MODEL TRAINING IN A WIRELESS COMMUNICATION NETWORK

TECHNICAL FIELD

[0001] The subject matter disclosed herein relates generally to the field of implementing model training in a wireless communication network. This document defines a first network function, a second network function and methods thereof.

BACKGROUND

[0002] A wireless communications system may include one or multiple network communication devices, such as base stations, which may support wireless communications for one or multiple user communication devices, which may be otherwise known as user equipment (UE), or other suitable terminology. The wireless communications system may support wireless communications with one or multiple user communication devices by utilizing resources of the wireless communication system (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers, or the like)). Additionally, the wireless communications system may support wireless communications across various radio access technologies including third generation (3G) radio access technology, fourth generation (4G) radio access technology, fifth generation (5G) radio access technology, among other suitable radio access technologies beyond 5G (e.g., sixth generation (6G)).

SUMMARY

[0003] An article “a” before an element is unrestricted and understood to refer to “at least one” of those elements or “one or more” of those elements. The terms “a,” “at least one,” “one or more,” and “at least one of one or more” may be interchangeable. As used herein, including in the claims, “or” as used in a list of items (e.g., a list of items prefaced by a phrase such as “at least one of” or “one or more of” or “one or both of”) indicates an inclusive list such that, for example, a list of at least one of A, B, or C means A or B or C or AB or AC or BC or ABC (i.e., A and B and C). Also, as used herein, the phrase “based on” shall not be construed as a reference to a closed set of conditions. For example, an example step that is described as “based on condition A” may be based on both a condition A and a

condition B without departing from the scope of the present disclosure. In other words, as used herein, the phrase “based on” shall be construed in the same manner as the phrase “based at least in part on. Further, as used herein, including in the claims, a “set” may include one or more elements.

[0004] There is provided a first network function in a mobile communications network, the first network function comprising: at least one memory; and at least one processor coupled with the at least one memory and configured to cause the first network function to: receive, from a second network function, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determine a data set available in the mobile communications network that matches the data set requirement; and send the data set to the second network function.

[0005] There is provided a method performed by a first network function in a mobile communications network, the method comprising: receiving, from a second network function, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determining a data set available in the mobile communications network that matches the data set requirement; and sending the data set to the second network function.

[0006] There is provided a processor for wireless communication, comprising: at least one controller coupled with at least one memory and configured to cause the processor to: receive, from a second network function, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determine a data set available in the mobile communications network that matches the data set requirement; and send the data set to the second network function.

[0007] There is provided a second network function comprising: at least one memory; and at least one processor coupled with the at least one memory and configured to cause the second network function to: send, to a first network function in a mobile communications network, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; receive, from the first network function, a data set that matches the data set requirement, wherein the first network node determined the data set to be available in the mobile communications network.

[0008] There is provided a method performed by a second network function, the method comprising: sending, to a first network function in a mobile communications network, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; receiving, from the first network function, a data set that matches the data set requirement, wherein the first network function determined the data set to be available in the mobile communications network.

[0009] There is provided a processor for wireless communication, comprising: at least one controller coupled with at least one memory and configured to cause the processor to: send, to a first network function in a mobile communications network, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; receive, from the first network function, a data set that matches the data set requirement, wherein the first network function determined the data set to be available in the mobile communications network.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Figure 1 illustrates an example of a wireless communications system in accordance with aspects of the present disclosure.

[0011] Figure 2 is a flow diagram illustrating the current approach of deriving and providing analytics to analytics consumer network functions.

[0012] Figure 3 is a flow diagram illustrating a NWDAF architecture for analytics generation based on trained models.

[0013] Figure 4 is a flow diagram illustrating horizontal federated learning.

[0014] Figure 5 is a flow diagram illustrating vertical federated learning.

[0015] Figure 6 is a flow diagram illustrating various types of Vertical Federated Learning (VFL) algorithms/models.

[0016] Figure 7a is a schematic diagram illustrating a non-split VFL with a coordinator.

[0017] Figure 7b is a schematic diagram illustrating a non-split VFL without a coordinator.

[0018] Figure 8 is a schematic diagram illustrating split VFL.

[0019] Figure 9 is a signalling diagram for registration discovery and selection of MTLF clients for FL.

[0020] Figure 10 is a signalling diagram illustrating a general procedure to support FL between MTLFs.

[0021] Figure 11 is a schematic diagram illustrating a use case for vertical federated learning between 3rd party application provider and 5G network.

[0022] Figure 12 is a schematic diagram of a vertical federated learning system according to one or more embodiments.

[0023] Figure 13a is a signalling diagram for a vertical federated learning (VFL) system according to one or more embodiments.

[0024] Figure 13b is a signalling diagram for a vertical federated learning (VFL) system according to one or more embodiments.

[0025] Figure 14 is a schematic diagram of a vertical federated learning system according to one or more embodiments.

[0026] Figure 15a is a signalling diagram for a vertical federated learning (VFL) system according to one or more embodiments.

[0027] Figure 15b is a signalling diagram for a vertical federated learning (VFL) system according to one or more embodiments.

[0028] Figure 16 is a schematic diagram of a vertical federated learning system according to one or more embodiments.

[0029] Figure 17a is a signalling diagram for a vertical federated learning (VFL) system according to one or more embodiments.

[0030] Figure 17b is a signalling diagram for a vertical federated learning (VFL) system according to one or more embodiments.

[0031] Figure 18 illustrates an example of a user equipment (UE) 1800 in accordance with aspects of the present disclosure.

[0032] Figure 19 illustrates an example of a processor 1900 in accordance with aspects of the present disclosure.

[0033] Figure 20 illustrates an example of a network equipment (NE) 2000 in accordance with aspects of the present disclosure.

[0034] Figure 21 illustrates a flowchart of a method performed by a first network function in accordance with aspects of the present disclosure.

[0035] Figure 22 illustrates a flowchart of a method performed by a second network function in accordance with aspects of the present disclosure.

DETAILED DESCRIPTION

[0036] As part of Release 19 study on Artificial Intelligence (AI)/Machine Learning (ML) one of the objectives is to provide solutions to support vertical federated learning enabling the 5GS to assist in collaborative AI/ML operation involving the 5GC/NWDAF or AF.

[0037] One of the use cases is the scenario where a 3rd party application provider needs to combine data available from the application with data available from a network operator in order to train an ML model.

[0038] One use case for vertical federated learning is when the 3rd party application/3rd party service provider (e.g., a bank application) needs a model to identify the user purchasing behaviour against its mobility trends. The user can be identifiable by an application ID or by a 3GPP subscription. However, the data (features) available for the same user will be different in the 3rd party and operator network since the 3rd party will have transaction details for the user whereas the core network will have network information, e.g., mobility / location information, for the same user. Vertical Federated Learning can support model training when different domains have the same sample data, e.g., for the same users, but have different feature space.

