United States Patent	12388722
Kind Code	B2
Date of Patent	August 12, 2025
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Multi-cloud data center architectures for providing network functions in telecommunications networks

Abstract

Data center architectures for providing Network Functions (NFs) in telecommunications networks are disclosed. A 5G or 6G wireless service provider with an existing 5G or 6G core network in one or more clouds can add several NFs in another cloud to optimize certain service(s). These NFs may already exist in the core, but for different services. A 4G Long Term Evolution (LTE) customer could also incrementally migrate to a public cloud rather than migrating all NFs at once.

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Appl. No.: **18/395022**

Filed: **December 22, 2023**

Prior Publication Data

Document Identifier	Publication Date
US 20250211500 A1	Jun. 26, 2025

Publication Classification

Int. Cl.: **H04L41/40** (20220101)

U.S. Cl.:

CPC **H04L41/40** (20220501);

Field of Classification Search

CPC: H04L (41/40)

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Background/Summary

FIELD

(1) The present invention generally relates to communications, and more specifically, to multi-cloud data center architectures for providing Network Functions (NFs) in telecommunications networks.

BACKGROUND

(2) A variety of cloud service providers exist that provide cloud platforms for hosting various applications. However, these cloud providers have different capabilities. Accordingly, an improved and/or alternative approach may be beneficial.

SUMMARY

(3) Certain embodiments of the present invention may provide solutions to the problems and needs in the art that have not yet been fully identified, appreciated, or solved by current communications technologies, and/or provide a useful alternative thereto. For example, some embodiments of the present invention pertain to multi-cloud data center architectures for providing NFs in telecommunications networks.

(4) In an embodiment, a multi-cloud system for providing telecommunications services includes one or more computing systems of a first cloud system hosting one or more respective NFs and one or more computing systems of a second cloud system hosting one or more respective NFs. The multi-cloud system also includes a Network Repository Function (NRF) hosted by at least one computing system of the one or more computing systems of the first cloud system, at least one computing system of the one or more computing systems of the second cloud system, or one or more other computing systems that are not a part of the first cloud system or the second cloud system. The NRF manages the one or more NFs of the first cloud system and the second cloud system, respectively. The one or more respective NFs of the first cloud system and the one or more respective NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the first cloud computing system and the second cloud

computing system.
(5) In another embodiment, a multi-cloud for providing telecommunications services includes one or more computing systems of a first cloud system hosting one or more respective NFs and one or more computing systems of a second cloud system hosting one or more respective NFs. The multi-cloud system also includes a NRF hosted by at least one computing system of the one or more computing systems of the first cloud system, at least one computing system of the one or more computing systems of the second cloud system, or one or more other computing systems that are not a part of the first cloud system or the second cloud system. The NRF manages the one or more NFs of the first cloud system and the second cloud system, respectively. The one or more respective NFs of the first cloud system, the one or more respective NFs of the second cloud system, or both, are containerized NFs (CNFs) or virtual NFs (VNFs) implemented by a platform for automating deployment, scaling, and management of containerized applications.
(6) In yet another embodiment, a multi-cloud system includes one or more computing systems of a first cloud system hosting one or more respective NFs. The multi-cloud system also includes one or more computing systems of a second cloud system hosting one or more respective NFs, one or more Network Exposure Functions (NEFs) configured to expose respective NFs of the one or more respective NFs of the first cloud system to external applications, and one or more Application Programming Interfaces (APIs) configured to call the one or more NEFs. The multi-cloud system further includes an NRF hosted by at least one computing system of the one or more computing systems of the first cloud system, at least one computing system of the one or more computing systems of the second cloud system, or one or more other computing systems that are not a part of the first cloud system or the second cloud system. The NRF manages the one or more NFs of the first cloud system and the second cloud system, respectively. The one or more respective NFs of the first cloud system and the one or more respective NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the first cloud computing system and the second cloud computing system. The one or more respective NFs of the first cloud system, the one or more respective NFs of the second cloud system, or both, are CNFs or VNFs implemented by a platform for automating deployment, scaling, and management of containerized applications.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) In order that the advantages of certain embodiments of the invention will be readily understood, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments that are illustrated in the appended drawings. While it should be understood that these drawings depict only typical embodiments of the invention and are not therefore to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings, in which:
(2) FIG. **1** is an architectural diagram illustrating a multi-cloud system where some NFs are hosted in one cloud and other NFs are hosted in another cloud, according to an embodiment of the present invention.
(3) FIG. **2** is an architectural diagram illustrating a multi-cloud system where a 5G provider uses two clouds for different NFs and an enterprise has its own core for some services, according to an embodiment of the present invention.
(4) FIG. **3** is an architectural diagram illustrating a multi-cloud system where an enterprise uses a high Quality of Service (QOS) and/or security cloud for certain services and a 5G provider cloud for other services, according to an embodiment of the present invention.
(5) FIG. **4** is an architectural diagram illustrating a multi-cloud system where a 5G provider

exposes its 5G core network to enterprises through Network Exposure Functions (NEFs), according to an embodiment of the present invention.
(6) FIG. **5**A is an architectural diagram illustrating an architecture for network event monitoring, according to an embodiment of the present invention.
(7) FIG. **5**B is an architectural diagram illustrating an architecture for data provisioning from external applications, according to an embodiment of the present invention.
(8) FIG. **5**C is an architectural diagram illustrating an architecture for policy control from external applications, according to an embodiment of the present invention.
(9) FIG. **6** is an architectural diagram illustrating a multi-cloud system where a 5G provider offers Location as a Service (LaaS) in a different cloud than another services, according to an embodiment of the present invention.
(10) FIG. **7** is an architectural diagram illustrating a telecommunications system, according to an embodiment of the present invention.
(11) FIG. **8** is a flow diagram illustrating a process for providing MEC in one cloud and providing other NFs another cloud, according to an embodiment of the present invention.
(12) FIG. **9** is a flow diagram illustrating a process for providing certain NFs in two clouds where an enterprise has its own core, according to an embodiment of the present invention.
(13) FIG. **10** is a flow diagram illustrating a process for providing a high QoS and/or security cloud and a 5G provider core network cloud, according to an embodiment of the present invention.
(14) FIG. **11** is aa flow diagram illustrating a process for providing a multi-cloud system where a 5G provider exposes its 5G core network to enterprise applications through APIs, according to an embodiment of the present invention.
(15) FIG. **12** is a flow diagram illustrating a process for providing LaaS in one cloud and other 5G services in another cloud, according to an embodiment of the present invention.
(16) FIG. **13** is an architectural diagram illustrating a computing system configured to participate in a multiple data center architecture for providing NFs in telecommunications networks, according to an embodiment of the present invention.
(17) FIG. **14** is a flowchart illustrating a process for providing multi-cloud telecommunications services, according to an embodiment of the present invention.
(18) Unless otherwise indicated, similar reference characters denote corresponding features consistently throughout the attached drawings.

