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EDGE DEVICE AND METHOD FOR HANDLING SERVICE FOR MULTIPLE SERVICE PROVIDERS

Abstract

An edge device that includes a processor which obtains sensing information of a surrounding area from one or more external sensing devices in a communication range of the edge device. The processor communicates the sensing information to a central cloud server and obtains wireless connectivity enhanced information from the central cloud server based on the communicated sensing information. The wireless connectivity enhanced information is for a first user equipment (UE) and a second UE. The processor directs a first beam of radio frequency (RF) signal in a first wireless carrier network to the first UE and a second beam of RF signal in a second wireless carrier network to the second UE based on the obtained wireless connectivity enhanced information for the first UE and the second UE.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS/INCORPORATION BY REFERENCE
[0001] This Patent Application makes reference to, claims priority to, claims the benefit of, and is a Continuation Application of U.S. patent application Ser. No. 18/967,703 filed on Dec. 4, 2024, which is a Continuation Application of U.S. patent application Ser. No. 17/661,037 filed on Apr. 27, 2022, which is a Continuation Application of U.S. Pat. No. 11,356,936 issued on Jun. 7, 2022, which is a Continuation Application of U.S. Pat. No. 11,191,013, issued on Nov. 30, 2021.

FIELD OF TECHNOLOGY
[0002] Certain embodiments of the disclosure relate to wireless communication. More specifically, certain embodiments of the disclosure relate to an edge device and a method for handling service for multiple service providers.
BACKGROUND
[0003] Wireless telecommunication in modern times has witnessed advent of various signal transmission techniques and methods, such as use of beamforming and beam steering techniques, for enhancing capacity of radio channels. Latency and the high volume of data processing are considered prominent issues with next generation networks, such as 5G. Currently, the use of edge computing in the next generation networks, such as 5G and upcoming 6G, is an active area of research and many benefits has been proposed, for example, faster communication between vehicles, pedestrians, and infrastructure, and other communication devices. For example, it is proposed that close proximity of conventional edge devices to user equipment (UEs) may likely reduce the response delay usually suffered by UEs while accessing the traditional cloud. However, there are many open technical challenges for a successful and practical use of edge computing in the modern networks, especially in 5G or the upcoming 6G environment.
[0004] In a first example, it is known that fast and efficient beam management mechanism may be a key enabler in advanced wireless communication technologies, for example, in millimeter wave (5G) or the upcoming 6G communications, to achieve low latency and high data rate requirements. One major technical challenge of the mmWave beamforming is the initial access latency. During the initial access phase, a UE and or a conventional repeater device need to scan multiple beams to find a suitable beam for attachment, for example, using the standard beam sweeping operation in the initial access phase. This process may introduce considerable latency depending on the number of beams in a beam book and a baseband decoding hardware latency. Such latency becomes even more critical for mobile systems (e.g., when UEs are in motion) in which the channel, and hence beams or base stations, such as a gNodeB (gNB), may be rapidly changing. For example, currently, an average mmWave gNB handover time is on the order of 10-20 seconds, assuming about 500 meter of cell radius and a UE (e.g., a vehicle or a UE in the vehicle) travelling at the speed of 50 miles per hour (MPH), which is not desirable.
[0005] In a second example, Quality of Experience (QoE) is another open issue, which is a measure

of a user's holistic satisfaction level with a service provider (e.g., Internet access, phone call, or other carrier network-enabled services). The challenge is how to ensure a seamless connectivity as well as QoE without significantly increasing infrastructure cost, which may be commercially unsustainable with present solutions.

[0006] In a third example, heterogeneity may be another issue, where many UEs may use different interfaces, radio access technologies (3G, 4G, 5G, or upcoming 6G), computing technologies (e.g., hardware and operating systems) to communicate with the edge cloud. Such heterogeneity in wireless communication may further aggravate the challenges in developing a solution that is practical and upgradable across different environment.

[0007] In yet another example, there is another challenge of high infrastructure cost incurred by each service provider separately to continuously upgrade their infrastructure to newer and advanced wireless communication technologies, for example, in 5G or the upcoming 6G communications, to achieve low latency and high data rate requirements. The high cost also substantially contributes to the delay in upgradation of their infrastructure, thereby leading a compromise on the QoE for the end users.

[0008] Further limitations and disadvantages of conventional and traditional approaches will become apparent to one of skill in the art, through comparison of such systems with some aspects of the present disclosure as set forth in the remainder of the present application with reference to the drawings.

BRIEF SUMMARY OF THE DISCLOSURE

[0009] An edge device and a method for handling service for multiple service providers for high performance and reliable communication, substantially as shown in and/or described in connection with at least one of the figures, as set forth more completely in the claims.

[0010] These and other advantages, aspects and novel features of the present disclosure, as well as details of an illustrated embodiment thereof, will be more fully understood from the following description and drawings.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0011] FIG. **1** is a network environment diagram illustrating various components of an exemplary communication system with a central cloud server and a plurality of edge devices, in accordance with an exemplary embodiment of the disclosure.

[0012] FIG. **2**A is a block diagram illustrating different components of an exemplary edge device, in accordance with an embodiment of the disclosure.

[0013] FIG. **2**B is a network environment diagram of an edge device for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure.

[0014] FIG. **3** is a block diagram illustrating different components of an exemplary central cloud server, in accordance with an embodiment of the disclosure.

[0015] FIG. **4** is a first exemplary scenario for implementation of the edge device, the central cloud server, and the method for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure.

[0016] FIG. **5** is a second exemplary scenario for implementation of the edge device, the central cloud server, and the method for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure.

[0017] FIG. **6** is a flowchart that illustrates an exemplary method for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure.

[0018] FIG. **7** is a flowchart that illustrates an exemplary method for handling service for multiple service providers for high performance and reliable communication, in accordance with another embodiment of the disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0019] Certain embodiments of the disclosure may be found in an edge device for handling service for multiple service providers for high performance and reliable communication. Certain embodiments of the disclosure may be further found in a method and a central cloud server for handling service for multiple service providers for high performance and reliable communication. Beneficially, the edge device has the capability to handle multiple service providers. Alternatively stated, a single edge device can service multiple UEs associated with different service providers, thereby reducing (i.e., optimizing) the total number of network nodes for each service provider required to be deployed or used to service the same number of UEs in one or more geographical areas. Further, the edge device, the central cloud server, and the method of the present disclosure ensure seamless connectivity as well as QoE while reducing the infrastructure cost by almost 50 percent considering just two different service providers. The edge device and the central cloud server are capable of seamlessly handling heterogeneity and support a plurality of different wireless carrier networks of different service providers for high performance and reliable communication. In the following description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown, by way of illustration, various embodiments of the present disclosure.

[0020] FIG. **1** is a network environment diagram illustrating various components of an exemplary communication system with a central cloud server and a plurality of edge devices, in accordance with an exemplary embodiment of the disclosure. With reference to FIG. **1**, there is shown a block diagram **100** of a network environment that includes a central cloud server **102**, a plurality of edge devices **104**, one or more user equipment (UEs) **106**, and a plurality of base stations **108**. There is further shown a plurality of different WCNs **110**, such as a first WCN **110**A of a first service provider and a second WCN **110**B of a second service provider.

[0021] The central cloud server **102** includes suitable logic, circuitry, and interfaces that may be configured to communicate with the plurality of edge devices **104**, the one or more UEs **106**, and the plurality of base stations **108**. In an example, the central cloud server **102** may be a remote management server that is managed by a third party different from the service providers associated with the plurality of different WCNs **110**. In another example, the central cloud server **102** may be a remote management server or a data center that is managed by a third party, or jointly managed, or managed in coordination and association with one or more of the plurality of different WCNs **110**. In an implementation, the central cloud server **102** may be a master cloud server or a master machine that is a part of a data center that controls an array of other cloud servers communicatively coupled to it for load balancing, running customized applications, and efficient data management.

[0022] Each edge device of the plurality of edge devices **104** includes suitable logic, circuitry, and interfaces that may be configured to communicate with the central cloud server **102**. Each edge device of the plurality of edge devices **104**, such as the edge device **104**A, may be one of an XG-enabled edge communication device, an XG-enabled edge repeater device, an XG-enabled relay device, an XG-enabled customer premise equipment (CPE), an XG-enabled small cell, an XG-enabled road side unit (RSU), or an XG-enabled user equipment (UE) controlled by the central cloud server **102**, where the term "XG" refers to 5G or 6G communication. In an example, the edge device **104**A may be controlled out-of-band, for example, in a management plane, by the central cloud server **102**. In an implementation, some of the edge devices of the plurality of edge devices **104** may be deployed at a fixed location while some may be portable. For example, an edge device may be a fixed wireless access (FWA) device, a repeater device, a small cell, or a CPE. In another example, some edge devices, such as an edge repeater device, may be installed in a vehicle, and thus the location of such edge repeater device may vary rapidly when the vehicle is in motion.

Moreover, some edge devices may be portable, and thus their location may change. In some implementations, an edge device may be a part of a telematics unit of a vehicle or implemented as a portable repeater device.

[0023] Each of one or more UEs **106**, such as a first UE **106**A and a second UE **106**B, may correspond to a telecommunication hardware used by an end-user to communicate. Alternatively stated, each of the one or more UEs **106** may refer to a combination of a mobile equipment and subscriber identity module (SIM). Each of the one or more UEs **106** may be a subscriber of at least one of the plurality of different WCNs **110**. Examples of the one or more UEs **106** may include, but are not limited to, a smartphone, a vehicle, a virtual reality headset, an augment reality device, an in-vehicle device, a wireless modem, a customer-premises equipment (CPE), a home router, a cable or satellite television set-top box, a VoIP station, or any other customized hardware for telecommunication.