[0039] The solution proposes a novel method to perform data alignment between the AF domain and 5GC domain during the federated learning process. The 5GC assist in determining how available samples at the AF matches available samples at the 5GC and ensures that vertical federated learning can be supported.

[0040] The disclosed solution enables the following in order to support cross domain vertical federated learning:

- Enables an AF and 5GC to ensure that both AF and 5GC have an aligned sample range, e.g., the same users, to support vertical federated learning (Data Alignment between NWDAF and AF).
- Enables an AF and 5GC to discover what features are available between domains (for the same sample range) in order to support vertical federated learning (Feature Alignment between NWDAF and AF).
- Enables general procedure to support vertical federated learning between AF and NWDAF/5GC.

[0041] Aspects of the present disclosure are described in the context of a wireless communications system.

[0042] Figure 1 illustrates an example of a wireless communications system 100 in accordance with aspects of the present disclosure. The wireless communications system 100 may include one or more NE 102, one or more UE 104, and a core network (CN) 106. The wireless communications system 100 may support various radio access technologies. In some implementations, the wireless communications system 100 may be a 4G network, such as an LTE network or an LTE-Advanced (LTE-A) network. In some other implementations, the wireless communications system 100 may be a NR network, such as a 5G network, a 5G-Advanced (5G-A) network, or a 5G ultrawideband (5G-UWB) network. In other implementations, the wireless communications system 100 may be a combination of a 4G network and a 5G network, or other suitable radio access technology including Institute of Electrical and Electronics Engineers (IEEE) 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20. The wireless communications system 100 may support radio access technologies beyond 5G, for example, 6G. Additionally, the wireless

communications system 100 may support technologies, such as time division multiple access (TDMA), frequency division multiple access (FDMA), or code division multiple access (CDMA), etc.

[0043] The one or more NE 102 may be dispersed throughout a geographic region to form the wireless communications system 100. One or more of the NE 102 described herein may be or include or may be referred to as a network node, a base station, a network element, a network function, a network entity, a radio access network (RAN), a NodeB, an eNodeB (eNB), a next-generation NodeB (gNB), or other suitable terminology. An NE 102 and a UE 104 may communicate via a communication link, which may be a wireless or wired connection. For example, an NE 102 and a UE 104 may perform wireless communication (e.g., receive signalling, transmit signalling) over a Uu interface.

[0044] An NE 102 may provide a geographic coverage area for which the NE 102 may support services for one or more UEs 104 within the geographic coverage area. For example, an NE 102 and a UE 104 may support wireless communication of signals related to services (e.g., voice, video, packet data, messaging, broadcast, etc.) according to one or multiple radio access technologies. In some implementations, an NE 102 may be moveable, for example, a satellite associated with a non-terrestrial network (NTN). In some implementations, different geographic coverage areas associated with the same or different radio access technologies may overlap, but the different geographic coverage areas may be associated with different NE 102.

[0045] The one or more UE 104 may be dispersed throughout a geographic region of the wireless communications system 100. A UE 104 may include or may be referred to as a remote unit, a mobile device, a wireless device, a remote device, a subscriber device, a transmitter device, a receiver device, or some other suitable terminology. In some implementations, the UE 104 may be referred to as a unit, a station, a terminal, or a client, among other examples. Additionally, or alternatively, the UE 104 may be referred to as an Internet-of-Things (IoT) device, an Internet-of-Everything (IoE) device, or machine-type communication (MTC) device, among other examples.

[0046] A UE 104 may be able to support wireless communication directly with other UEs 104 over a communication link. For example, a UE 104 may support wireless

communication directly with another UE 104 over a device-to-device (D2D) communication link. In some implementations, such as vehicle-to-vehicle (V2V) deployments, vehicle-to-everything (V2X) deployments, or cellular-V2X deployments, the communication link may be referred to as a sidelink. For example, a UE 104 may support wireless communication directly with another UE 104 over a PC5 interface.

[0047] An NE 102 may support communications with the CN 106, or with another NE 102, or both. For example, an NE 102 may interface with other NE 102 or the CN 106 through one or more backhaul links (e.g., S1, N2, N3, or network interface). In some implementations, the NE 102 may communicate with each other directly. In some other implementations, the NE 102 may communicate with each other indirectly (e.g., via the CN 106). In some implementations, one or more NE 102 may include subcomponents, such as an access network entity, which may be an example of an access node controller (ANC). An ANC may communicate with the one or more UEs 104 through one or more other access network transmission entities, which may be referred to as a radio heads, smart radio heads, or transmission-reception points (TRPs).

[0048] The CN 106 may support user authentication, access authorization, tracking, connectivity, and other access, routing, or mobility functions. The CN 106 may be an evolved packet core (EPC), or a 5G core (5GC), which may include a control plane entity that manages access and mobility (e.g., a mobility management entity (MME), an access and mobility management functions (AMF)) and a user plane entity that routes packets or interconnects to external networks (e.g., a serving gateway (S-GW), a Packet Data Network (PDN) gateway (P-GW), or a user plane function (UPF)). In some implementations, the control plane entity may manage non-access stratum (NAS) functions, such as mobility, authentication, and bearer management (e.g., data bearers, signal bearers, etc.) for the one or more UEs 104 served by the one or more NE 102 associated with the CN 106.

[0049] The CN 106 may communicate with a packet data network over one or more backhaul links (e.g., via an S1, N2, N3, or another network interface). The packet data network may include an application server. In some implementations, one or more UEs 104 may communicate with the application server. A UE 104 may establish a session (e.g., a protocol data unit (PDU) session, or the like) with the CN 106 via an NE 102. The CN

106 may route traffic (e.g., control information, data, and the like) between the UE 104 and the application server using the established session (e.g., the established PDU session). The PDU session may be an example of a logical connection between the UE 104 and the CN 106 (e.g., one or more network functions of the CN 106).

[0050] In the wireless communications system 100, the NEs 102 and the UEs 104 may use resources of the wireless communications system 100 (e.g., time resources (e.g., symbols, slots, subframes, frames, or the like) or frequency resources (e.g., subcarriers, carriers)) to perform various operations (e.g., wireless communications). In some implementations, the NEs 102 and the UEs 104 may support different resource structures. For example, the NEs 102 and the UEs 104 may support different frame structures. In some implementations, such as in 4G, the NEs 102 and the UEs 104 may support a single frame structure. In some other implementations, such as in 5G and among other suitable radio access technologies, the NEs 102 and the UEs 104 may support various frame structures (i.e., multiple frame structures). The NEs 102 and the UEs 104 may support various frame structures based on one or more numerologies.

