**.

(92) FIG. **10** is a block diagram of an example computer that can be operable to execute processes and methods in accordance with various aspects and embodiments of the subject disclosure. The example computer can be adapted to implement, for example, a server **300**, a CDN server **420**, a DC server **510**, network node device **504**A, or other computing devices described herein.

(93) FIG. **10** and the following discussion are intended to provide a brief, general description of a suitable computing environment **1000** in which the various embodiments of the embodiment described herein can be implemented. While the embodiments have been described above in the general context of computer-executable instructions that can run on one or more computers, those skilled in the art will recognize that the embodiments can be also implemented in combination with other program modules and/or as a combination of hardware and software.

(94) Generally, program modules include routines, programs, components, data structures, etc., that perform particular tasks or implement particular abstract data types. Moreover, those skilled in the art

art will appreciate that the methods can be practiced with other computer system configurations, including single-processor or multiprocessor computer systems, minicomputers, mainframe computers, IoT devices, distributed computing systems, as well as personal computers, hand-held computing devices, microprocessor-based or programmable consumer electronics, and the like, each of which can be operatively coupled to one or more associated devices.

(95) The illustrated embodiments of the embodiments herein can be also practiced in distributed computing environments where certain tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules can be located in both local and remote memory storage devices.

(96) Computing devices typically include a variety of media, which can include computer-readable storage media, machine-readable storage media, and/or communications media, which two terms are used herein differently from one another as follows. Computer-readable storage media or machine-readable storage media can be any available storage media that can be accessed by the computer and includes both volatile and nonvolatile media, removable and non-removable media. By way of example, and not limitation, computer-readable storage media or machine-readable storage media can be implemented in connection with any method or technology for storage of information such as computer-readable or machine-readable instructions, program modules, structured data or unstructured data.

(97) Computer-readable storage media can include, but are not limited to, random access memory (RAM), read only memory (ROM), electrically erasable programmable read only memory (EEPROM), flash memory or other memory technology, compact disk read only memory (CD-ROM), digital versatile disk (DVD), Blu-ray disc (BD) or other optical disk storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, solid state drives or other solid state storage devices, or other tangible and/or non-transitory media which can be used to store desired information. In this regard, the terms “tangible” or “non-transitory” herein as applied to storage, memory or computer-readable media, are to be understood to exclude only propagating transitory signals per se as modifiers and do not relinquish rights to all standard storage, memory or computer-readable media that are not only propagating transitory signals per se.

(98) Computer-readable storage media can be accessed by one or more local or remote computing devices, e.g., via access requests, queries or other data retrieval protocols, for a variety of operations with respect to the information stored by the medium.

(99) Communications media typically embody computer-readable instructions, data structures, program modules or other structured or unstructured data in a data signal such as a modulated data signal, e.g., a carrier wave or other transport mechanism, and includes any information delivery or transport media. The term “modulated data signal” or signals refers to a signal that has one or more of its characteristics set or changed in such a manner as to encode information in one or more signals. By way of example, and not limitation, communication media include wired media, such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media.

(100) With reference again to FIG. **10**, the example environment **1000** for implementing various embodiments of the aspects described herein includes a computer **1002**, the computer **1002** including a processing unit **1004**, a system memory **1006** and a system bus **1008**. The system bus **1008** couples system components including, but not limited to, the system memory **1006** to the processing unit **1004**. The processing unit **1004** can be any of various commercially available processors. Dual microprocessors and other multi-processor architectures can also be employed as the processing unit **1004**.

(101) The system bus **1008** can be any of several types of bus structure that can further interconnect to a memory bus (with or without a memory controller), a peripheral bus, and a local bus using any of a variety of commercially available bus architectures. The system memory **1006**

includes ROM **1010** and RAM **1012**. A basic input/output system (BIOS) can be stored in a non-volatile memory such as ROM, erasable programmable read only memory (EPROM), EEPROM, which BIOS contains the basic routines that help to transfer information between elements within the computer **1002**, such as during startup. The RAM **1012** can also include a high-speed RAM such as static RAM for caching data.

(102) The computer **1002** further includes an internal hard disk drive (HDD) **1014** (e.g., EIDE, SATA), one or more external storage devices **1016** (e.g., a magnetic floppy disk drive (FDD) **1016**, a memory stick or flash drive reader, a memory card reader, etc.) and an optical disk drive **1020** (e.g., which can read or write from a CD-ROM disc, a DVD, a BD, etc.). While the internal HDD **1014** is illustrated as located within the computer **1002**, the internal HDD **1014** can also be configured for external use in a suitable chassis (not shown). Additionally, while not shown in environment **1000**, a solid state drive (SSD) could be used in addition to, or in place of, an HDD **1014**. The HDD **1014**, external storage device(s) **1016** and optical disk drive **1020** can be connected to the system bus **1008** by an HDD interface **1024**, an external storage interface **1026** and an optical drive interface **1028**, respectively. The interface **1024** for external drive implementations can include at least one or both of Universal Serial Bus (USB) and Institute of Electrical and Electronics Engineers (IEEE) 1394 interface technologies. Other external drive connection technologies are within contemplation of the embodiments described herein.