[0024] Each of the plurality of base stations **108** may be a fixed point of communication that may communicate information, in the form of a plurality of beams of RF signals, to and from communication devices, such as the one or more UEs **106** and the plurality of edge devices **104**. Multiple base stations corresponding to one service provider may be geographically positioned to cover specific geographical areas. Typically, bandwidth requirements serve as a guideline for a location of a base station based on a relative distance between the plurality of UEs and the base station. The count of base stations depends on population density and geographic irregularities, such as buildings and mountain ranges, which may interfere with the plurality of beams of RF signals. In an implementation, each of the plurality of base stations **108** may be a gNB. In another implementation, the plurality of base stations **108** may include eNBs, Master eNBs (MeNBs) (for non-standalone mode), and gNBs.

[0025] Each of the plurality of different WCNs **110** is owned, managed, or associated with a mobile network operator (MNO), also referred to as a mobile carrier, a cellular company, or a wireless service provider that provides services, such as voice, SMS, MMS, Web access, data services, and the like, to its subscribers, over a licensed radio spectrum. Each of the plurality of different WCNs **110** may own or control elements of network infrastructure to provide services to its subscribers over the licensed spectrum, for example, 4G LTE or 5G spectrum (FR1 or FR2). For example, the first base station **108**A or the first UE **106**A may be controlled, managed, or associated with the first WCN **110**A, and the second base station **108**B or the second UE **106**B may be controlled, managed, or associated with the second WCN **110**B different from the first WCN **110**A. The plurality of different WCNs **110** may also include mobile virtual network operators (MVNO).

[0026] Beneficially, the central cloud server **102** and the plurality of edge devices **104** exhibit a decentralized model that not only brings cloud computing capabilities closer to UEs in order to reduce latency but also manifests several known benefits for various service providers associated with the plurality of different WCNs **110**. For example, backhaul traffic is reduced by provisioning content at the edge, computational resources are distributed geographically in different locations (e.g., on premise mini cloud, central offices, customer premises, etc.,) depending on the use case requirements and reliability of a network is improved by distributing content between edge devices and the centralized cloud server **102**. Apart from these and other known benefits (or inherent properties) of edge computing, the central cloud server **102** improves and solves many open issues related to the convergence of edge computing and modern wireless networks, such as 5G or upcoming 6G. The central cloud server **102** significantly improves the beam management mechanism of 5G new radio (NR), true 5G, and creates a platform for upcoming 6G communications, to achieve low latency and high data rate requirements. Based on the various information acquired from the plurality of edge devices **104** over a period of time, the central cloud server **102** creates a connectivity enhanced database that specifies a plurality of specific uplink and downlink wireless connectivity beam alignment-wireless connectivity relationships for a surrounding area of each of the plurality of edge devices **104** independent of the plurality of

different WCNs **110**. This removes the complexity and substantially reduces the initial access latency as the standard beam sweeping operation in the initial access phase is bypassed and is not required to be performed at the end-user device or edge devices, which in turn improves network performance of all associated WCNs of the plurality of different WCNs **110**. The central cloud server **102** is able to handle heterogeneity in wireless communication in terms of different interfaces, radio access technologies (3G, 4G, 5G, or upcoming 6G), computing technologies (e.g., hardware and operating systems) and even one or more carrier networks used by the one or more UEs **106**. Moreover, the central cloud server **102** takes into account the dynamic nature of surroundings by use of the sensing information obtained from the plurality of edge devices **104** in real-time or near real time, to proactively avoid any adverse impact on reliability due to any sudden signal blockage or signal loss, thereby provisioning consistent high-speed low latency wireless connectivity. Thus, the central cloud server **102** manifest higher Quality of experience (QoE) as compared to existing systems.

[0027] FIG. **2**A is a block diagram illustrating different components of an exemplary edge device, in accordance with an embodiment of the disclosure. FIG. **2**A is explained in conjunction with elements from FIG. **1**. With reference to FIG. **2**A, there is shown a block diagram **200** of the edge device **104**A with various components. The edge device **104**A has a donor side **202**A facing towards the plurality of base stations **108**, such as the first base station **108**A and the second base station **108**B (of FIG. **1**). The edge device **104**A also has a service side **202**B facing towards a plurality of UEs, such as the first UE **106**A and the second UE **106**B. In an implementation, the edge device **104**A may include a control section **204** and a front-end radio frequency (RF) section, which may include one or more first antenna arrays **206** and a first plurality of signal processing chains **208** (such as a first uplink chain **208**A and a second uplink chain **208**B) at the donor side **202**A, and further one or more second antenna arrays **210** and a second plurality of signal processing chains **212** (such as a first downlink chain **212**A and a second downlink chain **212**B) at the service side **202**B. The control section **204** may be communicatively coupled to the front-end RF section, such as the one or more first antenna arrays **206**, the first plurality of signal processing chains **208**, the one or more second antenna arrays **210**, and the second plurality of signal processing chains **212**. The front-end RF section supports millimeter wave (mmWave) communication as well communication at a sub 6 gigahertz (GHz) frequency. The control section **204** may further include control circuitry **214**, a memory **216**, and one or more filters **218**.

[0028] The edge device **104**A includes suitable logic, circuitry, and interfaces that may be configured to communicate with one or more network nodes, such as one or more base stations of the plurality of base stations **108**, another edge devices of the plurality of edge devices **104**, and user equipment (UEs). In accordance with an embodiment, the edge device **104**A may support multiple and a wide range of frequency spectrum, for example, 2G, 3G, 4G, 5G, and 6G (including out-of-band frequencies). The edge device **104**A may be one of an XG-enabled edge communication device, an XG-enabled edge repeater device, an XG-enabled relay device, an XG-enabled customer premise equipment (CPE), an XG-enabled small cell, or an XG-enabled user equipment (UE) controlled by the central cloud server **102**, where the term "XG" refers to 5G or 6G communication. Other examples of the edge device **104**A may include, but is not limited to, a 5G wireless access point, an evolved-universal terrestrial radio access-new radio (NR) dual connectivity (EN-DC) device, a Multiple-input and multiple-output (MIMO)-capable repeater device, or a combination thereof.

[0029] The one or more first antenna arrays **206** may be provided at the donor side **202**A and may be communicatively coupled to the first plurality of signal processing chains **208**, such as the first uplink chain **208**A and the second uplink chain **208**B. The one or more second antenna arrays **210** may be provided at the service side **202**B and may be communicatively coupled to the second plurality of signal processing chains **212**, such as the first downlink chain **212**A and the second downlink chain **212**B. Each of the first plurality of signal processing chains **208**, such as the first

uplink chain **208**A and the second uplink chain **208**B, may include a transceiver chain. The control circuitry **214** may be further configured to receive a first donor beam from the first base station **108**A and a second donor beam from the second base station **108**B using the one or more first antenna arrays **206**. In an example, each of the first plurality of signal processing chains **208**, such as the first uplink chain **208**A and the second uplink chain **208**B, and each of the second plurality of signal processing chains **212**, such as the first downlink chain **212**A and the second downlink chain **212**B, may include a cascading receiver chain and a cascading transmitter chain, each of which comprises various components for baseband signal processing or digital signal processing. For example, the cascading receiver chain may include various components, such as a set of low noise amplifiers (LNA), a set of receiver front end phase shifters, and a set of power combiners, for the signal reception (not shown here for brevity). Similarly, the cascading transmitter chain comprises various components for baseband signal processing or digital signal processing, such as a set of power dividers, a set of phase shifters, a set of power amplifiers (PA). The control circuitry **214** maybe further configured to direct a first beam of RF signal in the first WCN **110**A to the first UE **106**A and a second beam of RF signal in the second WCN **110**B to the second UE **106**B using the one or more second antenna arrays **210** provided at the service side **202**B.

[0030] In an implementation, the one or more first antenna arrays **206** and the one or more second antenna arrays **210** supports multiple-input multiple-output (MIMO) operations and may be configured to execute MIMO communication with a plurality of UEs, such as the first UE **106**A and the second UE **106**B. The MIMO communication may be executed at a sub 6 gigahertz (GHz) frequency or at mmWave frequency for 5G NR communication. Each of the one or more first antenna arrays **114** and the one or more second antenna arrays **116** may be one of an XG phased-array antenna panel, an XG-enabled antenna chipset, an XG-enabled patch antenna array, or an XG-enabled servo-driven antenna array, where the "XG" refers to 5G or 6G. Examples of implementations of the XG phased-array antenna panel include, but is not limited to, a linear phased array antenna, a planar phased array antenna, a frequency scanning phased array antenna, a dynamic phased array antenna, and a passive phased array antenna.

[0031] The control circuitry **214** may be communicatively coupled to the memory **216**, the one or more filters **218**, and the front-end RF section. The control circuitry **214** may be configured to execute various operations of the edge device **104**A. The control circuitry **214** may be configured to control various components of the front-end RF section, such as the one or more first antenna arrays **206** and the first plurality of signal processing chains **208** at the donor side **202**A; and the one or more second antenna arrays **210** and the second plurality of signal processing chains **212** at the service side **202**B. The edge device **104**A may be a programmable device, where the control circuitry **214** may execute instructions stored in the memory **216**. An exemplary implementation of the control circuitry **214** may include, but are not limited to an embedded processor, a baseband processor, a microcontroller, a specialized digital signal processor (DSP), a control chip, a Reduced Instruction Set Computing (RISC) processor, an Application-Specific Integrated Circuit (ASIC) processor, a Complex Instruction Set Computing (CISC) processor, and/or other processors, or state machines.