[0051] One or more numerologies may be supported in the wireless communications system 100, and a numerology may include a subcarrier spacing and a cyclic prefix. A first numerology (e.g., μ=0) may be associated with a first subcarrier spacing (e.g., 15 kHz) and a normal cyclic prefix. In some implementations, the first numerology (e.g., μ=0) associated with the first subcarrier spacing (e.g., 15 kHz) may utilize one slot per subframe. A second numerology (e.g., μ=1) may be associated with a second subcarrier spacing (e.g., 30 kHz) and a normal cyclic prefix. A third numerology (e.g., μ=2) may be associated with a third subcarrier spacing (e.g., 60 kHz) and a normal cyclic prefix or an extended cyclic prefix. A fourth numerology (e.g., μ=3) may be associated with a fourth subcarrier spacing (e.g., 120 kHz) and a normal cyclic prefix. A fifth numerology (e.g., μ=4) may be associated with a fifth subcarrier spacing (e.g., 240 kHz) and a normal cyclic prefix.

[0052] A time interval of a resource (e.g., a communication resource) may be organized according to frames (also referred to as radio frames). Each frame may have a duration, for example, a 10 millisecond (ms) duration. In some implementations, each frame may include multiple subframes. For example, each frame may include 10 subframes, and each

subframe may have a duration, for example, a 1 ms duration. In some implementations, each frame may have the same duration. In some implementations, each subframe of a frame may have the same duration.

[0053] Additionally or alternatively, a time interval of a resource (e.g., a communication resource) may be organized according to slots. For example, a subframe may include a number (e.g., quantity) of slots. The number of slots in each subframe may also depend on the one or more numerologies supported in the wireless communications system 100. For instance, the first, second, third, fourth, and fifth numerologies (i.e., μ=0, μ=1, μ=2, μ=3, μ=4) associated with respective subcarrier spacings of 15 kHz, 30 kHz, 60 kHz, 120 kHz, and 240 kHz may utilize a single slot per subframe, two slots per subframe, four slots per subframe, eight slots per subframe, and 16 slots per subframe, respectively. Each slot may include a number (e.g., quantity) of symbols (e.g., OFDM symbols). In some implementations, the number (e.g., quantity) of slots for a subframe may depend on a numerology. For a normal cyclic prefix, a slot may include 14 symbols. For an extended cyclic prefix (e.g., applicable for 60 kHz subcarrier spacing), a slot may include 12 symbols. The relationship between the number of symbols per slot, the number of slots per subframe, and the number of slots per frame for a normal cyclic prefix and an extended cyclic prefix may depend on a numerology. It should be understood that reference to a first numerology (e.g., μ=0) associated with a first subcarrier spacing (e.g., 15 kHz) may be used interchangeably between subframes and slots.

[0054] In the wireless communications system 100, an electromagnetic (EM) spectrum may be split, based on frequency or wavelength, into various classes, frequency bands, frequency channels, etc. By way of example, the wireless communications system 100 may support one or multiple operating frequency bands, such as frequency range designations FR1 (410 MHz – 7.125 GHz), FR2 (24.25 GHz – 52.6 GHz), FR3 (7.125 GHz – 24.25 GHz), FR4 (52.6 GHz – 114.25 GHz), FR4a or FR4-1 (52.6 GHz – 71 GHz), and FR5 (114.25 GHz – 300 GHz). In some implementations, the NEs 102 and the UEs 104 may perform wireless communications over one or more of the operating frequency bands. In some implementations, FR1 may be used by the NEs 102 and the UEs 104, among other equipment or devices for cellular communications traffic (e.g., control information, data).

In some implementations, FR2 may be used by the NEs 102 and the UEs 104, among other equipment or devices for short-range, high data rate capabilities.

[0055] FR1 may be associated with one or multiple numerologies (e.g., at least three numerologies). For example, FR1 may be associated with a first numerology (e.g., μ=0), which includes 15 kHz subcarrier spacing; a second numerology (e.g., μ=1), which includes 30 kHz subcarrier spacing; and a third numerology (e.g., μ=2), which includes 60 kHz subcarrier spacing. FR2 may be associated with one or multiple numerologies (e.g., at least 2 numerologies). For example, FR2 may be associated with a third numerology (e.g., μ=2), which includes 60 kHz subcarrier spacing; and a fourth numerology (e.g., μ=3), which includes 120 kHz subcarrier spacing.

[0056] In the current 3GPP architecture (up to Release 18) a First NWDAF 221 and/ or a second NWDAF 222 provides analytic output to one or more Analytics Consumer NFs based on Data Collected from one or more Data Producer NFs.

[0057] Figure 2 is a flow diagram, indicated generally by reference numeral 200, illustrating the current approach of deriving and providing analytics to analytics consumer network functions.

[0058] The Analytics Consumer NFs may include one or more of an Application Function (AF) 212, 5G Network Functions (5GNFs) 214, Operations, Administration, and Maintenance (OAM) 216. The Data Producer NFs may include one or more of an AF 242, a User Equipment 252, 5GNFs 244, and an OAM 246.

[0059] A Data Collection Coordination Function (DCCF) 232 may collect data from one or more of the First NWDAF 221, Second NWDAF 222, 5GNFs 244 or OAM 246.

[0060] Figure 3 is a flow diagram, indicated generally by reference numeral 300, illustrating a NWDAF architecture for analytics generation based on trained models.

[0061] In Release 17 the NWDAF is split into an Analytics Logical Function (AnLF) 314 and a Model Training Function (MTLF) 316, 318, 320 as shown in Figure 3.

[0062] An MTLF 316, 318, 320 trains a Machine Learning (ML) model related to an analytic identifier (analytic ID). An ML model is configured by a ML model Designer 324

and the MTLF 316, 318, 320 train it by collecting data from Data Producer NFs (e.g. location information from AMF) or by receiving historical data from a Data Collection Coordination Function (DCCF) 322 or from ADRF (not shown).

[0063] The AnLF 314 receives the trained ML models for a specific Analytic ID from the MTLF 316, 318, 320 and use the model plus new data from Data Producer NF(s)/DCCF 322 to derive requested analytics.

[0064] The AnLF 314 may subscribe to the MTLF 316, 318, 320 to receive trained ML models for an Analytic ID using a specific API. The AnLF 314 subscribes based on an analytics request from a consumer NF 312. An NWDAF may support both Analytics inference and ML Model Training functions.

[0065] In some cases, data cannot be exchanged directly from data producers NF 322 to the NWDAF (MTLF 316, 318, 320 or AnLF 314). This may be due to: privacy concerns as an operator of an edge network or a private slice may not want to share data to external networks or high signalling load: signalling load may be increased considerably when data is provided to a centralized training function. It may be more efficient for a network at the edge to receive trained models rather than collect data to derive analytics.