DETAILED DESCRIPTION OF THE EMBODIMENTS

(19) Some embodiments pertain to multi-cloud data center architectures for providing NFs in telecommunications networks. A 5G or Sixth Generation (6G) wireless service provider with an existing 5G or 6G core network in one or more clouds can add several NFs in another cloud to optimize certain service(s). These NFs may already exist in the core, but for different services. A 4G Long Term Evolution (LTE) customer could also incrementally migrate to a public cloud rather than migrating all NFs at once.
(20) Currently in 5G, there is a shift to virtualization and containerization of NFs, microservices, cloud native, everything-as-a-service (XaaS), automation and orchestration, Continuous Integration and Continuous Delivery (CICD), automatic scaling (up and down), etc. This trend will likely continue into 6G and beyond. Also, artificial intelligence/machine learning (AI/ML) will be used in 5G Advance and 6G. This trend can provide flexibility, reduced time to market, lower total cost of ownership, and optimized network energy consumption for the service providers. Different public cloud providers offer different features and capabilities to differentiate themselves in this competitive market. A service provider can take advantage of multiple cloud provider offerings with different features to optimize network performance, services, energy consumption, and cost.
(21) Various NFs exist in telecommunications networks, such as User Plane Function data traffic (UPF-d), UPF for voice traffic (UPF-v), Short Message Service Function (SMSF), Session Management Function (SMF), Unified Data Repository (UDR), Internet Protocol (IP) Multimedia

Subsystem (IMS)+Telephone Answering Service (TAS), IP-SM Gateway (IP-SM-GW) (the network functionality that provides the messaging service in the IMS network), Enhanced Serving Mobile Location Center (E-SMLC) for former generation wireless networks, Gateway Mobile Location Center (GMLC), Location Retrieval Function (LRF), Location Management Function (LMF), Home Location Register (HLR), Home Subscriber Server (HSS), UPF+PGW-U, Access and Mobility Management Function (AMF), HSS+Unified Data Management (UDM), Authentication Server Function (AUSF), SMF+PGW-C, Short Message Service Center (SMSC), Policy Control Function (PCF), Mobile Edge Computing (MEC), Network Exposure Functions (NEFs) or Common API Framework (CAPIF) for Third Generation Partnership Project (3GPP) northbound APIs, Network Slice Selection Function (NSSF), Non-3GPP InterWorking Function (N3IWF), Network Data Analytics Function (NWDAF), Mediation and Delivery Function (MDF), Service Communication Proxy (SCP), Security Edge Protection Proxy (SEPP), etc. The Network Repository Function (NRF) is a repository of profiles of the NFs that are available in the network, including those provided by multiple data centers in some embodiments. In other words, the NRF can coordinate between the NFs of multiple clouds.

(22) The NRF is used appropriately for the management of NFs, service discovery and registration, and authorization. The purpose of the NRF is to allow a service consumer (e.g., an NF) to discover and select suitable service producers (i.e., NFs and NF services) without having to be configured beforehand. The NRF keeps a repository of the available NF instances and their exposed service instances. The repository is maintained dynamically by NF producers registering their so-called NF profile in the NRF. This, in turn, enables the NFs to discover other available NF instances, their service instances, and status dynamically. If one NF requires the services of another NF, it communicates with the NRF to find the other NF and communicate therewith. In other words, the NRF facilitates service discovery. The NF profile contains relevant data pertaining to the respective NF.

(23) When a new instance of an NF is deployed or an existing instance is changed (e.g., due to scaling), the NRF is updated with the new profile information. The NRF can be updated by the NF itself or by another entity on behalf of the NF. There is also a keep alive mechanism that allows the NRF to maintain the repository and remove the profiles of missing or dormant NFs. The NF profile in the NRF contains information such as the NF type, address, capacity, supported NF services, and addresses for each NF instance. The information is provided to the NF service consumer in the discovery procedure and enough information for the service consumer to use the service-based interface of the selected NF and NF service. The NRF profile also contains authorization information, and the NRF only provides the profiles to a consumer that can discover the specific NF or service.

(24) Communications between NF services on the control plane typically occur via HyperText Transfer Protocol 2 (HTTP2) Representative State Transfer (REST)-ful APIs. An NF service includes operations that are based on a request-response or a subscribe-notify model. Services are modeled as resources that are provisioned or can be created, updated, or deleted using RESTful HTTP2-based procedures.

(25) Once an NF consumer has discovered NF producer instances, the NF consumer removes the NF producer instances that do not meet the desired service criteria (e.g., network slice, Data Network Name (DNN), etc.). From that smaller set, the NF consumer selects an NF producer instance, taking into account capacity, load, etc. If resources are created as part of a service request, the created resource is assigned a unique Uniform Resource Identifier (URI) pointing to the created resource.