[0032] The memory **216** may be configured store wireless connectivity enhanced information for a plurality of UEs, such as the first UE **106**A and the second UE **106**B, obtained from the central cloud server **102**. The memory **216** may be further configured store values calculated by the control circuitry **214**. Examples of the implementation of the memory **216** may include, but not limited to, a random access memory (RAM), a dynamic random access memory (DRAM), a static random access memory (SRAM), a processor cache, a thyristor random access memory (T-RAM), a zero-capacitor random access memory (Z-RAM), a read only memory (ROM), a hard disk drive (HDD), a secure digital (SD) card, a flash drive, cache memory, and/or other non-volatile memory. It is to be understood by a person having ordinary skill in the art that the control section **204** may further include one or more other components, such as an analog to digital converter (ADC), a digital to

analog (DAC) converter, a cellular modem, and the like, known in the art, which are omitted for brevity.

[0033] The one or more filters **218** may be a band-pass filter, a multi-band filter or other channel select filter. The one or more filters **218** may be used to allow or reject one or more bandwidth parts (BWPs) of one or more NR frequency bands in an uplink and a downlink direction using the one or more filters **218**. The one or more filters **218** may also be used to segregate uplink and downlink communication of RF signals from the first WCN **110**A with the second WCN **110**B based on the wireless connectivity enhanced information obtained from the central cloud server **102**.

[0034] FIG. **2**B is a network environment diagram of an edge device for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure. FIG. **2**B is explained in conjunction with elements from FIGS. **1** and **2**A. With reference to FIG. **2**B, there is shown the edge device **104**A that may be independent of the plurality of different WCNs **110** and can handle services for multiple service providers. There is further shown the first base station **108**A of the first WCN **110**A of a first service provider and the second base station **108**B of the second WCN **110**B of a second service provider different from the first service provider.

[0035] In operation, the control circuitry **214** may be configured to receive a first connection request from the first UE **106**A associated with the first WCN **110**A of a first service provider. The first UE **106**A may be subscribed to the first WCN **110**A of the first service provider. In an example, the connection request may be received via an out-of-band communication, such as WI-FI™, BLUETOOTH™, Li-Fi, a sidelink request (e.g., LTE sidelink, 5G New Radio (NR) sidelink, NR C-V2X sidelink), a vehicle-to-infrastructure (V2I) request, a personal area network (PAN) connection, or other out-of-band connection requests. Similarly, the control circuitry **214** may be further configured to receive a second connection request from the second UE **106**B associated with the second WCN **110**B of a second service provider. The second UE **106**B may be subscribed to the second WCN **110**B of the second service provider.

[0036] In accordance with an embodiment, the control circuitry **214** may be further configured to activate the edge device **104**A and establish a connection with each of the first UE **106**A and the second UE **106**B based on the corresponding connection request. In an implementation, the control circuitry **214** may be further configured to obtain a corresponding activation signal from each of the first UE **106**A and the second UE **106**B, where the corresponding activation signal is generated at the first UE **106**A and the second UE **106**B using at least one of an application installed in the first UE **106**A and the second UE **106**B, an authentication key, or a registered gesture. In an example, the first UE **106**A or the second UE **106**B may be a smartphone or other UE that may have the application installed in it, where the application may be communicatively coupled to the central cloud server **102**. In another example, the first UE **106**A or the second UE **106**B may be a vehicle, in which the application may be installed in a smartphone connected to an in-vehicle infotainment system of the vehicle or the application may be preinstalled in the vehicle (e.g., in the in-vehicle infotainment system). A unique identity, for example, in the form of the authentication key, or the registered gesture, or other identifying means may be used to identify users associated with the first UE **106**A or **106**B as a valid user to receive services of the central cloud server **102** and the edge device **104**A. The control circuitry **214** may be further configured to activate the edge device **104**A to service the first UE **106**A and the second UE **106**B based on an authentication of the corresponding activation signal. In an implementation, the corresponding activation signal from each of the first UE **106**A and the second UE **106**B may be a part of the first connection request and second connection request, respectively. In another implementation, the corresponding activation signal from each of the first UE **106**A and the second UE **106**B may be sent even prior to the connection request, during the connection request, or post the connection request. The control circuitry **214** may be further configured to identify the one or more UEs, such as the first UE **106**A and the second UE **106**B based on the connection request.

[0037] In an implementation, the first connection request from the first UE **106**A and the second connection request from the second UE **106**B may be automatically sent by the first UE **106**A and the second UE **106**B when such UEs are in the communication range of the edge device **104**A. In some implementations, the communication of the first connection request from the first UE **106**A and the second connection request from the second UE **106**B is controlled by the central cloud server **102** based on communication of sensing information (e.g., a current position, a moving direction, a time-of-day, and surrounding information, such as the presence of reflective objects or signal blocking objects) associated with the corresponding UEs, such as the first UE **106**A and the second UE **106**B. The central cloud server **102** may be configured to determine that a handover is required, and accordingly send a wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B to the edge device **104**A.

[0038] The control circuitry **214** may be further configured to obtain wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B from the central cloud server **102**. In accordance with an embodiment, the control circuitry **214** may be further configured to obtain the wireless connectivity enhanced information from the central cloud server **102** based on a position of the edge device **104**A. The wireless connectivity enhanced information provided by the central cloud server **102** for the first UE **106**A and the second UE **106**B may include selected initial access information to accelerate a UE-specific beam alignment for each of the first UE **106**A and the second UE **106**B and connectivity to one or more base stations, such as the first base station **108**A and the second base station **108**B, from the edge device **104**A bypassing an initial access-search on the edge device **104**A.

[0039] The selected initial access information for the first UE **106**A and the second UE **106**B may indicate the best and/or optimal transmit (Tx) and receive (Rx) beam for the donor side **201**A and the best Tx-Rx beam for the service side **202**B, best Physical Cell Identities (PCIDs) associated with different service providers, best and/or optimal absolute radio-frequency channel number (ARFCNs), and a signal strength information associated with each of Tx beam and the Rx beam of the edge device **104**A. The best and/or optimal refers to wireless connectivity using multiple beams of RF signals at both the donor side **202**A and service side **202**B that has the highest signal strength (or among the top three available signal strengths), for example, for 5G NR signals and data throughput rate higher than one or more specified threshold values, while executing uplink and downlink communication using the plurality of different WCNs **110**. In an example, the selected initial access information in the wireless connectivity enhanced information for the first UE **106**A may include a first decoded Physical Cell Identity (PCID) of the first base station **108**A (i.e., 5G-enabled gNB) of the first WCN **110**A and a first beam index used to switch beam reception and transmission from the one or more first antenna arrays **206** at the donor side **202**A of the edge device **104**A to the first base station **108**A. The selected initial access information obtained by the edge device **104**A for the first UE **106**A may further include a first absolute radio-frequency channel number (ARFCN) or other base station properties of the first base station **108**A to establish a Radio Resource Control (RRC) connection, for example, in a first 5G NR carrier frequency, with the first base station **108**A. Similarly, the selected initial access information in the wireless connectivity enhanced information for the second UE **106**B may include a second decoded Physical Cell Identity (PCID) of the second base station **108**B (i.e., another 5G-enabled gNB) of the second WCN **110**B, and a second beam index used to switch beam reception and transmission from the one or more first antenna arrays **206** at the donor side **202**A of the edge device **104**A to the second base station **108**B at the edge device **104**A. The selected initial access information obtained by the edge device **104**A for the second UE **106**B may further include a second ARFCN or other base station properties of the second base station **108**B to establish a Radio Resource Control (RRC) connection, for example, in a second 5G NR carrier frequency, with the second base station **108**B. For the service side **202**B to service the first UE **106**A and the second UE **106**B, the wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B may

further include a first service side beam index and a second service side beam index for the first UE **106**A and the second UE **106**B, respectively. The first service side beam index and the second service side beam index correspond to the strongest UE-specific beam predetermined for a corresponding location of the first UE **106**A and the second UE **106**B, respectively. Thus, the selected initial access information may be the best (or optimal) initial access information that provides initial access to the first UE **106**A and the second UE **106**B to the best gNBs, such as the first base station **108**A and the second base station **108**B. The best (or optimal) refers to wireless connectivity using multiple beams of RF signals at both the donor side **202**A and service side **202**B that has the highest signal strength (or among the top three available signal strengths), for example, for 5G NR signals and data throughput rate higher than a threshold, while executing uplink and downlink communication using the plurality of different WCNs **110**, given the current location of the first UE **106**A and the second UE **106**B. Thus, the central cloud server **102** assists the edge device **104**A by providing them with optimized initial access information (e.g., best beam index, best beam configuration, best ARFCN, and PCID) that it has learned the machine learning model **308** during the training phase (described in detail, for example, in FIG. **3**).

[0040] In accordance with an embodiment, the control circuitry **214** may be further configured to receive a first donor beam **220**A from the first base station **108**A and a second donor beam **220**B from the second base station **108**B. The edge device **104**A may be within the coverage area of each of the first base station **108**A of the first WCN **110**A and the second base station **108**B of the second WCN **110**B that may be different from the first WCN **110**A. As the edge device **104**A includes a plurality of signal processing chains, such as the first plurality of signal processing chains **208**, at the donor side **202**A, the first donor beam **220**A from the first base station **108**A and the second donor beam **220**B from the second base station **108**B may be received concurrently from two different base stations of two different service providers and processed concurrently. For example, the first uplink chain **208**A may be configured to process the first donor beam **220**A associated with the first WCN **110**A, and the second uplink chain **208**B may be configured to process the second donor beam **220**B associated with the first WCN **110**A, where the first donor beam **220**A and the second donor beam **220**B are received via the one or more first antenna arrays **206** at the donor side **202**A of the edge device **104**A. Thus, each signal processing chain of the first plurality of signal processing chains **208** may be associated with one WCN to segregate an uplink and a downlink communication of RF signals from the first WCN **110**A with the second WCN **110**B. Each of the first plurality of signal processing chains **208** at the donor side **202**A and second plurality of signal processing chains **212** at the service side **202**B may be controlled by the control circuitry **214**.