[0066] Federated learning may support privacy and signalling load efficiency. Federated Learning allows local Model Training functions to exchange model parameters and aggregate trained model and/or intermediate training results instead of centrally training models by collecting raw data. It is a distributed machine learning framework that allows a model to be trained collectively from data that is distributed across different data owners. An advantage may be that Artificial Intelligence (AI)/ Machine Learning (ML) models can be trained closer to the data source, rather than sending raw data to centralised training node. In federated learning, only parameters/weights or intermediate results of an AI/ML model need to be sent back to the centralized node to assist generic model training.

[0067] Federated learning may involve horizontal federated learning. Federated learning may involve vertical federated learning.

[0068] Horizontal federated learning, or sample-based federated learning, is introduced in the scenarios that data sets share the same feature space but have different samples. The feature space may correspond to the data. The samples may correspond to users.

[0069] Figure 4 is a flow diagram, indicated generally by reference numeral 400, illustrating horizontal federated learning.

[0070] The flow diagram 400 illustrates a first isolated network 441, a second isolated network 442 and a third isolated network 443. The first isolated network 441, second isolated network 442 and third isolated network 443 comprises a first Data Producer NF(s) 431, a second Data Producer NF(s) 432 and a third Data Producer NF(s) 433, respectively. The first Data Producer NF(s) 431, second Data Producer NF(s) 432 and third Data Producer NF(s) 433 provide a first feature, second feature and third feature to a first Model Training Function 421, second Model Training Function 422 and third Model Training Function 423, respectively. The first Model Training Function 421, second Model Training Function 422 and third Model Training Function 423 may each provide model parameters to a Model Aggregator 412.

[0071] The first feature, second feature and third feature may correspond to a first data set, a second data set and a third data set, respectively. In horizontal federated learning, each of the first feature, second feature and third feature may comprise the same number of features. In horizontal federated learning, each of the first data set, second data set and third data set may comprise the same number of data. In horizontal federated learning, each of the first feature, second feature and third feature may have been collected by different sample spaces; for example, different users. In horizontal federated learning, each of the first data set, second data set and third data set may have been collected by different sample spaces; for example, different users.

[0072] Figure 5 is a flow diagram, indicated generally by reference numeral 500, illustrating vertical federated learning.

[0073] The flow diagram 500 illustrates a first isolated network 541, a second isolated network 542 and a third isolated network 543. The first isolated network 541, second isolated network 542 and third isolated network 543 comprises a first Data Producer NF(s)

531, a second Data Producer NF(s) 532 and a third Data Producer NF(s) 533, respectively. The first Data Producer NF(s) 531, second Data Producer NF(s) 532 and third Data Producer NF(s) 533 provide a first feature, second feature and third feature to a first Model Training Function 521, second Model Training Function 522 and third Model Training Function 523, respectively. The first Model Training Function 521, second Model Training Function 522 and third Model Training Function 523 may each provide model parameters to a Model Aggregator 512.

[0074] The first feature, second feature and third feature may correspond to a first data set, a second data set and a third data set, respectively. In vertical federated learning, each of the first feature, second feature and third feature may comprise different features. In vertical federated learning, each of the first data set, second data set and third data set may comprise different data. In vertical federated learning, each of the first feature, second feature and third feature may have been collected by the same sample spaces; for example, the same users. In vertical federated learning, each of the first data set, second data set and third data set may have been collected by the same sample spaces; for example, different users.

[0075] In both horizontal and vertical federated learning model parameters from each local model training function are sent to a model aggregator 412, 512 to calculate an aggregate model. The model aggregator 412, 512 provides updated model parameters to each MTLF that each MTLF uses to re-train its own model thus allowing every local model training function to have a trained model using data from multiple sources.

[0076] Federated Machine Learning: Concept and Applications, ACM Transactions on Intelligent Systems and Technology (TIST) Volume 10 Issue 2, Article No. 12, January 2019 and 5GPPP, “AI and ML - Enablers for Beyond 5G Networks” provide examples on how a model aggregator generates aggregated models for each type of federated learning.

[0077] Figure 6 is a flow diagram, indicated generally by reference numeral 600, illustrating various types of Vertical Federated Learning (VFL) algorithms/models 612.

[0078] A VFL model may be one of a Non-Split VFL 622, Split VFL 624 or Customized VFL 626. A Non-split VFL 622 may be with a Coordinator 631. A Non-split VFL 622 may be without a Coordinator 632.

[0079] One scenario for supporting VFL within 5GS is non-split VFL 622 where each participant owns a full model, whereas in split VFL 624 each participant owns part of the model.

[0080] There are different approaches on how to train a model with VFL depending on whether non-split 622 or split VFL 624 is used.

[0081] In non-split VFL 622, VFL is either supported through the use of a Coordinator VFL 632 where each party exchange intermediate results and computes gradients for the model which are sent to a coordinator and the coordinator updates each model. In non-split VFL 622 where no coordinator is used 632, each party autonomously trains their model based on exchanging intermediate results and gradients.

[0082] Figure 7a is a schematic diagram, indicated generally by reference numeral 700, illustrating a non-split VFL with a coordinator. In non-split VFL with a coordinator 700, party A (label owner) 712 and party B 714 receive public keys from a coordinator C 716 (illustrated by arrows labelled 1 in Figure 7a). Party A 712 and party B 714 exchange intermediate results (illustrated by arrows labelled 2 in Figure 7a). Party A 712 and party B 714 send computing gradients to coordinator C 716 (illustrated by arrows labelled 3 in Figure 7a). Coordinator C 716 updates models (illustrated by arrows labelled 4 in Figure 7a).

[0083] Figure 7b is a schematic diagram, indicated generally by reference numeral 750, illustrating a non-split VFL without a coordinator. In non-split VFL without a coordinator 750, party A (label owner) 752 sends public keys to party B 754 (illustrated by arrows labelled 1 in Figure 7b). Party B 754 sends intermediate results to party A 752 (illustrated by arrows labelled 2 in Figure 7b). Party A 752 sends loss to Party B 754 (illustrated by arrows labelled 3 in Figure 7b). Party B 754 sends encrypted gradients to party A 752 (illustrated by arrows labelled 4 in Figure 7b). Party A 752 sends decrypted gradients to

Party B 754 (illustrated by arrows labelled 5 in Figure 7b). Party A 752 and Party B 754 update models at each party.

[0084] Figure 8 is a schematic diagram, indicated generally by reference numeral 800, illustrating split VFL. In split VFL 800, the model is split between several parties. One party (Server (label owner)) 812 owns the top model (global model) and other parties (party A 814, party B 816, party N 818) own one or more bottom models (that are used to train the top model 812).