(26) The NRF provides three services to allow NFs and NF services to discover, select, and connect to peer NFs and NF services with the correct capabilities. These services are: Nnrf_NFManagement, Nnrf_NFDiscovery, and Nnrf_AccessToken. Nnrf_NFManagement enables NFs to register and manage their NF services and capabilities in the NRF. Nnrf_NFDiscovery

allows NFs and NF services to discover other NFs and NF services that match the provided criteria. Nnrf_AccessToken allows the NFs to request Auth2.0 access tokens that can be used to access services from other NFs.
(27) In multi-cloud implementations, the NRF should be able to register NFs in these clouds and be accessible to the NFs in the different clouds so NFs in one cloud can find and utilize the services of NFs in another cloud. The NRF may be housed in a different location than the clouds or may be at the location of one of the clouds, but able to register/deregister services of NFs regardless of their location. This may be achieved using Nnrf_NFManagement_NFRegister and Nnrf_NFManagement_NFDeregister service operations, respectively.
(28) NFs in the cloud platforms may be grouped together in the same cluster (e.g., a Kubernetes® cluster) or hosted in separate clusters to minimize issues therebetween (e.g., due to configuration issues, memory leaks, etc.). NFs and/or clusters of NF groups could be located in different clouds to increase resiliency against problems with one of the sites. The NFs may be containerized NFs (CNFs) or virtual NFs at the microservice level.
(29) Kubernetes® may be used to provide a portable, extensible, open source platform for managing containerized workloads and services that facilitates both declarative configuration and automation. Containers are similar to Virtual Machines (VMs). However, they have relaxed isolation properties to share the Operating System (OS) among the applications. Therefore, containers are considered lightweight. Similar to a VM, a container has its own file system, a share of Central Processing Unit (CPU) resources, memory, process space, etc. Since containers are decoupled from the underlying infrastructure, they are portable across clouds and OS distributions.
(30) Kubernetes® runs workloads by placing containers into pods to run on nodes. A node may be a virtual machine or a physical machine, depending on the cluster design. Each node is managed by the control plane and contains the services necessary to run the pods. Typically, multiple nodes are included in a cluster.
(31) A pod is the smallest and simplest Kubernetes® object, representing one or more running containers on a cluster that have shared storage and network resources, as well as a specification for how to run the containers. The contents of a pod are co-located and co-scheduled, as well as run in a shared context. A pod models an application-specific “logical host”. It contains one or more application containers that are relatively tightly coupled. In non-cloud contexts, applications executed on the same physical or virtual machine are analogous to cloud applications executed on the same logical host. An example of a pod that consists of a container running the image dish:1.1.1 is provided below. apiVersion: v1 kind: Pod metadata: name: dish spec: containers: - name: dish image: dish: 1.1.1 ports: - containerPort: 80
(32) FIG. **1** is an architectural diagram illustrating a multi-cloud system **100** where some NFs are hosted in one cloud and other NFs are hosted in another cloud, according to an embodiment of the present invention. In this embodiment, a 5G provider has its complete 5G core NFs in cloud **120**. Cloud **120** provides control plane NFs including AMF, SMF, PCF, UDM, AUSF, UDR, NRF, and NEF (if used), as well as UPF for the user plane. Simply put, the control plane carries the signaling traffic and the user plane carries the user data (i.e., the content of the communications, such as voice and SMS, data, etc.).
(33) Here, the 5G provider decides to support MEC for an enterprise located at enterprise site **110** with very low latency service. However, the 5G provider does not have a data center in the same region as enterprise site **110**. In order to provide low latency MEC service, the 5G provider puts the MEC NFs in cloud **130**, which is more proximate to enterprise site **110** and has latency and Quality of Service (QOS) capabilities to meet the low latency requirements for MEC. Enterprise site **110** uses cloud **120** for control plane NFs and UPF for non-MEC services (e.g., Internet, voice, SMS, etc.), but uses cloud **130** for control plane and user plane NFs for MEC. Cloud **120** and cloud **130** exchange control plane information with respect to MEC services, when required.
(34) The MEC performs selection of a UPF relatively close to the mobile device and local UPF

reselection based on mobility events for the mobile device. The MEC also provides concurrent access to a local Data Network (DN) and central DN in a single Protocol Data Unit (PDU) session. The MEC further supports MEC requests for local traffic steering locally (per mobile device or a group of mobile devices), provides local UPF access to applications, provides delivery of mobile device mobility information to trigger UPF reselection, indicates Local Access Data Network (LADN) availability, provides an interface for information exposure towards MEC applications, and provides charging support for locally steered traffic.

(35) Consider the scenario where a 5G wireless provider is planning to support several private networks/enterprises. Such enterprises may have their own AMF, SMF, and UPF, or use a slice of the 5G provider. However, a specific cloud provider offers a lower cost and/or better performance to the 5G provider for certain services. The 5G provider decides to allocate specific control plane functions (e.g., UDM, UDR, and PCF) to this cloud for these enterprises.

(36) FIG. **2** is an architectural diagram illustrating a multi-cloud system **200** where a 5G provider uses two clouds for different NFs and an enterprise has its own core for some services, according to an embodiment of the present invention. Here, one enterprise site **210** completely uses the NFs of the 5G provider (i.e., cloud B **240** via cloud A **230** for UDM, AUSF, UDR, and PCF and cloud A **230** for all other NFs). However, another enterprise site **220** uses a core **250** of that enterprise for AMF, SMF, UPF, and radio. Enterprise site **220** uses the 5G provider for the remaining NFs (i.e., cloud B **240** for UDM, AUSF, UDR, and PCF and cloud A **230** via cloud B **240** for all other NFs not hosted in enterprise core **250** or cloud B **240**). However, it should be noted that any sets of NFs may be provided by cloud A **230** and cloud B **240** without deviating from the scope of the invention.

(37) In some cases, a certain cloud provider may support a better QoS and/or security features than one currently used by a 5G provider. A certain enterprise needs a high level of performance and/or security for specific services and is willing to pay for this higher performance and/or security. FIG. **3** is an architectural diagram illustrating a multi-cloud system **300** where an enterprise uses a high QoS and/or security cloud for certain services and a 5G provider cloud for other services, according to an embodiment of the present invention. In this scenario, enterprise site **310** uses cloud B **330** only for the services that require high QoS and/or high security. For QoS, UDR/UDM, SMF, UPF, Deep Packet Inspection (DPI), PCF, and NEF(s)/API(s) are involved. For security, SMF, UPF, DPI, and NEF(s)/API(s) are involved. Enterprise site **310** uses 5G provider cloud A **310** for all other services (e.g., due to a lower cost than cloud B **330**). As such, enterprise site **310** can use cloud A **320** for “ordinary” services, such as voice, Internet, etc.

(38) In some cases, a 5G provider may decide to expose its 5G core network to enterprises through the Network Exposure Function (NEF) (or CAPIF). The NEF supports interaction with external applications, exposing network capabilities that can be used in various ways by these applications. Some functions that may be available via the NEF provide monitoring network events associated with mobile devices, provisioning, and policy and charging control. CAPIF is a set of specifications from 3GPP to standardize some common capabilities exposed by 5G core network northbound APIs that provide a unified and standardized northbound API framework across several 3GPP functions, allowing for the utilization of 5G capabilities exposed on 5G networks. NEF and CAPIF can be used by enterprises for their specific target services.