[0041] In some implementations, the control circuitry **214** may be further configured to utilize the one or more filters **218** to maintain mutual isolation of a first data stream of the first donor beam **220**A from a second data stream of the second donor beam **220**B. In other words, the one or more filters **218** may also be used to segregate uplink and downlink communication of RF signals from the first WCN **110**A with the second WCN **110**B based on the wireless connectivity enhanced information obtained from the central cloud server **102**. Alternatively, the control circuitry **214** may be further configured to receive the first donor beam **220**A directly from the first base station **108**A and the second donor beam **220**B associated with the second base station **108**B from another edge device (such as the edge device **104**B) that is a part of a network of edge devices, such as the plurality of edge devices **104**. For example, in certain scenarios, there may be temporary signal blockage due to a moving object that may block signals between the edge device **104**A and the second base station **108**B or there may be a blockage due to a non-line-of-sight (NLOS) between the second base station **108**B and a particular edge device due to its position, such as the edge device **104**A. In such scenarios, the other edge device that may be in a line-of-sight (LOS) between the second base station **108**B and the other edge device, such as the edge device **104**B, may first receive the second donor beam **220**B associated with the second base station **108**B and relay the

second donor beam **220**B to the edge device **104**A. The other edge device, such as the edge device **104**B, receives the second donor beam **220**B for further relay to the destination edge device, such as the edge device **104**A, based on an instruction from the central cloud server **102** or a request from the edge device **104**A.

[0042] The control circuitry **214** may be further configured to direct a first beam **222**A of radio frequency (RF) signal in the first WCN **110**A to the first UE **106**A and a second beam **222**B of RF signal in the second WCN **110**B to the second UE **106**B based on the obtained connectivity enhanced information for the first UE **106**A and the second UE **106**B. The edge device **104**A is independent of a plurality of different WCNs **110** such that any one of the plurality of different WCNs **110** is used to service a specific UE in accordance with an association of the specific UE to a specific WCN. In some implementations, the first beam of RF signal in the first WCN **110**A to the first UE **106**A and the second beam of RF signal in the second WCN **110**B to the second UE **106**B are concurrently directed from the edge device **104**A. The first beam of RF signal may carry a first payload of the first data stream associated with the first WCN **110**A to the first UE **106**A and the second beam of RF signal carry at least one of a second payload of the second data stream associated with the second WCN **110**B to the second UE **106**B or a null payload associated with the second WCN **110**B to the second UE **106**B.

[0043] In some implementations, the first beam of RF signal in the first WCN **110**A to the first UE **106**A and the second beam of RF signal in the second WCN **110**B to the second UE **106**B are alternatingly directed from the edge device **104**A (e.g., in a switching pattern). In such a case, each of the donor side **202**A and the service side **202**B of the edge device **104**A may utilize one signal processing chain which may be configured to alternatively process RF signals from the first WCN **110**A and the second WCN **110**B in a switching pattern under the control of the control circuitry **214**.

[0044] In some implementations, the control circuitry **214** may be further configured to receive two or more time division duplex (TDD) patterns from two or more base stations (e.g., gNBs, such as the first base station **108**A and the second base station **108**B) of different service providers. The control circuitry **214** may be further configured to find a common TDD pattern for the received two or more TDD patterns and follow the common TDD pattern for switching RF signals between different wireless carrier networks of the different service providers for uplink and downlink communication. The common TDD pattern allows uplink and downlink to use complete 5G NR frequency spectrum, but in different time slots, where some short time slots are designated for uplink while other time slots are designated for downlink and coordinate switching of the RF signals between the first WCN **110**A and the second WCN **110**B of the different service providers for uplink and downlink communication. In an implementation, the two or more TDD patterns for the two or more base stations (e.g., gNBs, such as the first base station **108**A and the second base station **108**B) of different service providers, may be received in the obtained wireless connectivity enhanced information from the central cloud server **102**. The common TDD pattern may indicate a common timing reference to align the edge device **104**A with that of a 5G NR cell frame for an uplink or a downlink time division duplex (TDD) switching for different service providers, for example, using a common phase clock reference (e.g., a coordinated universal time), and a switching-point periodicity, for example, a switching periodicity from the uplink to the downlink and for different service providers based on the common TDD pattern.

[0045] Beneficially, multiple UEs, such as the first UE **106**A and the second UE **106**B, associated with different service providers is serviced by a single edge device, such as the edge device **104**A (e.g., a repeater device or an RSU). Alternatively stated, a single edge device can service multiple UEs associated with different service providers, thereby reducing (i.e., optimizing) the total number of network nodes for each service provider required to be deployed or used to service the same number of UEs in one or more geographical areas. Furthermore, the edge device **104**A ensures seamless connectivity as well as QoE while reducing the infrastructure cost by greater than **50**

percent considering just two different service providers, such as the first WCN **110**A and the second WCN **110**B. The edge device **104**A seamlessly handles heterogeneity and supports the plurality of different WCNs **110** for high performance and reliable communication. Furthermore, a consumer, such as the first UE **106**A, is provided to choose which WCN (i.e., which service provider) they like to connect to, and this is enabled from the cloud, such as the central cloud server **102**. The central cloud server **102** transmits specific initial access information (optimal initial access information) associated with one or more WCNs, such as the first WCN **110**A and the second WCN **110**B, to the edge device **104**A, where such specific initial access information is used by the edge device **104**A to establish wireless connectivity by passing conventional initial-access search. Hence, beneficially, a consumer of a UE, such as the first UE **106**A, subscribed to the first WCN **110**A can request the edge device **104**A in the connection request to relay an RF signal of the first WCN **110**A, and if the consumer of the first UE **106**A is subscribed to the second WCN **110**B, then the first UE **106**A can request the edge device **104**A, to relay an RF signal of the second WCN **110**B. Additionally, and advantageously, as the obtained connectivity enhanced information for the first UE **106**A and the second UE **106**B is independent of the plurality of different WCNs **110**, the complexity and the initial access latency is significantly reduced as the standard beam sweeping operation in the initial access phase is bypassed and is not required to be performed at the first UE **106**A and the second UE **106**B and the edge device **104**A, which in turn improves network performance and reduces additional signaling load (due to standard initial-access search) on associated WCNs of the plurality of different WCNs **110**.

[0046] In accordance with an embodiment, the control circuitry **214** is further configured to utilize the obtained connectivity enhanced information to, for example: reduce time to align to a timing offset of a beam reception at the edge device **104**A to a frame structure of a 5G NR radio frame, and allow uplink and downlink to use complete 5G NR frequency spectrum for different service providers; set beam index or set phase values of the received RF signals to design beams to service the first UE **106**A and the second UE **106**B in real time or near real time; set parameters, e.g., amplifier gains, and phase responses associated with the one or more first antenna arrays **206** or the one or more second antenna arrays **210**; form specific beam patterns from the edge device **104**A specific to the first UE **106**A and the second UE **106**B; execute dynamic partitioning of a plurality of antenna elements of an antenna array of the one or more second antenna arrays **210** at the service side **202**B into a plurality of spatially separated antenna sub-arrays to generate multiple beams associated with different WCNs in different directions at the same time or in a different time slot; set a suitable adjustment of a power back-off to minimize (i.e., substantially reduce) the impact of interference (echo or noise signals) and hence only use as much power as needed to achieve low error communication with the first base station **108**A and the second base station **108**B in the uplink or the first UE **106**A and the second UE **106**B in the downlink communication; and optimize blocks of radio and perform Radio access network optimization to improve coverage, capacity and service quality of a geographical area surrounding the edge device **104**A.

[0047] FIG. **3** is a block diagram illustrating different components of an exemplary central cloud server, in accordance with an embodiment of the disclosure. FIG. **3** is explained in conjunction with elements from FIGS. **1**, **2**A, and **2**B. With reference to FIG. **3**, there is shown a block diagram **300** of the central cloud server **102**. The central cloud server **102** may include a processor **302**, a network interface **304**, and a primary storage **306** (e.g., a datacenter, a memory, cloud storage, etc.). The primary storage **306** may further include sensing information and beam alignment information. In an implementation, the primary storage **306** may further include processing chain parameters. There is further shown a machine learning model **308** and a connectivity enhanced database **310**.

[0048] In operation, in accordance with an embodiment, the processor **302** may be configured to obtain the sensing information of the surrounding area of the edge device **104**A. The sensing information may be periodically or continually obtained from the edge device **104**A. The processor **302** may be further configured to communicate wireless connectivity enhanced information to the

edge device **104**A for the first UE **106**A and the second UE **106**B. The communication may be executed based on the corresponding request from the first UE **106**A and the second UE **106**B and the position of the edge device **104**A. In some implementations, the communication may be executed based on the obtained sensing information. For example, the processor **302** may be further configured to determine, based on the position information of the edge device **104**A, whether the handover is required, and if so, communicate the wireless connectivity enhanced information including, the specific initial access information to the edge device **104**A to bypass the initial access-search on the edge device **104**A. The wireless connectivity enhanced information, including the specific initial access information to the edge device **104**A, is extracted from the connectivity enhanced database **310**. The connectivity enhanced database **310** may be a low-latency database, for example, "DynamoDB", "Scylla", or other proven and known low-latency databases that can handle one or more million transactions per second on a single cloud server. The connectivity enhanced database **310** may be an intelligent and learned database that is generated based on the training of the machine learning model **308** previously (explained in detail later in FIG. **3**, for example, under "the training phase"), which specifies a plurality of specific uplink and downlink wireless connectivity enhanced information for a surrounding area of each of the plurality of edge devices **104** independent of a plurality of different WCN **110** of different service providers.