[0085] Figure 9 is a signalling diagram, indicated generally by reference numeral 900, for registration discovery and selection of MTLF clients for FL. The signalling diagram 900 illustrates 3GPP (Release 18) defined federated learning amongst different NWDAF MTLFs (e.g. a server NWDAF 920, Client NWDAF 921, 922) and a Network Repository Function 960.

[0086] The signalling diagram 900 describes NWDAF registration 992, NWDAF discovery 994 and selection of NWDAF clients 921, 922 for federated learning. Each MTLF 920, 921, 922 registers its FL capability (FL client or FL server) within the NWDAF profile in the NRF 960 (steps 971a, 971b). The profile includes additionally information on the analytic IDs supported for FL and/or location area and/or Event ID(s) where data collection is supported. The NWDAF MTLF 920 supporting FL server 920 capability discovers candidate FL clients 921, 922 for training a model using federated learning by receiving a list of FL clients 921, 922 from the NRF 960 that support the analytic ID and/or location area and/or Event IDs needed to train the model (steps 972 to 976). Step 976 comprises the NRF 960 sending a discovery request response to the Server NWDAF 920 listing the one or multiple Client NWDAFT instances i.e. Client NWDAF 1 921, and so on, up to Client NWDAF N 922. The FL server 920 sends a preparation request to all candidates 921, 922 to check if they are capable to join the FL process, i.e., in terms of the data availability and required time schedule, (steps 977-979) and each FL client 921, 922 respond if it can join the process or not.

[0087] Figure 10 is a signalling diagram, indicated generally by reference numeral 1000, illustrating a general procedure to support FL between MTLFs. The signalling diagram 1000 comprises a Consumer 1030, a Server NWDAF (FL server) 1020, Client

NWDAF 1 1021, Client NWDAF N 1022 (FL clients), NRF 1060 and data provider Network Functions (NF) 1010. The signalling diagram 1000 describes the procedures for FL once the FL clients 1021, 1022 have been selected and joined the FL process. The general procedure for FL is that the FL server 1020 sends a subscription request 1072 related to federated learning for model training to each selected FL client 1021, 1022 including local model parameters and each FL client 1021, 1022 trains the model (steps 1074 to 1078) using data from local NFs 1010 (collected at step 1073). Steps 1074 to 1078 may be repeated.

[0088] Figure 11 is a schematic diagram, indicated generally by reference numeral 1100, illustrating a use case for vertical federated learning between 3rd party application provider and 5G network. The schematic diagram 1100 illustrates a first domain (Application Function (AF) cloud 1105) comprising an AF 1106 having a VFL capable function 1124 that receives model parameters from a first VFL capable function (Model B) 1125 and a second VFL capable function (Model B) 1126. The first VFL capable function (Model B) 1125 and second VFL capable function (Model B) 1126 may collect data from various data sets (e.g. Data Set 1 1131, Data Set 2… Data Set N 113). The VFL capable function 1124 may collect model parameters from Model Training Logical Functions (MTFL) in a second domain (Operator Core Network 1140). The Operator Core Network 1140 may comprise several areas (Area 1 1141, Area 2 1142 and Area 3 1143). Each of the Area 1 1141, Area 2 1142 and Area 3 1143 comprises a Data Producer NF i.e. Area 1 Data Producer NF 1110, Area 2 Data Producer NF 1111 and Area 3 Data Producer NF 1112. Each data producer NF 1110, 1111, 1112 feeds data into a respective MTLF (Model A) i.e. Area 1 MTLF 1121, Area 2 MTLF 1122 and Area 3 MTLF 1123. The schematic diagram may be a use case for vertical federated learning between 3rd party application provider (AF cloud 1105) and a 5G network (Operator Core Network 1140).

[0089] As part of Release 19 study on AI/ML, one of the objectives is to provide solutions to support vertical federated learning enabling the 5GS to assist in collaborative AI/ML operation involving the 5GC/NWDAF or AF.

[0090] One of the use cases is shown in schematic diagram 1100 which describes the scenario where a 3rd party application provider needs to combine data available from the application with data available from a network operator in order to train an ML model.

[0091] For example, a use case for vertical federated learning may be when the 3rd party application/3rd party service provider AF cloud 1105 (e.g., a bank application) needs a model to identify the user purchasing behaviour against its mobility trends. The user can be identifiable by an application ID or by a 3GPP subscription. However, the data (features) available for the same user will be different in the 3rd party AF cloud 1105 and operator network 1140 since the 3rd party 1105 will have transaction details for the user whereas the core network 1140 will have network information, e.g., mobility / location information, for the same user. Vertical Federated Learning can support model training when different domains have the same sample data, e.g., for the same users, but have different feature space. Some examples of feature data are: Number of transactions, number of purchases in a particular area, number of cash withdrawals, shopping trends etc. Examples of sample data may be user equipment identifier, time of day, area etc. Other examples of feature data may be UE mobility, UE communication pattern or top 10 applications used over mobile core network etc. Other examples of sample data may be user equipment identifier, time, area etc. It will be understood that these are purely examples, and many other types of data may be categorized as feature data or sample data.

[0092] In this disclosure, the following points are addressed in order to support cross domain vertical federated learning:

- How an AF and 5GC ensure that both AF and 5GC have an aligned sample range, e.g., the same users, to support vertical federated learning (Data Alignment between NWDAF and AF).
- How an AF and 5GC discover what features are available between domains (for the same sample range) in order to support vertical federated learning (Feature Alignment between NWDAF and AF).
- General procedure to support vertical federated learning between AF and NWDAF/5GC.

[0093] Figure 12 is a schematic diagram of a vertical federated learning system, indicated generally by reference numeral 1200, according to one or more embodiments.

[0094] In the VFL system 1200, a Network Exposure Function (NEF) 1250 (in a mobile communications network) performs Data Alignment and FL client selection based on Federated Learning request initiated by 3rd party Application Function (AF) 1242 (which may be outside of the mobile communications network). The mobile communications network may be a 5G core network.

[0095] The main entities affected by the VFL (vertical federated learning) system 1200 and their operations are shown in Figure 12. The AF 1242 communicates with NEF 1250 to request support to train a model. The AF 1242 may exchange VFL parameters with one or more Federated Learning (FL) functions (Model B) 1226. The NEF 1250 may perform VFL discovery with a first Network Repository Function (NRF) 1260. The NEF 1250 may further exchange data set alignment with a second Network Repository Function (NRF)/ADRF 1262 and one or more models (Model A) Model Training Logical Function(s) (MTLF(s)) which may be FL functions e.g. a first MTLF 1220, a second MTLF 1221 and a third MTLF 1222. The first MTLF 1220 may receive a first data set from one or more first Data Producer Network Functions (NFs) 1210. The third MTLF 1222 may receive a third data set from one or more third Data Producer NFs 1211. The second MTLF 1221 may receive a Data Alignment and FL request from a fourth MTLF 1223, a fifth MTLF 1224 and a sixth MTLF 1225.