(39) FIG. **4** is an architectural diagram illustrating a multi-cloud system **400** where a 5G provider exposes its 5G core network to enterprises through NEFs, according to an embodiment of the present invention. Enterprise applications **410**, **412**, . . . , **414** are able to call enterprise APIs on cloud B **430** via the Internet **420**. Cloud B **430** also hosts NEFs (or CAPIFs) in this embodiment. The enterprise APIs make calls to the NEFs/CAPIFs, which, in turn, communicate with the appropriate NFs on 5G provider cloud A **440**. Cloud A **440** communicates with mobile devices **460**, **462**, . . . , **464** via a Radio Access Network (RAN) **450**. In this embodiment, Cloud B **430** is the better option for the 5G operator to enterprises to place the NEF/CAPIF and for the enterprises to

place their APIs. This may be due to proximity, latency, cost, etc. It should be noted that various AF/NEF/CAPIF functions may be implemented using the architecture of FIG. **4**, such as those shown in FIGS. **5**A-C.

(40) Different NEFs/CAPIFs may support different capabilities, have different capacities, etc. One enterprise may pay more to support specific feature(s), so they will be mapped to a better NEF/CAPIF. Another enterprise may be satisfied with basic features, and thus is not willing to pay more to use a more expensive NEF/CAPF.

(41) FIG. **5**A is an architectural diagram illustrating an architecture **500** for network event monitoring, according to an embodiment of the present invention. An external enterprise application **561** monitors network events associated with mobile devices **510**, **512**, . . . , **524**. This monitoring may include whether mobile devices **510**, **512**, . . . , **524** are reachable, what their locations are, whether they are roaming, etc. monitoring application **561** calls AFs **560** that instructs an NEF **550** to retrieve this information from AMF **530** and UDM **540** via a Radio Access Network (RAN) (i.e., New Radio in 5G).

(42) FIG. **5**B is an architectural diagram illustrating an architecture **502** for data provisioning from external applications, according to an embodiment of the present invention. In this embodiment, a provisioning application **563** provisions information into the network via AF **562** that applies to mobile devices **510**, **512**, . . . , **524**. This information may pertain to expected device mobility patterns, for example, which can be used by AMF **530** to instruct RAN **520** tune certain settings, such as how to minimize state changes for mobile devices **510**, **512**, . . . , **524** to optimize overall network signaling capacity.

(43) FIG. **5**C is an architectural diagram illustrating an architecture **504** for policy control from external applications, according to an embodiment of the present invention. A policy control application **565** can use AF **564** and NEF **550** to control various aspects of data sessions, such as influencing traffic routing to influence when and how local breakout routing should be applied for certain devices. Also QoS and charging policies can be controlled and enforced by policy control application **565** via NEF **550**, providing information about the data traffic. For such functionality, NEF **550** interacts with a PCF **580**, which determines QoS and charging information based on application information provided by AF **564** and NEF **550**.

(44) Alternatively, support may be provided for negotiation of transfer policies for future background data transfer. NEF **550** may support allowing policy control application **565** to define background templates used in a UPF **590** to detect that certain traffic is related to specific external application traffic. NEF **550** may interact with an SMF **570** to achieve this, and SM **570** forwards these templates to UPF **590**.

(45) FIG. **6** is an architectural diagram illustrating a multi-cloud system **600** where a 5G provider offers Location as a Service (LaaS) in a different cloud than another services, according to an embodiment of the present invention. LaaS includes GMLC and LMF functions that are expensive. The 5G provider chooses to instantiate the LaaS NFs in cloud B **630** due to performance, capacity, cost, and/or any other key performance indicators (KPIs). Enterprise site **610** uses cloud B **630** for LaaS communications and cloud A **620** for all other NFs.

(46) LaaS supports two classes of positioning methods: CP and UP. Thus, the UP is connected to the LaaS for UP types of positioning. In some embodiments, the LaaS architecture supports both direct connection to an enterprise (e.g., enterprise site **610**) or indirectly through Cloud A **620**.

(47) FIG. **7** is an architectural diagram illustrating a telecommunications system **700**, according to an embodiment of the present invention. User equipment (UE) **710** (e.g., a mobile phone, a tablet, a laptop computer, etc.) communicates with a RAN **720**. RAN **720** sends communications to UE **710**, as well as from UE **710** into the core carrier network. In some embodiments, communications are sent to/from RAN **720** via a Performance Edge Data Center (PEDC) **730** to provide lower latency. However, in some embodiments, RAN **720** communicates directly with a Breakout Edge Data Center (BEDC) **740** or a Regional Data Center (RDC) **750**. BEDCs are typically smaller data