[0049] In accordance with an embodiment, the processor **302** may be further configured to control the edge device **104**A to concurrently direct the first beam of RF signal in the first WCN **110**A to the first UE **106**A and the second beam of RF signal in the second WCN **110**B to the second UE **106**B in accordance with the wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B bypassing an initial access-search on the edge device **104**A. Alternatively, the processor **302** may be further configured to control the edge device **104**A to alternatingly direct the first beam of RF signal in the first WCN **110**A to the first UE **106**A and the second beam of RF signal in the second WCN **110**B to the second UE **106**B in accordance with the wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B bypassing an initial access-search on the edge device **104**A.

The Training Phase

[0050] The connectivity enhanced database **310** may be generated based on the training of the machine learning model **308** in the training phase. In an exemplary training phase, the processor **302** may be configured to periodically obtain sensing information from the plurality of edge devices **104**. Each of the plurality of edge devices **104** may be deployed at different locations. The machine learning model **308** of the central cloud server **102** may be periodically (e.g., daily and for different times-of-day) trained on data points that are uploaded to the central cloud server **102** from the plurality of edge devices **104**. In an example, the sensing information may comprise a position of each of the plurality of edge devices **104**, a location of the one or more UEs **106** in the motion state or in the stationary state in the surrounding area of each of the plurality of edge devices **104**, a moving direction of different UEs (such as the one or more UEs **106**), a time-of-day, traffic information, road information, construction information, and traffic light information. The central cloud server **102** obtains such sensing information and stores the data points of such sensing information as input features. As the sensing information is obtained periodically from various edge devices of the plurality of edge devices **104**, all changes in the surroundings of each edge device are adequately captured and relayed to the central cloud server **102**.

[0051] In some implementations, each edge device of the plurality of edge devices **104** may be configured to utilize external sensing devices, such as Lidar, camera, accelerometer, Global Navigation Satellite System (GNSS), gyroscope, or Internet-of-Things (IoT) devices (e.g., video surveillance devices, roadside sensor systems for measuring speed, local road conditions, local traffic, and the like) located within its communication range to acquire sensing information from such external devices. For example, an edge device may be an edge repeater device mounted on a vehicle and communicatively coupled to different in-vehicle sensors via an in-vehicle network, so

as to acquire the sensing information from such in-vehicle sensors (i.e., the external sensors) in real time or near time.

[0052] In accordance with an embodiment, the sensing information may further comprise a distance of each of the plurality of edge devices **104** from the one or more UEs **106** and other movable and immobile physical structures in the surrounding area of each of the plurality of edge devices **104**. In an implementation, the distance of each of the plurality of edge devices **104** from one or more UEs within its range, such as the one or more UEs **106**, and other movable and immobile physical structures in the surrounding area of each of the plurality of edge devices **104**, may be determined at each of the plurality of edge devices **104** or at least some edge devices of the plurality of edge devices **104**, and then communicated to the central cloud server **102** as the sensing information. In some implementations, the central cloud server **102** may be configured to determine such distance based on the position information received from the plurality of edge devices **104**.

[0053] In an example, the processor **302** may be further configured to determine a distance of each edge device (e.g., an edge repeater device) from its surrounding objects, such as other vehicles, buildings, or edges of a building, distance of one or more serving base stations of the plurality of base stations, trees, and other immobile physical structures (such as reflective objects) or other mobile objects. Moreover, Lidar information from vehicles, information from a navigation system (such as maps, for example, identifying cross-sections of streets), satellite imagery of buildings of a surrounding area, bridges, any signal obstruction from a change in construction structure, etc., may be stored in the cloud, such as the central cloud server **102**.

[0054] The machine learning model **308** of the central cloud server **102** may be periodically (e.g., daily and for different times of day) updated on such data points in real-time or near time. The central cloud server **102** may be further configured to cause the machine learning model **308** to find correlation among such data points to be used for a plurality of predictions and formulate rules to establish, maintain, and select one or more edge devices in advance for various traffic scenarios to serve UEs and to identify improved (e.g., optimal) signal transmission paths to reach to UEs and for efficient handover for wireless connectivity at a later stage (i.e., in the inference phase). Based on the sensing information obtained from the plurality of edge devices **104**, the processor **302** may be further configured to detect where reflective objects are located and used that information in radiation pattern of the RF signals, such as 5G signals. The sensing information may configure the radiation pattern so that it is correlated to areas such that reflection of the communicated RF signals is mitigated or eliminated. This means that when one or more beams of RF signals are communicated from the plurality of edge devices **104**, comparatively significantly lower or almost negligible RF signals are reflected back to the plurality of edge devices **104**. The location of the reflective objects and the correlation of the areas associated with reflective objects with the radiation pattern to design enhanced or most suited beam configurations may be further used by the processor **302** to formulate rules for later use.

[0055] In accordance with an embodiment, the sensing information may further comprise weather information. It is known that more attention is provided in the region between 30-300 GHz frequencies due to the large bandwidth which is available in this region to enable the plurality of different WCNs **110** to cope with the increasing demand for higher data rates and ultra-low latency services. However, the signals at frequencies above 30 GHz may not propagate for long distances as those below 30 GHz. Moreover, there is signal attenuation due to weather factors, such as humidity, rain, ice, different types of storms, and even there is a difference observed during summer and winter on the signal power level. For example, the signal loss difference between winter and summer for 28 GHz may be about 1 dB, about 2 dB for 37 GHZ, about 4 dB for 60 GHz. The losses may increase with frequency and distance. The processor **302** utilizes such weather information to determine one or more changes in a performance state of each of the plurality of edge devices **104** in servicing the one or more UEs **106** in its surrounding area in

different weather conditions and accordingly may learn a correlation between different weather condition and signal power level and other performance states of each of the plurality of edge devices **104** in servicing the one or more UEs **106** in its surrounding area. Accordingly, the processor **202** may be further configured to formulate rules to establish, maintain, and select one or more edge devices in advance to mitigate signal losses in various weather conditions to serve UEs and to identify improved signal transmission paths to reach to UEs via one or more edge devices of the plurality of edge devices **104** at a later stage (i.e., in the inference phase). For example, the processor **302** may be further configured to cause the one or more edge devices to select a most appropriate beam configuration or radiation pattern in real time or near real time in accordance with the weather condition obtained as a part of the sensing information (i.e., in the inference phase).

[0056] The processor **302** may be further configured to periodically obtain beam alignment information from the plurality of edge devices **104**. The beam alignment information may be obtained and stored for the plurality of different WCNs **110**. In an implementation, the beam alignment information received by the central cloud server **102** from the plurality of edge devices **104** during the training phase may comprise one or more of a transmit (Tx) beam information, a receive (Rx) beam information, a Physical Cell Identity (PCID), and an absolute radio-frequency channel number (ARFCN), and a signal strength information associated with each of Tx beam and the Rx beam of the plurality of edge devices **104**.

[0057] The processor **302** may be further configured to correlate the obtained sensing information and the beam alignment information for different times-of-day such that the connectivity enhanced database **310** is generated that specifies a plurality of time-of-day specific uplink and downlink beam alignment-wireless connectivity relationships for a surrounding area of each of the plurality of edge devices **104** independent of the plurality of different WCNs **110**. The correlation indicates that for a given set of input features extracted from the sensing information, what is the most suitable (i.e., best) initial access information for a given edge device according to its position to service one or more UEs in its surrounding area such that a high-speed and low latency wireless connectivity can be achieved with increased consistency for different times-of-day.

[0058] The time-of day specific uplink beam-alignment-wireless connectivity relation specifies, for the given set of input features for a given time-of-day, which beam index to set at an edge device for the uplink communication, a specific Physical Cell Identity (PCID) which indicates which gNB to connect to, or which WCN to select, which specific beam configuration to set, or whether a connection to the base station is to be established directly or indirectly in a NLOS path using another edge device (e.g., another edge device) in a network of edge devices depending on the current location of the edge device. Similarly, the time-of day specific downlink beam-alignment-wireless connectivity relation specifies, for the given set of input features for a given time-of-day, which beam index to set at an edge device for the downlink communication, which WCN to select, which specific beam configuration to set, what power level of the RF signal may be sufficient, or an expected time period to service one or more UEs, such as the first UE **106**A, depending on the current location of the edge device. In an implementation, the processor **302** may be further configured to extract and tag parameters of the beam alignment information as learning labels. The obtained sensing information may be considered as input features, whereas the beam alignment information may be considered as learning labels for the correlation. The processor **302** may be further configured to execute a mapping of the learning labels with one or more features of the obtained sensing information until the plurality of time-of-day specific uplink and downlink beam alignment-wireless connectivity relationships is established for the surrounding area of each of the plurality of edge devices **104**. In an implementation, a machine learning algorithm, for example, an artificial neural network algorithm, may be used at the beginning before training with the real-world training data of input features and parameters of the beam alignment information as supervised learning labels. When the machine learning algorithm is passed through the training

data of correlated input features and parameters of the beam alignment information, the machine learning algorithm determines patterns such that the input features (e.g., a distance of edge device with a UE, weather condition, a UE location, moving direction, time-of-day, etc.) are mapped to the learning labels (e.g., best initial access information, such as best PCID, best beam index to be used, signal strength measurement of a Tx/Rx beam, beam configuration, best transmission path, an absolute radio-frequency channel number (ARFCN), etc.). Since the machine learning model **308** is trained periodically, so if the base station (e.g., a gNB) configuration is changed (e.g., a new sector or gNB is added or the PCID, ARFCN is changed), the machine learning model **308** quickly adapts to the change. The processor **302** is further configured to cause the machine learning model **308** to assign more weight to recent data points using, for example, an exponential time decay process. The machine learning model **308** may be a learned model generated as output in the training process, and thus, over a period of time, the machine learning model **308** is able to predict the specific initial access information most suited for a given set of input features. Alternatively, in another implementation, a convolutional neural network (CNN) may be used for deep learning, where the input features of the sensing information and their relationship with the desired output values may be derived automatically. Thus, at the end of the training phase, the connectivity enhanced database **310** is generated that specifies the plurality of time-of-day specific uplink and downlink beam alignment-wireless connectivity relationships for the surrounding area of each of the plurality of edge devices **104** independent of the plurality of different WCNs **110**.