[0096] The fourth MTLF 1223 may receive a fourth data set from one or more fourth Data Producer NF(s) 1212. The fifth MTLF 1224 may receive a fifth data set from one or more fifth Data Producer NF(s) 1213. The sixth MTLF 1225 may receive a sixth data set from one or more sixth Data Producer NF(s) 1214.

[0097] In some embodiments, non-split VFL is used and it is envisioned that for cross-domain VFL operation the FL functions of one domain (e.g. 5GC) will support a specific Model (Model A) and FL function in the second domain (i.e. at AF 1242) will support a second model (Model B). Both domains use vertical federated learning in order to collaboratively train their models.

[0098] A FL function is a logical functionality/capability or service that can be supported by NF (e.g. NWDAF MTLF) or AF 1242.

[0099] Model training using vertical federated learning is supported by an FL function located in the 3rd party that may act as VFL coordinator receiving VFL parameters from FL functions located in the 3rd party and VFL parameters from FL functions in the operator core network. The FL function then based on vertical federated learning operation sends updated VFL parameters to FL functions in the core network and in the 3rd party and each FL function trains their model based on the updated VFL parameters. In some embodiments, the FL function that coordinates VFL may be located in the 3rd party and requests VFL training/parameters from the core network.

[0100] In an alternative embodiment, the VFL process may be supported without a coordinator and that FL functions in each domain exchange VFL parameters directly.

[0101] In some embodiments, the operator core network may have multiple FL functions deployed. In some embodiments, the FL function may be part of the NWDAF MTLF. Each FL function may collect data directly from data producers for training an ML model using VFL or may carry out further FL (e.g., using horizontal federated learning) by interfacing with other MTLF FL functions using FL to train an ML model.

[0102] In some embodiments, the NEF 1250 may be a logical function. In some embodiments, the NEF 1250 or logical function checks what samples are available for the same feature and identifies FL clients that have the same sample range based on features available in the operator network (i.e. mobile communications network).

[0103] In some embodiments, the AF 1242 requests FL training including a Data Set Requirement. The Data Set Requirement may provide information on features and/or sample range available that is required for FL.

[0104] In some embodiments, the AF 1242 comprises a FL function. The FL function may act as a VFL coordinator. The FL function may be a separate entity located in the 3rd party cloud.

[0105] In some embodiments, the system 1200 may support cross-domain VFL. In these embodiments, an Application Function 1242 (supporting an FL function 1226 with VFL capabilities or FL function or triggered by a separate FL function with VFL capabilities) will send a request to the 5GC core network to initiate model training. In some embodiments, the request may be a federated learning request (alternatively a vertical federated learning request) and/or include a vertical federated learning indicator. The recipient of such request may be the NEF 1250. The AF 1242 may invoke an Nnef SBI service to request model training and/or data alignment. In some embodiments, the request may be an VFL Preparation Request. In some embodiments, the request may be a data alignment request. The request may include one or more of the following parameters/information:

- Analytic identifier (ID) or Model ID or an general identifier (e.g. VFL service identifier or an identifier of an application) denoting the details of the VFL service or a combination of the above. The VFL service may point to use of a specific ML model and the data required to train such model.
- A vertical federated learning or federated learning indicator.
- Model Parameters (e.g. model algorithm or address where local model parameters can be retrieved).
- Data Set Requirements which may contain information on the data required to train the ML model. Data Set requirements may contain one or more of the following information:
    - A (list of) Event ID(s) (features) required to train the local model.
    - The sample range where FL must be performed. For example, the sample range may be a list of User Equipments (UEs) identified by an application identifier or 3GPP subscription (GPSI, SUPI), a location area, a time range or a combination of.

[0106] If the NEF 1250 receives the request from the AF 1242, the NEF 1250 (or a function in the NEF 1250) may perform one or more of the following tasks:

- Identify the FL function(s) that perform VFL operation based on the model/VFL service/analytic ID requested by the AF 1242. Alternatively, if a VFL indicator is not provided, forward the request to an FL function and the FL function determines VFL is needed based on the analytic ID/model ID/service ID provided. The FL function then discovers and select FL functions supporting the VFL operation.
- Identify if the mobile core network has data (features) available for VFL operation based on the Data Set Requirement and/or Model/VFL service/Analytic ID requested by the AF.
- Carry out data set alignment which may comprise checking what of the samples requested by the AF 1242 matches the samples available at the core network operator and indicating to the AF 1242 which data sets are aligned.
- Identify/Select the FL functions that have data (Features/Samples) available in order to support the FL training process based on the Data Set requirement and/or Model/VFL service/Analytic ID requested by the AF. Otherwise, trigger the FL clients to collect the missing data based on the Data Set Requirement.
- Provide a list of candidate FL function(s) able to support VFL operation based on the Data Set Requirement back to the AF 1242.
- Identify what Features are available for the Analytic ID/Model ID/Service ID requested.

[0107] In some embodiments, the NEF 1250 may act as FL coordinator collecting VFL parameters from FL functions of each domain and providing updated trained ML models based on the VFL parameters to each FL function in each domain.

[0108] The capability of each NF to support VFL may be based on the Analytic ID/Service ID/Model ID of the ML model which is stored in the NRF 1260. In some embodiments, a specific VFL capability may be stored in the NRF 1260. In some embodiments, an FL function supporting FL coordinator capability may be stored in the NRF 1260.

[0109] When NEF 1250 or FL function sends to NRF 1260 a discovery request to discover other FL functions that support VFL, the FL function identifies that VFL is supported based on specific VFL capability indication or based on the analytic ID/Model ID/Service ID.

[0110] Figure 13a is a signalling diagram for a vertical federated learning (VFL) system, indicated generally by reference numeral 1300, according to one or more embodiments. The VFL system 1300 may comprise the following entities: an Application Function (AF) (Federated Learning (FL) function) 1342, AF (FL clients) 1344, a Network Exposure Function (NEF) 1350, a Network Repository Function (NRF) 1360, an Analytics Data Repository Function (ADRF) 1362, one or more Model Training Logical Function client(s) 1320, 1321 and one or more Data Producer(s) Network Functions (NF)/ADRF 131.

[0111] The signalling diagram may be for a VFL preparation process in which the VFL system 1300 may perform a procedure where an AF 1342 sends a first (model training) request to a Network Exposure Function 1350 (see step 1371). In some embodiments, the AF 1342 may send a data alignment request separately from first (model training) request in step 1371.