(103) The drives and their associated computer-readable storage media provide nonvolatile storage of data, data structures, computer-executable instructions, and so forth. For the computer **1002**, the drives and storage media accommodate the storage of any data in a suitable digital format. Although the description of computer-readable storage media above refers to respective types of storage devices, it should be appreciated by those skilled in the art that other types of storage media which are readable by a computer, whether presently existing or developed in the future, could also be used in the example operating environment, and further, that any such storage media can contain computer-executable instructions for performing the methods described herein.

(104) A number of program modules can be stored in the drives and RAM **1012**, including an operating system **1030**, one or more application programs **1032**, other program modules **1034** and program data **1036**. All or portions of the operating system, applications, modules, and/or data can also be cached in the RAM **1012**. The systems and methods described herein can be implemented utilizing various commercially available operating systems or combinations of operating systems.

(105) Computer **1002** can optionally comprise emulation technologies. For example, a hypervisor (not shown) or other intermediary can emulate a hardware environment for operating system **1030**, and the emulated hardware can optionally be different from the hardware illustrated in FIG. **10**. In such an embodiment, operating system **1030** can comprise one virtual machine (VM) of multiple VMs hosted at computer **1002**. Furthermore, operating system **1030** can provide runtime environments, such as the Java runtime environment or the .NET framework, for applications **1032**. Runtime environments are consistent execution environments that allow applications **1032** to run on any operating system that includes the runtime environment. Similarly, operating system **1030** can support containers, and applications **1032** can be in the form of containers, which are lightweight, standalone, executable packages of software that include, e.g., code, runtime, system tools, system libraries and settings for an application.

(106) Further, computer **1002** can be enabled with a security module, such as a trusted processing module (TPM). For instance, with a TPM, boot components hash next in time boot components, and wait for a match of results to secured values, before loading a next boot component. This process can take place at any layer in the code execution stack of computer **1002**, e.g., applied at the application execution level or at the operating system (OS) kernel level, thereby enabling security at any level of code execution.

(107) A user can enter commands and information into the computer **1002** through one or more wired/wireless input devices, e.g., a keyboard **1038**, a touch screen **1040**, and a pointing device,

such as a mouse **1042**. Other input devices (not shown) can include a microphone, an infrared (IR) remote control, a radio frequency (RF) remote control, or other remote control, a joystick, a virtual reality controller and/or virtual reality headset, a game pad, a stylus pen, an image input device, e.g., camera(s), a gesture sensor input device, a vision movement sensor input device, an emotion or facial detection device, a biometric input device, e.g., fingerprint or iris scanner, or the like. These and other input devices are often connected to the processing unit **1004** through an input device interface **1044** that can be coupled to the system bus **1008**, but can be connected by other interfaces, such as a parallel port, an IEEE 1394 serial port, a game port, a USB port, an IR interface, a BLUETOOTH® interface, etc.

(108) A monitor **1046** or other type of display device can be also connected to the system bus **1008** via an interface, such as a video adapter **1048**. In addition to the monitor **1046**, a computer typically includes other peripheral output devices (not shown), such as speakers, printers, etc.

(109) The computer **1002** can operate in a networked environment using logical connections via wired and/or wireless communications to one or more remote computers, such as a remote computer(s) **1050**. The remote computer(s) **1050** can be a workstation, a server computer, a router, a personal computer, portable computer, microprocessor-based entertainment appliance, a peer device or other common network node, and typically includes many or all of the elements described relative to the computer **1002**, although, for purposes of brevity, only a memory/storage device **1052** is illustrated. The logical connections depicted include wired/wireless connectivity to a local area network (LAN) **1054** and/or larger networks, e.g., a wide area network (WAN) **1056**. Such LAN and WAN networking environments are commonplace in offices and companies, and facilitate enterprise-wide computer networks, such as intranets, all of which can connect to a global communications network, e.g., the internet.

(110) When used in a LAN networking environment, the computer **1002** can be connected to the local network **1054** through a wired and/or wireless communication network interface or adapter **1058**. The adapter **1058** can facilitate wired or wireless communication to the LAN **1054**, which can also include a wireless access point (AP) disposed thereon for communicating with the adapter **1058** in a wireless mode.