centers that are proximate to the populations they serve. BEDCs may break out User Plane Function data traffic (UPF-d) and provide cloud computing resources and cached content to UE **710**, such as providing NF application services for gaming, enterprise applications, etc. In certain embodiments, RAN **720** may include a Local Data Center (LDC) (not shown) that hosts one or more Distributed Units (DUs) in a 5G Open RAN (O-RAN) architecture. In some O-RAN embodiments, a centralized unit (CU) may be located at BEDC **740** or an LDC. LDCs, PEDCs, and/or BEDCs may provide MEC services in some embodiments.
(48) The carrier network may provide various NFs and other services. For instance, BEDC **740** may provide cloud computing resources and cached content to mobile device **710**, such as providing NF application services for gaming, enterprise applications, etc. An RDC **750** may provide core network functions, such as UPF-v, UPF-d (if not in PEDC **730** or BEDC **740**, for example), SMF, and AMF functionality. The SMF includes PGW Control Plane (PGW-C) functionality. The UPF includes PGW User Data Plane (PGW-U) functionality.
(49) A National Data Center (NDC) **760** may provide UDR and user verification services, for example. Other network services that may be provided may include, but are not limited to, IMS+TAS, IP-SM-GW (i.e, the network functionality that provides the messaging service in the IMS network), E-SMLC, GMLC, LRF, LMF, HLR, HSS, UDM, AUSF, UDR, SMSC, PCF, NEF, NRF, NSSF, SCP, and/or SEPP functionality. It should be noted that additional and/or different network functionality may be provided without deviating from the present invention. The various functions in these systems may be performed using dockerized clusters in some embodiments.
(50) BEDC **740** may utilize other data centers for NF authentication services. RDC **750** receives NF authentication requests from BEDC **740**. RDC **750** may help with managing user traffic latency, for instance. However, RDC **750** may not perform NF authentication in some embodiments.
(51) From RDC **750**, NF authentication requests may be sent to NDC **760**, which may be located far away from UE **710**, RAN **720**, PEDC **730**, BEDC **740**, and RDC **750**. NDC **760** may provide a UDR, and user verification may be performed at NDC **760**. Enterprise cloud platforms **770** may host certain NFs themselves. In such embodiments, PEDC **730**, BEDC **740**, RDC **750**, and/or NDC **760** may communicate with enterprise platforms (e.g., to allow NFs in enterprise cloud platforms to access services provided by NFs in the carrier network). The NRF may be located on computing systems of PEDC **730**, BEDC **740**, RDC **750**, and/or NDC **760**, and may expose carrier NFs to those of enterprise cloud platforms **770**.
(52) FIG. **8** is a flow diagram illustrating a process **800** for providing MEC in one cloud and providing other NFs another cloud, according to an embodiment of the present invention. A core network cloud **830** is used by mobile computing systems of an enterprise site **810** for most NFs. However, the computing systems of enterprise site **810** use an MEC cloud **820** for MEC NFs. The MEC NFs in MEC cloud **820** look up NF services in core cloud **830** using an NRF. The MEC NFs determine the appropriate NF service instances, access these NF service instances, and receive responses therefrom (e.g., with the requested information). The MEC NFs then provide pertinent information to computing systems of enterprise site **810**.
(53) FIG. **9** is a flow diagram illustrating a process **900** for providing certain NFs in two clouds where an enterprise has its own core, according to an embodiment of the present invention. Computing systems of a first enterprise site **950** use carrier core network cloud A **940** and carrier core network cloud B **930** for all NFs. In this case, carrier core network cloud B **930** provides UDM, AUSF, UDR, and PCF and carrier core network cloud A **940** provides all other NFs. However, it should be noted that any sets of NFs may be provided by carrier core network cloud A **940** and carrier core network cloud B **930** without deviating from the scope of the invention.
(54) A second enterprise, however, has its own enterprise core **920** that provides certain NFs, such as AMF, SMF, UPF, and radio. Computing systems of second enterprise site **910** use enterprise core **920** for these services. However, for UDM, AUSF, UDR, and PCF, enterprise core **920** uses carrier

core network cloud B **930** and for other NFs, enterprise core **920** uses carrier core network cloud A **940**.

(55) FIG. **10** is a flow diagram illustrating a process **1000** for providing a high QoS and/or security cloud and a 5G provider core network cloud, according to an embodiment of the present invention. Computing systems of an enterprise site **1010** use a 5G provider core cloud **1030** for most services such as voice, Internet, etc. However, certain applications running on these computing systems require a higher QoS and/or a higher level of security. For these applications, the computing systems of enterprise site **1010** use a high performance and/or security cloud **1020**.

(56) FIG. **11** is a flow diagram illustrating a process for providing a multi-cloud system **1100** where a 5G provider exposes its 5G core network to enterprise applications through APIs, according to an embodiment of the present invention. The process begins with an enterprise application **1110** calling API(s) on cloud B **1130** via the Internet **1120**. The API(s) call one or more NEFs on cloud B **1130** exposed by the carrier. The NEF(s), in turn, interact with NFs of the carrier on core cloud A **1140** to perform the desired operations, such as monitoring, provisioning, policy control, etc.

(57) The NFs obtain the desired information or make the desired changes to mobile devices via a RAN **1150**. The NFs then inform the NEF(s) that the operations were completed and provide any requested information associated with the operations thereto. The NEF(s) pass this information to the API(s), and the API(s) inform the calling application that the operations were completed and provide any requested information.

(58) FIG. **12** is a flow diagram illustrating a process **1200** for providing LaaS in one cloud and other 5G services in another cloud, according to an embodiment of the present invention. Computing systems of enterprise site **1210** use NFs of a core network cloud **1230** for most services. However, for LaaS services such as GMLC and LMF, the computing systems of enterprise site **1210** use LaaS NFs in LaaS cloud **1220**. LaaS NFs communicate with NFs of core cloud **1230** for other NF services that may be required by the LaaS NFs.

(59) FIG. **13** is an architectural diagram illustrating a computing system **1300** configured to participate in a multiple data center architecture for providing NFs in telecommunications networks, according to an embodiment of the present invention. In some embodiments, computing system **1300** may be one or more of the computing systems depicted and/or described herein, such as an enterprise mobile device or other computing system, a server in a cloud, a computing system of a RAN, a user mobile device, another carrier network server or other type of computing system, etc. Computing system **1300** includes a bus **1305** or other communication mechanism for communicating information, and processor(s) **1310** coupled to bus **1305** for processing information. Processor(s) **1310** may be any type of general or specific purpose processor, including a Central Processing Unit (CPU), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), a Graphics Processing Unit (GPU), multiple instances thereof, and/or any combination thereof. Processor(s) **1310** may also have multiple processing cores, and at least some of the cores may be configured to perform specific functions. Multi-parallel processing may be used in some embodiments. In certain embodiments, at least one of processor(s) **1310** may be a neuromorphic circuit that includes processing elements that mimic biological neurons. In some embodiments, neuromorphic circuits may not require the typical components of a Von Neumann computing architecture.

(60) Computing system **1300** further includes memory **1315** for storing information and instructions to be executed by processor(s) **1310**. Memory **1315** can be comprised of any combination of random access memory (RAM), read-only memory (ROM), flash memory, cache, static storage such as a magnetic or optical disk, or any other types of non-transitory computer-readable media or combinations thereof. Non-transitory computer-readable media may be any available media that can be accessed by processor(s) **1310** and may include volatile media, non-volatile media, or both. The media may also be removable, non-removable, or both.