[0112] In some embodiments, the VFL system 1300 may perform the following steps in a process:

[0113] In step 1371, a the AF 1342 sends a request for model training/data alignment where the request may include a (vertical) federated learning indication, an identifier identifying the type of model training required (analytic ID, model ID or FL service ID) and data set requirements including the data needed to be collected to train a model (in one embodiment identified by an Event ID(s), in another embodiment data that needs to be collected includes statistics and features) and sample range requirements. In one embodiment the sample range may be identified by UE identifiers (SUPI, GPSI, user application ID), location area, time range or a combination.

[0114] In step 1372, the NEF 1350 on reception of the first request may interface with the ADRF 1362 and/or NRF 1360 to check which of the Data Set Requirements matches

the data available in the operator network. The NEF 1350 may respond back to AF 1342 (as in step 1380) with the matched data set containing data set available in the operator network that matches the data available in the 3rd party AF 1342. This step may be carried out later (i.e. in step 1376).

[0115] In step 1373, the NEF 1350 identifies an initial list of FL functions. In one embodiment, the NEF 1350 (based on the first request in 1371), identifies the type of FL operation needed (i.e. VFL) and selects FL functions supporting VFL.

[0116] In step 1374, the NEF 1350 sends a discovery request to the NRF 1360 to receive a list of FL functions 1320, 1321 supporting the analytic ID/Model ID/VFL service requirements and data set requirements (i.e. able to retrieve data according to Event ID).

[0117] In step 1375, the NEF 1350 determines which of the candidate FL functions 1320, 1321 can be part of the FL process according to the Data Set requirements and/or data features.

[0118] In step 1376, the NEF 1350 sends a request for model training preparation request using federated learning and includes the parameters provided by the AF 1342 in step 1371.

[0119] In step 1377, the FL function 1320, 1321 may check with ADRF the available samples based on the data set requirement.

[0120] In step 1378, the FL function 1320, 1321 determines if it can participate in the FL process by checking whether the data according to data set requirement are available (or can be retrieved) and other factors (e.g. load of NF). The FL function 1320, 1321 may determine that vertical federated learning is to be used based on Analytic ID/Service ID/Model ID or a specific trigger in the FL request (i.e. VFL indicator/indication).

[0121] In step 1379, the FL function 1320, 1321 responds (to the request in step 1376 from the NEF 1350). The response may indicate that the FL function 1320, 1321 can participate/support the model training or not. The response may include the Available Data Set or Data Set matching the Data Set requirements (features) and an indication to join the FL process (i.e. the model training).

[0122] In step 1380, the NEF 1350 selects candidate FL function 1320, 1321 for the VFL process. The NEF 1350 may also align data sets.

[0123] In step 1381, the NEF 1350 responds to the AF 1342 including the candidate FL list to the AF 1342 (this may be a list of NF IDs, or IP addresses) and may include the matched data set.

[0124] Figure 13b is a signalling diagram for a vertical federated learning (VFL) system, indicated generally by reference numeral 1301, according to one or more embodiments. The VFL system 1301 may comprise the following entities: an Application Function (AF) (Federated Learning (FL) function) 1342, AF (FL clients) 1344, a Network Exposure Function (NEF) 1350, a Network Repository Function (NRF) 1360, an ADRF 1362, one or more Model Training Logical Function client(s) 1320, 1321 and one or more Data Producer(s) Network Functions (NF)/ADRF 131.

[0125] The signalling diagram may be for a VFL procedure, for example following the VFL preparation process described above in relation to VFL system 1300 in Figure 13a.

[0126] In step 1382, the AF 1342 starts the FL process (i.e. the VFL procedure/VFL process).

[0127] In steps 1383-1388, there may be a direct interface between the FL functions 1320, 1321 in each domain. In some embodiments, the second request may be sent via the NEF 1350. In the latter case requests to NEF 1350 include in the Service Based Interface (SBI) request the target recipient (e.g. target NF ID, IP address etc).

[0128] In step 1383, the AF 1342 sends a second (Federated Learning Training) Request to the candidate FL Functions 1320, 1321 including one or more of the Analytic ID/Model ID/Service ID and Data set requirements.

[0129] In step 1384, the FL functions 1320, 1321 train the model by collecting the required data. The FL function may interact also with other FL functions (e.g. using horizontal federated learning).

[0130] In step 1385, the FL function 1320, 1321 provides VFL parameter information to the AF 1342 in a (Model Training) Response. The VFL parameters may be intermediate

results to FL functions of the AF domain 1344 or may be gradients/loss that are sent to a FL function acting as a coordinator. In some embodiments, the FL function 1320, 1321 instead of providing VFL parameters in the response may trigger a new SBI request to provide intermediate results or gradients/losses. A separate container within VFL parameters or separate containers may be defined to convey intermediate results and gradients/losses for model training.

[0131] In step 1386, the AF 1342 may receive VFL parameter information from FL Functions in the AF domain 1344.

[0132] In step 1387, the AF 1342 performs derives updated model parameters using VFL and may start a new iteration (i.e. step 1382) to provide the updated VFL parameters. The updated VFL parameters in this case may be gradients to assist model training or an updated ML model.

[0133] Steps 1382-1387 are repeated where the AF 1342 includes updated VFL parameters and/or provides updated ML model (if the FL function acts as a coordinator) and each FL function trains their model using the updated FL parameters or updates the model. In this step the AF 1342 may invoke a separate SBI service.

[0134] In some embodiments, the NEF 1350 may act as an FL coordinator. In these embodiments, step 1383 is initiated by the NEF 1350. The NEF 1350 sends model training requests to both FL functions 1320, 1321 in the 5GC and FL functions in the AF 1342 and collects gradient/losses and intermediate results. The NEF 1350 then provides updated ML models to each FL function in each domain. The NEF 1350 then repeats step 1388 if more training is needed.

[0135] Figure 14 is a schematic diagram of a vertical federated learning system, indicated generally by reference numeral 1400, according to one or more embodiments.

[0136] In the VFL system 1400, a Network Exposure Function (NEF) 1450 (in a mobile communications network) performs Data Alignment and Federated Learning request initiated by 3rd party Application Function (AF) 1442 (which may be outside of the mobile communications network). The mobile communications network may be a 5G core network.

[0137] The main entities affected by the VFL (vertical federated learning) system 1400 and their operations are shown in Figure 14. The AF 1442 communicates with NEF 1450 to request support to train a model. The NEF 1450 may perform VFL discovery with a first Network Repository Function (NRF) 1460. The NEF 1450 may further exchange data set alignment with a second Network Repository Function (NRF)/ADRF 1462 and one or more Model Training Logical Function(s) (MTLF(s)) which may be FL functions e.g. a first MTLF 1420, a second MTLF 1421 and a third MTLF 1422. The first MTLF 1420 may receive a first data set from one or more first Data Producer Network Functions (NFs) 1410. The third MTLF 1422 may receive a third data set from one or more third Data Producer NFs 1411. The second MTLF 1421 may receive a Data Alignment and FL request from a fourth MTLF 1423, a fifth MTLF 1424 and a sixth MTLF 1425. The fourth MTLF 1423, fifth MTLF 1424 and sixth MTLF 1425 may be FL clients.