(111) When used in a WAN networking environment, the computer **1002** can include a modem **1060** or can be connected to a communications server on the WAN **1056** via other means for establishing communications over the WAN **1056**, such as by way of the internet. The modem **1060**, which can be internal or external and a wired or wireless device, can be connected to the system bus **1008** via the input device interface **1044**. In a networked environment, program modules depicted relative to the computer **1002** or portions thereof, can be stored in the remote memory/storage device **1052**. It will be appreciated that the network connections shown are example and other means of establishing a communications link between the computers can be used.

(112) When used in either a LAN or WAN networking environment, the computer **1002** can access cloud storage systems or other network-based storage systems in addition to, or in place of, external storage devices **1016** as described above. Generally, a connection between the computer **1002** and a cloud storage system can be established over a LAN **1054** or WAN **1056** e.g., by the adapter **1058** or modem **1060**, respectively. Upon connecting the computer **1002** to an associated cloud storage system, the external storage interface **1026** can, with the aid of the adapter **1058** and/or modem **1060**, manage storage provided by the cloud storage system as it would other types of external storage. For instance, the external storage interface **1026** can be configured to provide access to cloud storage sources as if those sources were physically connected to the computer **1002**.

(113) The computer **1002** can be operable to communicate with any wireless devices or entities operatively disposed in wireless communication, e.g., a printer, scanner, desktop and/or portable computer, portable data assistant, communications satellite, any piece of equipment or location associated with a wirelessly detectable tag (e.g., a kiosk, news stand, store shelf, etc.), and

telephone. This can include Wireless Fidelity (Wi-Fi) and BLUETOOTH® wireless technologies. Thus, the communication can be a predefined structure as with a conventional network or simply an ad hoc communication between at least two devices.

(114) The above description includes non-limiting examples of the various embodiments. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing the disclosed subject matter, and one skilled in the art can recognize that further combinations and permutations of the various embodiments are possible. The disclosed subject matter is intended to embrace all such alterations, modifications, and variations that fall within the spirit and scope of the appended claims.

(115) With regard to the various functions performed by the above described components, devices, circuits, systems, etc., the terms (including a reference to a “means”) used to describe such components are intended to also include, unless otherwise indicated, any structure(s) which performs the specified function of the described component (e.g., a functional equivalent), even if not structurally equivalent to the disclosed structure. In addition, while a particular feature of the disclosed subject matter may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application.

(116) The terms “exemplary” and/or “demonstrative” as used herein are intended to mean serving as an example, instance, or illustration. For the avoidance of doubt, the subject matter disclosed herein is not limited by such examples. In addition, any aspect or design described herein as “exemplary” and/or “demonstrative” is not necessarily to be construed as preferred or advantageous over other aspects or designs, nor is it meant to preclude equivalent structures and techniques known to one skilled in the art. Furthermore, to the extent that the terms “includes,” “has,” “contains,” and other similar words are used in either the detailed description or the claims, such terms are intended to be inclusive—in a manner similar to the term “comprising” as an open transition word—without precluding any additional or other elements.

(117) The term “or” as used herein is intended to mean an inclusive “or” rather than an exclusive “or.” For example, the phrase “A or B” is intended to include instances of A, B, and both A and B. Additionally, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless either otherwise specified or clear from the context to be directed to a singular form.

(118) The term “set” as employed herein excludes the empty set, i.e., the set with no elements therein. Thus, a “set” in the subject disclosure includes one or more elements or entities. Likewise, the term “group” as utilized herein refers to a collection of one or more entities.

(119) The terms “first,” “second,” “third,” and so forth, as used in the claims, unless otherwise clear by context, is for clarity only and doesn't otherwise indicate or imply any order in time. For instance, “a first determination,” “a second determination,” and “a third determination,” does not indicate or imply that the first determination is to be made before the second determination, or vice versa, etc.

(120) The description of illustrated embodiments of the subject disclosure as provided herein, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosed embodiments to the precise forms disclosed. While specific embodiments and examples are described herein for illustrative purposes, various modifications are possible that are considered within the scope of such embodiments and examples, as one skilled in the art can recognize. In this regard, while the subject matter has been described herein in connection with various embodiments and corresponding drawings, where applicable, it is to be understood that other similar embodiments can be used or modifications and additions can be made to the described embodiments for performing the same, similar, alternative, or substitute function of the disclosed subject matter without deviating therefrom. Therefore, the disclosed subject matter should not be

limited to any single embodiment described herein, but rather should be construed in breadth and scope in accordance with the appended claims below.