(61) Additionally, computing system **1300** includes a communication device **1320**, such as a

transceiver, to provide access to a communications network via a wireless and/or wired connection. In some embodiments, communication device **1320** may be configured to use Frequency Division Multiple Access (FDMA), Single Carrier FDMA (SC-FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiplexing (OFDM), Orthogonal Frequency Division Multiple Access (OFDMA), Global System for Mobile (GSM) communications, General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS), cdma2000, Wideband CDMA (W-CDMA), High-Speed Downlink Packet Access (HSDPA), High-Speed Uplink Packet Access (HSUPA), High-Speed Packet Access (HSPA), Long Term Evolution (LTE), LTE Advanced (LTE-A), 802.11x, Wi-Fi, Zigbee, Ultra-WideBand (UWB), 802.16x, 802.15, Home Node-B (HnB), Bluetooth, Radio Frequency Identification (RFID), Infrared Data Association (IrDA), Near-Field Communications (NFC), 5G, 6G, New Radio (NR), any combination thereof, and/or any other currently existing or future-implemented communications standard and/or protocol without deviating from the scope of the invention. In some embodiments, communication device **1320** may include one or more antennas that are singular, arrayed, phased, switched, beamforming, beamsteering, a combination thereof, and or any other antenna configuration without deviating from the scope of the invention.
(62) Processor(s) **1310** are further coupled via bus **1305** to a display **1325**, such as a plasma display, a Liquid Crystal Display (LCD), a Light Emitting Diode (LED) display, a Field Emission Display (FED), an Organic Light Emitting Diode (OLED) display, a flexible OLED display, a flexible substrate display, a projection display, a 4K display, a high definition display, a Retina® display, an In-Plane Switching (IPS) display, or any other suitable display for displaying information to a user. Display **1325** may be configured as a touch (haptic) display, a three-dimensional (3D) touch display, a multi-input touch display, a multi-touch display, etc. using resistive, capacitive, surface-acoustic wave (SAW) capacitive, infrared, optical imaging, dispersive signal technology, acoustic pulse recognition, frustrated total internal reflection, etc. Any suitable display device and haptic I/O may be used without deviating from the scope of the invention.
(63) A keyboard **1330** and a cursor control device **1335**, such as a computer mouse, a touchpad, etc., are further coupled to bus **1305** to enable a user to interface with computing system **1300**. However, in certain embodiments, a physical keyboard and mouse may not be present, and the user may interact with the device solely through display **1325** and/or a touchpad (not shown). Any type and combination of input devices may be used as a matter of design choice. In certain embodiments, no physical input device and/or display is present. For instance, the user may interact with computing system **1300** remotely via another computing system in communication therewith, or computing system **1300** may operate autonomously.
(64) Memory **1315** stores software modules that provide functionality when executed by processor(s) **1310**. The modules include an operating system **1340** for computing system **1300**. The modules further include a network operations module **1345** that is configured to perform all or part of the processes described herein or derivatives thereof. Computing system **1300** may include one or more additional functional modules **1350** that include additional functionality.
(65) One skilled in the art will appreciate that a “computing system” could be embodied as a server, an embedded computing system, a personal computer, a console, a cell phone, a tablet computing device, a quantum computing system, or any other suitable computing device, or combination of devices without deviating from the scope of the invention. Presenting the above-described functions as being performed by a “system” is not intended to limit the scope of the present invention in any way, but is intended to provide one example of the many embodiments of the present invention. Indeed, methods, systems, and apparatuses disclosed herein may be implemented in localized and distributed forms consistent with computing technology, including cloud computing systems. The computing system could be part of or otherwise accessible by a local area network (LAN), a mobile communications network, a satellite communications network, the Internet, a public or private cloud, a hybrid cloud, a server farm, any combination thereof, etc. Any

localized or distributed architecture may be used without deviating from the scope of the invention.
(66) It should be noted that some of the system features described in this specification have been presented as modules, in order to more particularly emphasize their implementation independence. For example, a module may be implemented as a hardware circuit comprising custom very large scale integration (VLSI) circuits or gate arrays, off-the-shelf semiconductors such as logic chips, transistors, or other discrete components. A module may also be implemented in programmable hardware devices such as field programmable gate arrays, programmable array logic, programmable logic devices, graphics processing units, or the like.
(67) A module may also be at least partially implemented in software for execution by various types of processors. An identified unit of executable code may, for instance, include one or more physical or logical blocks of computer instructions that may, for instance, be organized as an object, procedure, or function. Nevertheless, the executables of an identified module need not be physically located together, but may include disparate instructions stored in different locations that, when joined logically together, comprise the module and achieve the stated purpose for the module. Further, modules may be stored on a computer-readable medium, which may be, for instance, a hard disk drive, flash device, RAM, tape, and/or any other such non-transitory computer-readable medium used to store data without deviating from the scope of the invention.
(68) Indeed, a module of executable code could be a single instruction, or many instructions, and may even be distributed over several different code segments, among different programs, and across several memory devices. Similarly, operational data may be identified and illustrated herein within modules, and may be embodied in any suitable form and organized within any suitable type of data structure. The operational data may be collected as a single data set, or may be distributed over different locations including over different storage devices, and may exist, at least partially, merely as electronic signals on a system or network.
(69) FIG. **14** is a flowchart illustrating a process **1400** for providing multi-cloud telecommunications services, according to an embodiment of the present invention. The process begins with hosting one or more NFs on a first cloud system at **1410** and hosting one or more other NFs on a second cloud system at **1420**. The NFs are registered via an NRF so they can find one another across the cloud systems at **1430**. The NRF may be hosted in the first cloud system, the second cloud system, or one or more computing systems that are not a part of the first cloud system or the second cloud system.
(70) In some embodiments the one or more NFs of the first cloud system include AMF, SMF, PCF, NSSF, UDM, AUSF, UDR, and UPF, the one or more NFs of the second cloud system include one or more MEC NFs configured to support MEC, and the second cloud system supports lower latency communications and a higher QoS than the first cloud system. In certain embodiments, NFs are hosted in three or more cloud systems and collectively managed by the NRF. In some such embodiments, one or more respective NFs of the third cloud system include AMF, SMF, and UPF, the one or more NFs of the second cloud system include PCF, AUSF, UDM, and UDR, and the one or more NFs of the third cloud system and the one or more NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the third cloud computing system and the second cloud computing system. In some embodiments, the second cloud system provides a better QoS and/or higher security than the first cloud computing system, the second cloud system is configured to provide the higher QoS and/or security for a subset of services, and the first cloud system is configured to provide other services, the other services comprising voice services.
(71) In some embodiments, the second cloud system includes one or more NEFs configured to expose respective NFs of the one or more respective NFs of the first cloud system to external applications and one or more APIs configured to call the one or more NEFs. In certain embodiments, the one or more NEFs are configured push settings changes to or receive information from one or more mobile devices accessible by one or more RANs using the one or more