[0059] Alternatively, in some implementations, the processor **302** may be further configured to obtain processing chain parameters from the plurality of edge devices **104**. In an implementation, the processing chain parameters may be additional parameters treated as learning labels (e.g., supervised learning labels or unsupervised output values) in addition to the beam alignment information. In another implementation, for processing purposes, the processing chain parameters may be treated and processed similar to that of the beam alignment information. The processing chain parameters may be obtained for further exhaustive training and inference of the machine learning model **308**.

[0060] The processing chain parameters includes information associated with elements of the first plurality of signal processing chains **208** and the second plurality of signal processing chains **212** (which includes one or more cascaded receiver chains and one or more cascaded transmitter chains) of each edge device, radio blocks information, and modem information of the plurality of edge devices **104**. The central cloud server **102** may be configured such that it has access to certain defined elements or all elements of the first plurality of signal processing chains **208** and the second plurality of signal processing chains **212**. The central cloud server **102** may be configured to securely access, monitor, and configure the information associated with such elements of the first plurality of signal processing chains **208** and the second plurality of signal processing chains **212** of each edge device to optimize each radio blocks and overall radio frequency signals, such as 5G signals. In an example, the central cloud server **102** may be further configured to access a Serial Peripheral Interface (SPI) between a modem and the radio (e.g., the front-end RF section) of each of the plurality of edge devices **104**. The SPI may be a full-duplex bus interface used to send data between the control section **204** (e.g., a microcontroller or DSP) and other peripheral components, such as the modem, for example, a 5G modem, in an edge device. The SPI interface supports very high speeds and throughput and is suitable for handling a lot of data. In an example, the processing chain parameters may be accesses using access to the SPI.

[0061] In a first example, the central cloud server **102** may remotely access elements of the one or more signal processing chains, like the set of phase shifters, and utilize that, for example, to train the machine learning model **308**, and optimize every block of an RF signal including phase (e.g., can control the phase-shifting), etc. In a second example, the central cloud server **102** may remotely access information associated with elements, such as a set of LNAs to train the machine learning model **308**, and utilize that information, for example, to learn and control amplification of input RF

signals received by an antenna array, such as the one or more first antenna arrays **314** or the one or more second antenna arrays **316**, in order to amplify input RF signals, which may have low-power, without significantly degrading corresponding signal-to-noise (SNR) ratio in the inference phase. In a third example, the central cloud server **102** may remotely access information (e.g., phase values of the input RF signals) associated with elements, such as a set of phase shifters, to train the machine learning model **308** and control adjustment in phase values of the input RF signals, till combined signal strength value of the received input RF signals, is maximized to design beams in the inference phase. In a fourth example, the central cloud server **102** may be configured to train the machine learning model **308** with parameters (e.g., amplifier gains and phase responses) associated with the one or more first antenna arrays **314** or the one or more second antenna arrays **316**, and later use learnings in the inference phase to send control signals to remotely configure or control such parameters. In a fifth example, the central cloud server **102** may be configured to access beamforming coefficients from elements of the one or more signal processing chains to train the machine learning model **308** and use such learnings to configure, control, and adjust beam patterns to and from each of the plurality of edge devices **104**. In a sixth example, since the central cloud server **102** has information associated with elements of one or more cascaded receiver chains and one or more cascaded transmitter chains of each edge device, the central cloud server **102** may configure dynamic partitioning of a plurality of antenna elements of an antenna array into a plurality of spatially separated antenna sub-arrays to generate multiple beams in different directions at the same time or in a different time slot. In a seventh example, since the central cloud server **102** has information associated with elements of one or more cascaded receiver chains and one or more cascaded transmitter chains of each edge device, the central cloud server **102** may configure and instruct an edge device for a suitable adjustment of a power back-off to minimize (i.e., substantially reduce) the impact of interference (echo or noise signals) and hence only use as much power as needed to achieve low error communication with one or more base stations in the uplink or the one or more UEs **106** in the downlink communication. In accordance with an embodiment, the central cloud server **102** may be further configured to configure, monitor, and provide management, monitoring, and configuration services to, various layers of each of the plurality of edge devices **104** to optimize blocks of radio and perform Radio access network optimization to improve coverage, capacity and/or service quality.

[0062] Similar to the correlation of the obtained sensing information and the beam alignment information, the processor **302** may be further configured to correlate the processing chain parameters with that of the obtained sensing information and the beam alignment information for different times-of-day such that the connectivity enhanced database **310** is updated and includes further learned information at holistic level for a plurality of different geographical areas associated with the plurality of different WCNs **110**. The correlation further improves QoE and indicates that for a given set of input features extracted from the sensing information, it provides insights as to what were the processing chain parameters when there was most suitable (i.e., best) initial access information for a given edge device according to its position to service one or more UEs in its surrounding area, and hence it allows optimal management of network resources including the plurality of edge devices **104** in the inference phase.

[0063] FIG. **4** is a first exemplary scenario for implementation of the edge device, the central cloud server, and the method for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure. FIG. **4** is explained in conjunction with elements from FIGS. **1**, **2**, and **3**. With reference to FIG. **4**, there is shown a first exemplary scenario **400**. The first exemplary scenario **400** includes a 5G-enabled repeater device, hereinafter simply referred to as a repeater device **402**, a first user **404**A carrying a first smartphone **406**A, and a second user **404**B carrying a second smartphone **406**B.

[0064] In accordance with the first exemplary scenario **400**, the repeater device **402** corresponds to the edge device **104**A, the first smartphone **406**A corresponds to the first UE **106**A and the second

smartphone **406**B corresponds to the second UE **106**B (FIGS. **1**, **2**A, and **2**B). The first smartphone **406**A may be in a building **410** (e.g., a home, an office, or an industrial area) and may be subscribed to the first WCN **110**A and serviced by a first base station (not shown) of the first WCN **110**A. However, due to inadequate data throughput and signal strength from the first base of the first WCN **110**A, the first user **404**A may provide an input via an application interface of a preinstalled application in the first smartphone **406**A to communicate a first connection request to the repeater device **402** over a Wi-Fi communication channel, in an example. The repeater device **402** may be configured to obtain a wireless connectivity enhanced information (that includes a best or optimal initial access information) for the first smartphone **406**A from the central cloud server **102** in order to bypass an initial access search on the repeater device **402** and become attached to the first base station of the first WCN **110**A in a first 5G NR carrier frequency. The repeater device **402** may be further configured to service the first smartphone **406**A via a first beam of RF signal **408**A associated with the first WCN **110**A in the first 5G NR carrier frequency. Thus, the first smartphone **406**A may be able to execute uplink and downlink communication in the first WCN **110**A via the repeater device **402**.

[0065] In the first exemplary scenario **400**, the second user **404**B carrying the second smartphone **406**B may arrive in the building **410** but may be subscribed to the second WCN **110**B, where the second smartphone **406**B in the building may not receive adequate coverage or signal strength from a second base station of the second WCN **110**B. The repeater device **402** may be further configured to receive a second connection request from the second smartphone **406**B, associated with the second WCN **110**B. The second connection request may be received based on a user-input (a gesture input, a voice input, or a touch input, or an authentication key) provided to the second smartphone **406**B (detected by an application installed in the second smartphone **406**B). Alternatively, the second connection request may be automatically sent based on the current location of the second smartphone **406**B and its association with the second WCN **110**B detected by the central cloud server **102** (or the repeater device **402**). The repeater device **402** may be further configured to obtain wireless connectivity enhanced information (that includes a best or optimal initial access information) for the second smartphone **406**B for its current location from the central cloud server **102**. The wireless connectivity enhanced information may be received in order to bypass the initial access search on the repeater device **402** and get attached to the second base station of the second WCN **110**B in a second 5G NR carrier frequency. The bypassing of the initial access search on the repeater device **402** significantly reduces signaling overhead of network by avoiding many of such standard beam management operations without any adverse impact and still maintain QoE with high reliability and consistency. The repeater device **402** may be further configured to concurrently direct the first beam of RF signal **408**A in the first WCN **110**A (of a first service provider) to the first smartphone **406**A and a second beam of RF signal **408**B in the second WCN **110**B (of a second service provider) to the second smartphone **406**B based on the obtained connectivity enhanced information for the first smartphone **406**A and the second smartphone **406**B. The first beam of RF signal **408**A may carry a first payload of a first data stream associated with the first WCN **110**A to the first smartphone **406**A and the second beam of RF signal **408**B may carry at least one of a second payload of a second data stream associated with the second WCN **110**B to the second smartphone **406**B or a null payload associated with the second WCN **110**B to the second smartphone **406**B. Advantageously, the repeater device **402** that acts as an edge device is independent of the plurality of different WCNs **110** and can handle services for multiple service providers to ensure seamless connectivity and increase QoE.