Claims

1. A method, comprising: receiving, from a content delivery network device by an edge computing device comprising a processor, future digital media content for a mobile device in response to location prediction information of the mobile device received by the content delivery network device and without the edge computing device requesting the future digital media content, wherein the future digital media content is received in advance of arrival of the mobile device in a service area of network equipment proximally coupled to the edge computing device, wherein the future digital media content comprises augmented reality content that is localized to the service area, wherein the augmented reality content comprises at least one localized augmented reality object and is sent from the content delivery network device, wherein the network equipment is separate from the content delivery network device, and wherein a device associated with a cellular service provider has predicted the arrival of the mobile device in the service area and provided the location prediction information to enable delivery of the future digital media content to the edge computing device by the content delivery network device; storing, by the edge computing device, the future digital media content in an edge content object store; and delivering, by the edge computing device, in response to the arrival of the mobile device in the service area, the future digital media content including the at least one localized augmented reality object to the mobile device.
2. The method of claim 1, wherein the future digital media content further comprises content based on session information associated with a session at the mobile device.
3. The method of claim 1, further comprising determining, by the edge computing device, digital content state information in response to the arrival of the mobile device in the service area, wherein the digital content state information comprises an identification of content currently being played on the mobile device during the arrival of the mobile device in the service area, and wherein the delivering the future digital media content to the mobile device is based on the digital content state information.
4. The method of claim 1, wherein the network equipment comprises equipment of a radio access network that provides wireless network service on behalf of the cellular service provider.
5. The method of claim 1, further comprising removing, by the edge computing device, the future digital media content from the edge content object store in response to a departure of the mobile device from the service area.
6. Network equipment, comprising: a processor; and a memory that stores executable instructions that, when executed by the processor, facilitate performance of operations, the operations comprising: predicting a future location of a mobile device, wherein the future location is within a service area of a network node of a cellular service network; and delivering, in advance of arrival of the mobile device in the service area, future digital media content to an edge content object store that is proximally coupled within a defined proximal distance of the network node via a content delivery network in response to location prediction information of the mobile device being sent to the content delivery network and without the edge content object store requesting the future digital media content, wherein the future digital media content comprises augmented reality content that is localized to the service area, wherein the augmented reality content comprises at least one localized augmented reality object, wherein the content delivery network is separate from the cellular service network, and wherein the location prediction information enables delivery, via the content delivery network, of the future digital media content including the at least one localized augmented reality object to the edge content object store.
7. The network equipment of claim 6, wherein the operations further comprise sending digital content state information to the content delivery network and wherein the digital content state

information comprises an identification of content currently being played on the mobile device during the arrival of the mobile device in the service area.

8. The network equipment of claim 6, wherein the future digital media content further comprises a future segment of a video for display at the mobile device.

9. The network equipment of claim 6, wherein the predicting the future location of the mobile device comprises using a location and a direction of travel of the mobile device or a navigation route of the mobile device.

10. The network equipment of claim 6, wherein the predicting the future location of the mobile device comprises determining a future location probability for the mobile device based on historical mobile device location data.

11. The network equipment of claim 6, wherein the operations further comprise sending, to the content delivery network, an estimated time of arrival of the mobile device in the service area.

12. The network equipment of claim 6, wherein: the predicting the future location of the mobile device comprises predicting multiple potential future locations of the mobile device, the multiple potential future locations are within multiple different service areas of multiple different network nodes, the multiple different network nodes are coupled with multiple different edge content stores, and the location prediction information identifies the multiple different edge content stores to enable delivery, by the content delivery network, of the future digital media content to the multiple different edge content stores.

13. The network equipment of claim 6, wherein: the future location of the mobile device comprises a future location of multiple mobile devices; and the future digital media content comprises digital content predicted to be requested by the multiple mobile devices at the future location of the multiple mobile devices.

14. A non-transitory machine-readable storage medium, comprising executable instructions that, when executed by a processor of a content delivery network device, facilitate performance of operations, the operations comprising: receiving, via a cellular service provider network that is separate from a content delivery network comprising the content delivery network device, location prediction information that enables identification of an edge content object store, wherein the edge content object store is proximally coupled with a network node that is part of the cellular service provider network, and wherein the edge content object store is configured to serve future digital media content to a mobile device in a service area of the network node while the mobile device is in the service area; and in response to the receiving the location prediction information via the cellular service provider network, delivering the future digital media content to the edge content object store in advance of arrival of the mobile device in the service area, without the edge content object store requesting the future digital media content, wherein the future digital media content comprises augmented reality content that is localized to the service area, and the augmented reality content comprises at least one localized augmented reality object.

15. The non-transitory machine-readable storage medium of claim 14, wherein the operations further comprise determining, based on the location prediction information, the future digital media content to deliver to the edge content object store.

16. The non-transitory machine-readable storage medium of claim 14, wherein the future digital media content further comprises augmented reality game information.

17. The non-transitory machine-readable storage medium of claim 14, wherein the future digital media content further comprises content based on object types associated with a session at the mobile device.

18. The non-transitory machine-readable storage medium of claim 14, wherein the location prediction information enables identification of multiple potential edge content object stores proximally coupled with multiple potential network nodes, and wherein the delivering the future digital media content to the edge content object store comprises delivering the future digital media content to the multiple potential edge content object stores.