respective NFs. In some embodiments, the one or more NEFs are configured to facilitate network event monitoring, data provisioning, and/or policy control.
(72) In some embodiments, the one or more NFs of the second cloud system provide LaaS and communicate via control plane signaling with at least one NF of the first cloud system. In certain embodiments, the one or more LaaS NFs include GMLC and LMF. In some embodiments, the one or more NFs of the first cloud system, the one or more NFs of the second cloud system, or both, are CNFs or VNFs implemented by a platform for automating deployment, scaling, and management of containerized applications.
(73) The process steps performed in FIGS. **8-12** and **14** may be performed by computer program(s), encoding instructions for the processor(s) to perform at least part of the process(es) described in FIGS. **8-12** and **14** in accordance with embodiments of the present invention. The computer program(s) may be embodied on non-transitory computer-readable media. The computer-readable media may be, but are not limited to, a hard disk drive, a flash device, RAM, a tape, and/or any other such medium or combination of media used to store data. The computer program(s) may include encoded instructions for controlling processor(s) of computing system(s) (e.g., processor(s) **1310** of computing system **1300** of FIG. **13**) to implement all or part of the process steps described in FIGS. **8-12** and **14** which may also be stored on the computer-readable medium.
(74) The computer program(s) can be implemented in hardware, software, or a hybrid implementation. The computer program(s) can be composed of modules that are in operative communication with one another, and which are designed to pass information or instructions to display. The computer program(s) can be configured to operate on a general purpose computer, an ASIC, or any other suitable device.
(75) It will be readily understood that the components of various embodiments of the present invention, as generally described and illustrated in the figures herein, may be arranged and designed in a wide variety of different configurations. Thus, the detailed description of the embodiments of the present invention, as represented in the attached figures, is not intended to limit the scope of the invention as claimed, but is merely representative of selected embodiments of the invention.
(76) The features, structures, or characteristics of the invention described throughout this specification may be combined in any suitable manner in one or more embodiments. For example, reference throughout this specification to “certain embodiments,” “some embodiments,” or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, appearances of the phrases “in certain embodiments,” “in some embodiment,” “in other embodiments,” or similar language throughout this specification do not necessarily all refer to the same group of embodiments and the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.
(77) It should be noted that reference throughout this specification to features, advantages, or similar language does not imply that all of the features and advantages that may be realized with the present invention should be or are in any single embodiment of the invention. Rather, language referring to the features and advantages is understood to mean that a specific feature, advantage, or characteristic described in connection with an embodiment is included in at least one embodiment of the present invention. Thus, discussion of the features and advantages, and similar language, throughout this specification may, but do not necessarily, refer to the same embodiment.
(78) Furthermore, the described features, advantages, and characteristics of the invention may be combined in any suitable manner in one or more embodiments. One skilled in the relevant art will recognize that the invention can be practiced without one or more of the specific features or advantages of a particular embodiment. In other instances, additional features and advantages may be recognized in certain embodiments that may not be present in all embodiments of the invention.
(79) One having ordinary skill in the art will readily understand that the invention as discussed

above may be practiced with steps in a different order, and/or with hardware elements in configurations which are different than those which are disclosed. Therefore, although the invention has been described based upon these preferred embodiments, it would be apparent to those of skill in the art that certain modifications, variations, and alternative constructions would be apparent, while remaining within the spirit and scope of the invention. In order to determine the metes and bounds of the invention, therefore, reference should be made to the appended claims.

Claims

1. A multi-cloud system for providing telecommunications services, comprising: one or more computing systems of a first cloud system hosting one or more respective Network Functions (NFs); one or more computing systems of a second cloud system hosting one or more respective NFs; and a Network Repository Function (NRF) hosted by at least one computing system of the one or more computing systems of the first cloud system, at least one computing system of the one or more computing systems of the second cloud system, or one or more other computing systems that are not a part of the first cloud system or the second cloud system, wherein the NRF manages the one or more NFs of the first cloud system and the second cloud system, respectively, and the one or more respective NFs of the first cloud system and the one or more respective NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the first cloud computing system and the second cloud computing system.
2. The multi-cloud system of claim 1, wherein the one or more respective NFs of the first cloud system comprise an Access and Mobility Management Function (AMF), a Session Management Function (SMF), a Policy Control Function (PCF), an Authentication Server Function (AUSF), Unified Data Management (UDM), a Unified Data Repository (UDR), a User Plane Function (UPF), or any combination thereof, the one or more respective NFs of the second cloud system comprise one or more Mobile Edge Computing (MEC) NFs configured to support MEC, and the second cloud system supports lower latency communications and a higher Quality of Service (QOS) than the first cloud system.
3. The multi-cloud system of claim 1, further comprising: one or more computing systems of a third cloud system hosting one or more respective NFs, wherein the one or more respective NFs of the third cloud system comprise an Access and Mobility Management Function (AMF), a Session Management Function (SMF), and a User Plane Function (UPF), the one or more respective NFs of the second cloud system comprise a Policy Control Function (PCF), an Authentication Server Function (AUSF), Unified Data Management (UDM), a Unified Data Repository (UDR), or any combination thereof, and the one or more respective NFs of the third cloud system and the one or more respective NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the third cloud computing system and the second cloud computing system.
4. The multi-cloud system of claim 1, wherein the second cloud system provides a better Quality of Service (QOS) and/or higher security than the first cloud computing system, the second cloud system is configured to provide the higher QoS and/or security for a subset of services, and the first cloud system is configured to provide other services, the other services comprising voice services.
5. The multi-cloud system of claim 1, wherein the second cloud system comprises: one or more Network Exposure Functions (NEFs) and/or Common Application Programming Interface (API) Frameworks (CAPIFs) configured to expose respective NFs of the one or more respective NFs of the first cloud system to external applications; and one or more Application Programming Interfaces (APIs) configured to call the one or more NEFs.
6. The multi-cloud system of claim 5, wherein the one or more NEFs and/or CAPIFs are configured push settings changes to or receive information from one or more mobile devices accessible by one or more Radio Access Networks (RANs) using the one or more respective NFs.