[0066] FIG. **5** is a second exemplary scenario for implementation of the edge device, the central cloud server, and the method for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure. FIG. **5** is explained in conjunction with elements from FIGS. **1**, **2**, **3**, and **4**. With reference to FIG. **5**, there is shown a second exemplary scenario **500**. The second exemplary scenario **500** includes a

5G-enabled road-side unit (RSU), hereinafter simply referred to as an RSU **502** that can concurrently handle services of multiple service providers, a first gNB **504**A associated with the first WCN **110**A of a first service provider, and a second gNB **504**B associated with the second WCN **110**B of a second service provider. There is further shown a road portion on which a first vehicle **506**A and a second vehicle **506**B may be in motion.

[0067] In the second exemplary scenario **500**, the RSU **502** corresponds to the edge device **104**A, the first vehicle **506**A corresponds to the first UE **106**A and the second vehicle **506**B corresponds to the second UE **106**B (FIGS. **1**, **2**A, and **2**B). In an implementation, each of the first vehicle **506**A and the second vehicle **506**B may correspond to a 5G-enabled UE controlled by the central cloud server **102** and may have an application installed in it (e.g., installed in an in-vehicle infotainment system) which is communicatively coupled to the central cloud server **102** to receive its services. In operation, the RSU **502** may be configured to receive a first connection request from the first vehicle **506**A associated with the first WCN **110**A of the first service provider and a second connection request from the second vehicle **506**B associated with the second WCN **110**B of the second service provider. The RSU **502** may be further configured to obtain wireless connectivity enhanced information for the first vehicle **506**A and the second vehicle **506**B from the central cloud server **102** (FIGS. **1** and **3**). Based on the obtained wireless connectivity enhanced information, the RSU **502** may be further configured to receive a first donor beam **508**A from the first gNB **504**A of the first WCN **110**A and a second donor beam **508**B from the second gNB **504**B of the second WCN **110**B. Thereafter, the RSU **502** may be further configured to concurrently direct a first beam of RF signal **510**A in the first WCN **110**A to the first vehicle **506**A and a second beam of RF signal **510**B in the second WCN **110**B to the second vehicle **506**B based on the obtained connectivity enhanced information for the first vehicle **506**A and the second vehicle **506**B. Thus, a single edge device, such as the RSU **502** in this case, is able to service multiple UEs in motion associated with different service providers, thereby reducing (i.e., optimizing) the total number of network nodes for each service provider required to be deployed or used in one or more geographical areas. Further, the RSU **502**, by virtue of handling services of multiple service providers at the same time, ensures seamless connectivity as well as QoE while significantly reducing the infrastructure cost.

[0068] FIG. **6** is a flowchart that illustrates an exemplary method for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure. FIG. **6** is explained in conjunction with elements from FIGS. **1**, **2**A, **2**B, **3**, **4**, and **5**. With reference to FIG. **6**, there is shown a flowchart **600** comprising exemplary operations **602** through **610**. The operations of the method depicted in the flowchart **600** may be implemented in the edge device **104**A (FIG. **2**A).

[0069] At **602**, a first connection request may be received from the first UE **106**A associated with the first WCN **110**A of a first service provider. The control circuitry **214** may be configured to receive the first connection request from the first UE **106**A associated with the first WCN **110**A. In an example, the connection request may be received via an out-of-band communication, such as WI-FI™, BLUETOOTH™, Li-Fi, a sidelink request (e.g., LTE sidelink, 5G New Radio (NR) sidelink, NR C-V2X sidelink), a vehicle-to-infrastructure (V2I) request, a personal area network (PAN) connection, or other out-of-band connection requests. The first UE **106**A may be identified as a priority user based on the connection request in order to prioritize servicing the first UE **106**A.

[0070] At **604**, a second connection request may be received from the second UE **106**B associated with the second WCN **110**B of a second service provider. The control circuitry **214** may be further configured to receive the second connection request from the second UE **106**B associated with the second WCN **110**B of the second service provider. In some implementations, a corresponding activation signal may be obtained from each of the first UE **106**A and the second UE **106**B, where the corresponding activation signal is generated at the first UE **106**A and the second UE **106**B using at least one of the application installed in the first UE **106**A and the second UE **106**B, an authentication key, or a registered gesture. Thereafter, the edge device **104**A may be activated to

service the first UE **106**A and the second UE **106**B based on an authentication of the corresponding activation signal. In some implementations, such corresponding activation signal from each of the first UE **106**A and the second UE **106**B may be a part of the first connection request and second connection request, respectively.

[0071] At **606**, wireless connectivity enhanced information may be received for the first UE **106**A and the second UE **106**B from the central cloud server **102**. In some implementations, the wireless connectivity enhanced information may be obtained from the central cloud server **102** based on a position of the edge device **104**A, where the wireless connectivity enhanced information provided by the central cloud server **102** for the first UE **106**A and the second UE **106**B includes selected initial access information to accelerate a UE-specific beam alignment for each of the first UE **106**A and the second UE **106**B and connectivity to one or more base stations from the edge device **104**A bypassing an initial access-search on the edge device **104**A. The control circuitry **214** may be further configured to obtain wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B from the central cloud server **102**.

[0072] At **608**, a first donor beam may be received from the first base station **108**A and a second donor beam may be received from the second base station **108**B. The control circuitry **214** may be further configured to receive the first donor beam from the first base station **108**A and the second donor beam from the second base station **108**B. In some implementations, the first donor beam may be directly received from the first base station **108**A, whereas the second donor beam associated with the second base station **108**B may be received from another edge device (such as the edge device **104**B) that is a part of a network of edge devices, such as the plurality of edge devices **104**.

[0073] At **610**, a first beam of radio frequency (RF) signal in the first WCN **110**A may be directed to the first UE **106**A, and a second beam of RF signal in the second WCN **110**B may be directed to the second UE **106**B based on the obtained connectivity enhanced information for the first UE **106**A and the second UE **106**B. In an implementation, the first beam of RF signal in the first WCN **110**A to the first UE **106**A and the second beam of RF signal in the second WCN **110**B to the second UE **106**B are concurrently directed from the edge device **104**A. In another implementation, the first beam of RF signal in the first WCN **110**A to the first UE **106**A and the second beam of RF signal in the second WCN **110**B to the second UE **106**B are alternatingly directed from the edge device **104**A. The control circuitry **214** may be further configured to direct the first beam of radio frequency (RF) signal in the first WCN **110**A to the first UE **106**A and a second beam of RF signal in the second WCN **110**B to the second UE **106**B based on the obtained connectivity enhanced information for the first UE **106**A and the second UE **106**B. In accordance with an embodiment, the first beam of RF signal carries a first payload of a first data stream associated with the first WCN **110**A to the first UE **106**A and the second beam of RF signal carry at least one of a second payload of a second data stream associated with the second WCN **110**B to the second UE **106**B or a null payload associated with the second WCN **110**B to the second UE **106**B.

[0074] FIG. **7** is a flowchart that illustrates an exemplary method for handling service for multiple service providers for high performance and reliable communication, in accordance with an embodiment of the disclosure. FIG. **7** is explained in conjunction with elements from FIGS. **1**, **2A**, **2B**, **3**, **4**, and **5**. With reference to FIG. **7**, there is shown a flowchart **700** comprising exemplary operations **702** to **706**. The operations of the method depicted in the flowchart **700** may be implemented in a cloud server, such as the central cloud server **102** (FIGS. **1** and **3**).

[0075] At **702**, sensing information of a surrounding area of the edge device **104**A may be obtained. The sensing information may be periodically or continually captured by the edge device **104**A and communicated to the central cloud server **102**. The processor **302** may be configured to obtain the sensing information of the surrounding area of the edge device **104**A.

[0076] At **704**, wireless connectivity enhanced information may be communicated to the edge device **104**A for the first UE **106**A and the second UE **106**B based a corresponding request from

the first UE **106**A and the second UE **106**B and a position of the edge device **104**A. The processor **302** may be further configured to communicate the wireless connectivity enhanced information to the edge device **104**A for the first UE **106**A and the second UE **106**B. The communication may be executed based on the corresponding request from the first UE **106**A and the second UE **106**B and the position of the edge device **104**A. In some implementations, the communication may be executed based on the obtained sensing information. For example, the processor **302** may be further configured to determine, based on the position information of the edge device **104**A, whether the handover is required, and if so, communicate the wireless connectivity enhanced information, including the specific initial access information to the edge device **104**A to bypass the initial access-search on the edge device **104**A.

[0077] At **706**, the edge device **104**A may be controlled to concurrently direct a first beam of radio frequency (RF) signal in the first WCN **110**A to the first UE **106**A, and a second beam of RF signal in the second WCN **110**B to the second UE **106**B in accordance with the wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B, bypassing an initial access-search on the edge device **104**A. The processor **302** may be further configured to control the edge device **104**A to concurrently direct the first beam of RF signal in the first WCN **110**A to the first UE **106**A and the second beam of RF signal in the second WCN **110**B to the second UE **106**B in accordance with the wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B.