7. The multi-cloud system of claim 6, wherein the one or more NEFs and/or CAPIFs are configured to facilitate network event monitoring, data provisioning, and/or policy control.
8. The multi-cloud system of claim 1, wherein the one or more respective NFs of the second cloud system provide Location as a Service (LaaS), and the one or more LaaS NFs of the second cloud system are configured to communicate via user plane and/or control plane signaling with at least one NF of the one or more respective NFs of the first cloud system.
9. The multi-cloud system of claim 8, wherein the one or more LaaS NFs comprise a Gateway Mobile Location Center (GMLC) and a Location Management Function (LMF).
10. The multi-cloud system of claim 1, wherein the one or more respective NFs of the first cloud system, the one or more respective NFs of the second cloud system, or both, are containerized NFs (CNFs) or virtual NFs (VNFs) implemented by a platform for automating deployment, scaling, and management of containerized applications.
11. A multi-cloud system for providing telecommunications services, comprising: one or more computing systems of a first cloud system hosting one or more respective Network Functions (NFs); one or more computing systems of a second cloud system hosting one or more respective NFs; and a Network Repository Function (NRF) hosted by at least one computing system of the one or more computing systems of the first cloud system, at least one computing system of the one or more computing systems of the second cloud system, or one or more other computing systems that are not a part of the first cloud system or the second cloud system, wherein the NRF manages the one or more NFs of the first cloud system and the second cloud system, respectively, and the one or more respective NFs of the first cloud system, the one or more respective NFs of the second cloud system, or both, are containerized NFs (CNFs) or virtual NFs (VNFs) implemented by a platform for automating deployment, scaling, and management of containerized applications.
12. The multi-cloud system of claim 11, wherein the one or more respective NFs of the first cloud system and the one or more respective NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the first cloud computing system and the second cloud computing system.
13. The multi-cloud system of claim 11, wherein the one or more respective NFs of the first cloud system comprise an Access and Mobility Management Function (AMF), a Session Management Function (SMF), a Policy Control Function (PCF), an Authentication Server Function (AUSF), Unified Data Management (UDM), a Unified Data Repository (UDR), a User Plane Function (UPF), or any combination thereof, the one or more respective NFs of the second cloud system comprise one or more Mobile Edge Computing (MEC) NFs configured to support MEC, and the second cloud system supports lower latency communications and a higher Quality of Service (QOS) than the first cloud system.
14. The multi-cloud system of claim 11, further comprising: one or more computing systems of a third cloud system hosting one or more respective NFs, wherein the one or more respective NFs of the third cloud system comprise an Access and Mobility Management Function (AMF), a Session Management Function (SMF), and a User Plane Function (UPF), the one or more respective NFs of the second cloud system comprise a Policy Control Function (PCF), an Authentication Server Function (AUSF), Unified Data Management (UDM), a Unified Data Repository (UDR), or any combination thereof, and the one or more respective NFs of the third cloud system and the one or more respective NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the third cloud computing system and the second cloud computing system.
15. The multi-cloud system of claim 11, wherein the second cloud system provides a better Quality of Service (QOS) and/or higher security than the first cloud computing system, the second cloud system is configured to provide the higher QoS and/or security for a subset of services, and the first cloud system is configured to provide other services, the other services comprising voice services.
16. The multi-cloud system of claim 11, wherein the second cloud system comprises: one or more

Network Exposure Functions (NEFs) and/or Common Application Programming Interface (API) Frameworks (CAPIFs) configured to expose respective NFs of the one or more respective NFs of the first cloud system to external applications; and one or more Application Programming Interfaces (APIs) configured to call the one or more NEFs and/or CAPIFs, wherein the one or more NEFs and/or CAPIFs are configured push settings changes to or receive information from one or more mobile devices accessible by one or more Radio Access Networks (RANs) using the one or more respective NFs, and the one or more NEFs and/or CAPIFs are configured to facilitate network event monitoring, data provisioning, and/or policy control.
17. The multi-cloud system of claim 11, wherein the one or more respective NFs of the second cloud system provide Location as a Service (LaaS), the one or more LaaS NFs comprising a Gateway Mobile Location Center (GMLC) and a Location Management Function (LMF), and the one or more LaaS NFs of the second cloud system are configured to communicate via user plane and/or control plane signaling with at least one NF of the one or more respective NFs of the first cloud system.
18. A multi-cloud system, comprising: one or more computing systems of a first cloud system hosting one or more respective Network Functions (NFs); one or more computing systems of a second cloud system hosting one or more respective NFs, one or more Network Exposure Functions (NEFs) and/or Common Application Programming Interface (API) Frameworks (CAPIFs) configured to expose respective NFs of the one or more respective NFs of the first cloud system to external applications, and one or more Application Programming Interfaces (APIs) configured to call the one or more NEFs and/or CAPIFs; and a Network Repository Function (NRF) hosted by at least one computing system of the one or more computing systems of the first cloud system, at least one computing system of the one or more computing systems of the second cloud system, or one or more other computing systems that are not a part of the first cloud system or the second cloud system, wherein the NRF manages the one or more NFs of the first cloud system and the second cloud system, respectively, the one or more respective NFs of the first cloud system and the one or more respective NFs of the second cloud system find one another using the NRF and communicate with one another over a control plane between the first cloud computing system and the second cloud computing system, the one or more respective NFs of the first cloud system, the one or more respective NFs of the second cloud system, or both, are containerized NFs (CNFs) or virtual NFs (VNFs) implemented by a platform for automating deployment, scaling, and management of containerized applications.
19. The multi-cloud system of claim 18, wherein the one or more NEFs and/or CAPIFs are configured push settings changes to or receive information from one or more mobile devices accessible by one or more Radio Access Networks (RANs) using the one or more respective NFs.
20. The multi-cloud system of claim 19, wherein the one or more NEFs and/or CAPIFs are configured to facilitate network event monitoring, data provisioning, and/or policy control.