[0078] Various embodiments of the disclosure may provide a non-transitory computer-readable medium having stored thereon, computer implemented instructions that when executed by a computer causes a communication apparatus to execute operations that include receiving a first connection request from the first UE **106**A associated with the first WCN **110**A of a first service provider. The operations further include receiving a second connection request from the second UE **106**B associated with the second WCN **110**B of a second service provider. The operations further include obtaining wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B from the central cloud server **102**. The operations further include directing a first beam of radio frequency (RF) signal in the first WCN **110**A to the first UE **106**A and a second beam of RF signal in the second WCN **110**B to the second UE **106**B based on the obtained connectivity enhanced information for the first UE **106**A and the second UE **106**B.

[0079] Various embodiments of the disclosure may provide a non-transitory computer-readable medium having stored thereon, computer implemented instructions that when executed by a computer causes the computer to execute operations that include communicating wireless connectivity enhanced information to the edge device **104**A for the first UE **106**A and the second UE **106**B based a corresponding request from the first UE **106**A and the second UE **106**B and a position of the edge device **104**A. The operations further include controlling the edge device **104**A to concurrently direct a first beam of radio frequency (RF) signal in the first WCN **110**A to the first UE **106**A and a second beam of RF signal in the second WCN **110**B to the second UE **106**B in accordance with the wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B, bypassing an initial access-search on the edge device **104**A.

[0080] Various embodiments of the disclosure may be the edge device **104**A, for example, a relay device, a small cell, or a repeater device. The edge device **104**A comprises control circuitry **214** configured to receive a first connection request from the first UE **106**A associated with the first WCN **110**A of a first service provider. The control circuitry **214** may be further configured to receive a second connection request from the second UE **106**B associated with the second WCN **110**B of a second service provider. The control circuitry **214** may be further configured to obtain wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B from the central cloud server **102**. The control circuitry **214** may be further configured to direct a first beam of radio frequency (RF) signal in the first WCN **110**A to the first UE **106**A and a second beam of RF signal in the second WCN **110**B to the second UE **106**B based on the obtained

connectivity enhanced information for the first UE **106**A and the second UE **106**B.

[0081] In accordance with an embodiment, the edge device **104**A has the donor side **202**A facing towards the plurality of base stations **108** and the service side **202**B facing towards a plurality of UEs, and where each of the donor side **202**A and the service side **202**B of the edge device **104**A comprises a plurality of signal processing chains, where each signal processing chain of the plurality of signal processing chains is associated with one wireless carrier network to segregate an uplink and a downlink communication of RF signals from the first WCN **110**A with the second WCN **110**B, and where each of the plurality of signal processing chains at the donor side **202**A and the service side **202**B is controlled by the control circuitry **214**.

[0082] In accordance with an alternative embodiment, each of the donor side **202**A and the service side **202**B of the edge device **104**A comprises a signal processing chain configured to alternatively process RF signals from the first WCN **110**A and the second WCN **110**B in a switching pattern under the control of the control circuitry **214**.

[0083] Various embodiments of the disclosure may comprise the central cloud server **102** (FIG. **1**). The central cloud server **102** comprises the processor **302** configured to communicate wireless connectivity enhanced information to the edge device **104**A for the first UE **106**A and the second UE **106**B based a corresponding request from the first UE **106**A and the second UE **106**B and a position of the edge device **104**A. The processor **302** may be further configured to control the edge device **104**A to concurrently direct a first beam of radio frequency (RF) signal in the first WCN **110**A to the first UE **106**A and a second beam of RF signal in the second WCN **110**B to the second UE **106**B in accordance with the wireless connectivity enhanced information for the first UE **106**A and the second UE **106**B, bypassing an initial access-search on the edge device **104**A.

[0084] While various embodiments described in the present disclosure have been described above, it should be understood that they have been presented by way of example, and not limitation. It is to be understood that various changes in form and detail can be made therein without departing from the scope of the present disclosure. In addition to using hardware (e.g., within or coupled to a central processing unit ("CPU"), microprocessor, microcontroller, digital signal processor, processor core, system on chip ("SOC") or any other device), implementations may also be embodied in software (e.g., computer readable code, program code, and/or instructions disposed in any form, such as source, object or machine language) disposed for example in a non-transitory computer-readable medium configured to store the software. Such software can enable, for example, the function, fabrication, modeling, simulation, description and/or testing of the apparatus and methods describe herein. For example, this can be accomplished through the use of general program languages (e.g., C, C++), hardware description languages (HDL) including Verilog HDL, VHDL, and so on, or other available programs. Such software can be disposed in any known non-transitory computer-readable medium, such as semiconductor, magnetic disc, or optical disc (e.g., CD-ROM, DVD-ROM, etc.). The software can also be disposed as computer data embodied in a non-transitory computer-readable transmission medium (e.g., solid state memory any other non-transitory medium including digital, optical, analog-based medium, such as removable storage media). Embodiments of the present disclosure may include methods of providing the apparatus described herein by providing software describing the apparatus and subsequently transmitting the software as a computer data signal over a communication network including the internet and intranets.

[0085] It is to be further understood that the system described herein may be included in a semiconductor intellectual property core, such as a microcontroller (e.g., embodied in HDL) and transformed to hardware in the production of integrated circuits. Additionally, the system described herein may be embodied as a combination of hardware and software. Thus, the present disclosure should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

Claims

1. An edge device, comprising: a processor configured to: obtain sensing information of a surrounding area of the edge device from one or more external sensing devices in a communication range of the edge device; communicate the sensing information to a central cloud server; obtain wireless connectivity enhanced information from the central cloud server based on the communicated sensing information, wherein the wireless connectivity enhanced information is for a first user equipment (UE) and a second UE; and direct a first beam of radio frequency (RF) signal in a first wireless carrier network to the first UE and a second beam of RF signal in a second wireless carrier network to the second UE based on the obtained wireless connectivity enhanced information for the first UE and the second UE.

2. The edge device according to claim 1, wherein the one or more external sensing devices comprise at least one of: a Lidar, a camera, an accelerometer, a Global Navigation Satellite System (GNSS), a gyroscope, or an Internet-of-Things (IoT) device.

3. The edge device according to claim 1, wherein the processor is further configured to reduce, based on the obtained wireless connectivity enhanced information, a time to align to a timing offset of a beam reception at the edge device to a frame structure of a 5G New Radio (NR) frame.

4. The edge device according to claim 1, wherein the first beam of RF signal in the first wireless carrier network to the first UE and the second beam of RF signal in the second wireless carrier network to the second UE are alternatingly directed from the edge device.

5. The edge device according to claim 1, wherein the first beam of RF signal in the first wireless carrier network to the first UE and the second beam of RF signal in the second wireless carrier network to the second UE are directed concurrently from the edge device.

6. The edge device according to claim 1, wherein the processor is further configured to form, based on the obtained wireless connectivity enhanced information, specific beam patterns specific to the first UE and the second UE.

7. The edge device according to claim 1, wherein the sensing information comprises at least one of: a position of the edge device, locations of the first UE and the second UE, moving directions of the first UE and the second UE, a time-of-day, traffic information, road information, construction information, or traffic light information.

8. The edge device according to claim 1, wherein the sensing information further comprises weather information, and the processor is further configured to select beam configurations for the first beam and the second beam based on the weather information.

9. The edge device according to claim 1, wherein the sensing information further comprises information about reflective objects and signal blocking objects in the surrounding area of the edge device.

10. The edge device according to claim 1, wherein the processor is further configured to execute, based on the obtained wireless connectivity enhanced information, a dynamic partitioning of a plurality of antenna elements of an antenna array at a service side into a plurality of spatially separated antenna sub-arrays.

11. The edge device according to claim 1, wherein the processor is further configured to adjust, based on the obtained wireless connectivity enhanced information, a power back-off to minimize an interference in a downlink communication with the first UE and the second UE.

12. A method for an edge device, the method comprising: obtaining, by the edge device, sensing information of a surrounding area of the edge device from one or more external sensing devices in a communication range of the edge device; communicating, by the edge device, the sensing information to a central cloud server; obtaining, by the edge device, wireless connectivity enhanced information from the central cloud server based on the communicated sensing information, wherein the obtained wireless connectivity enhanced information is for a first user equipment (UE) and a

second UE; and directing, by the edge device, a first beam of radio frequency (RF) signal in a first wireless carrier network to the first UE and a second beam of RF signal in a second wireless carrier network to the second UE based on the obtained wireless connectivity enhanced information for the first UE and the second UE.

13. The method according to claim 12, wherein the one or more external sensing devices comprise at least one of: a Lidar, a camera, an accelerometer, a Global Navigation Satellite System (GNSS), a gyroscope, or an Internet-of-Things (IoT) device.

14. The method according to claim 12, further comprising reducing, by the edge device, a time to align to a timing offset of a beam reception at the edge device to a frame structure of a 5G New Radio (NR) frame based on the obtained wireless connectivity enhanced information.

15. The method according to claim 12, wherein the first beam of RF signal in the first wireless carrier network to the first UE and the second beam of RF signal in the second wireless carrier network to the second UE are alternatingly directed from the edge device.

16. The method according to claim 12, wherein the first beam of RF signal in the first wireless carrier network to the first UE and the second beam of RF signal in the second wireless carrier network to the second UE are directed concurrently from the edge device.

17. The method according to claim 12, further comprising forming, by the edge device, specific beam patterns specific to the first UE and the second UE based on the obtained wireless connectivity enhanced information.

18. The method according to claim 12, wherein the sensing information comprises at least one of: a position of the edge device, locations of the first UE and the second UE, moving directions of the first UE and the second UE, a time-of-day, weather information, traffic information, road information, construction information, or traffic light information.

19. The method according to claim 18, further comprising selecting, by the edge device, beam configurations for the first beam and the second beam based on the weather information.

20. The method according to claim 12, wherein the sensing information further comprises information about reflective objects and signal blocking objects in the surrounding area of the edge device.