[0138] The fourth MTLF 1423 may receive a fourth data set from one or more fourth Data Producer NF(s) 1412. The fifth MTLF 1424 may receive a fifth data set from one or more fifth Data Producer NF(s) 1413. The sixth MTLF 1425 may receive a sixth data set from one or more sixth Data Producer NF(s) 1414.

[0139] In some embodiments, the NEF 1450 on reception of an FL request from an AF 1442 selects an FL function that is capable to support vertical federated learning based on the analytic ID or model ID or service ID requested and data statistics/features. The FL function then performs data alignment and handles VFL operations illustrated in Figure 14.

[0140] In some embodiments, it is assumed that the AF 1442 sends an FL request as also described in relation to VFL system 1300 in Figure 13a. On reception of the request, the NEF 1450 may carry out the following procedure:

- Identify if the 5G core network has available data according to data set requirements provided by AF 1442.
- Perform data set alignment.
- Select a FL function 1420, 1421, 1422 that is able to support the VFL operation based on the AF request.

- Alternatively, if VFL indicator/indication is not provided, forward the request to an FL function 1420, 1421, 1422 and the FL function determines VFL is needed based on the analytic ID/model ID/service ID provided. The FL function 1420, 1421, 1422 then discovers and select FL functions 1420, 1421, 1422 supporting the VFL operation.
- Forward VFL parameters provided by the AF 1442 to the selected FL function(s) 1420, 1421, 1422.
- In response to receiving VFL parameters from the selected FL function 1420, 1421, 1422, forward the VFL parameters to the AF 1442.

[0141] In some embodiments, the NEF 1450 may act as FL coordinator collecting VFL parameters from FL functions 1420, 1421, 1422 of each domain and providing updated trained ML models based on the VFL parameters to each FL function 1420, 1421, 1422 in each domain.

[0142] The FL function 1420, 1421, 1422 on reception of a VFL operation request from the NEF 1450 may perform the following tasks:

- Identify other FL clients 1423, 1424, 1425 that perform VFL operation based on the model requested by the AF 1442.
- Identify if the mobile core network has data (features/samples) available for VFL operation based on the Data Set Requirement and/or Model ID/Analytic ID/Service ID provided by the AF 1442.
- Carry out data set alignment checking what of the samples requested by the AF 1442 for the analytic ID/model ID/service ID requested matches the samples available at the core network operator and indicating to the AF 1442 which data sets are aligned.
- Identify/Select the FL function 1420, 1421, 1422 or Data Producers 1410, 1411 or ADRF 1462 that have data (Features) available in order to support the FL training process based on the Data Set requirement provided by the AF 1442. Otherwise,

trigger the FL clients 1423, 1424, 1425 to collect the missing data based on the Data Set Requirement.

- Identify what Features are available for the Analytic ID/Model ID/Service ID requested.

[0143] In some embodiments, the FL function 1420, 1421, 1422 in 5GC may act as FL coordinator collecting VFL parameters from FL functions of each domain and providing updated trained ML models based on the VFL parameters to each FL function in each domain.

[0144] The capability of each NF to support VFL may be based on the Analytic ID/Service ID/Model ID of the ML model which is stored in the NRF 1460. In some embodiments, a specific VFL capability may be stored in the NRF 1460. In some embodiments, an FL function 1420, 1421, 1422 supporting FL coordinator capability may be stored in the NRF 1460.

[0145] When NEF 1450 or FL function 1420, 1421, 1422 sends to NRF 1460 a discovery request to discover other FL functions 1420, 1421, 1422 that support VFL, the FL function 1420, 1421, 1422 identifies that VFL is supported based on specific VFL capability indication or based on the analytic ID/Model ID/Service ID.

[0146] Figure 15a is a signalling diagram for a vertical federated learning (VFL) system, indicated generally by reference numeral 1500, according to one or more embodiments. The VFL system 1500 may comprise the following entities: an Application Function (AF) (Federated Learning (FL) function) 1542, AF (FL clients) 1544, a Network Exposure Function (NEF) 1550, a Network Repository Function (NRF) 1560, an ADRF 1562, one or more FL Function(s) 1520, 1521 and one or more Data Provider Network Function (NF)/ADRF 1510. In operation, the VFL system 1500 performs the following steps.

[0147] In step 1571, the AF 1542 sends a request for model training where the request may include a (vertical) federated learning indication, an identifier identifying the type of model training required (analytic ID, model ID or service ID) and data set requirements including the data needed to be collected to train a model (in one embodiment identified by

an Event ID(s)) and sample range requirements. In one embodiment the sample range may be identified by UE identifiers (SUPI, GPSI, user application ID), location area, time range or a combination.

[0148] In step 1572, the NEF 1550 may check if data requested by the AF 1542 are available or can be retrieved. The NEF 1550 may interface with the NRF 1560 or ADRF 1562 to retrieve such information. If data is not available, the NEF 1550 may reject the AF service.

[0149] In step 1573, the NEF 1550 sends a discovery request to the NRF 1560 to receive a list of FL functions supporting the analytic ID/service ID/model ID.

[0150] In step 1574, the NEF 1550 selects an FL function 1522 and sends a Model Training request including the parameters provided by the AF.

[0151] In step 1575, the FL function 1522 may interact directly with data sources to retrieve the available samples in order to train the model based on the analytic ID/model ID/service ID requested. The FL function 1522 determining vertical federated learning may be based on one or more parameters.

[0152] In step 1576a,if the model to be trained requires support from other FL functions 1520, 1521 the FL function 1522 sends a discovery request to the NRF 1560 to receive a list of FL functions 1520, 1521 supporting the analytic ID/model ID/service ID and data set requirements (i.e. able to retrieve data according to Event ID). The FL function 1522 determines which of the candidate FL function 1520, 1521 can be part of the FL process according to the Data Set requirements.

[0153] In step 1576b, the FL function sends a request for model training using federated learning and includes the parameters provided by the AF in step 1. The FL function may also include local model parameters.

[0154] In step 1576c, the FL functions 1520, 1521 determine if they can participate in the FL process by checking whether the data according to data set requirement are available (or can be retrieved) and other factors (e.g. load of NF, feature support).

[0155] In step 1576d, the FL functions 1520, 1521 responds if they can join or not and may include the Available Data Set + features if they can join the FL process.

[0156] In step 1577, the FL function 1522 selects candidate FL functions 1520, 1521 or Data Producer/provider NF(s) 1510 for the VFL process.

[0157] In step 1578, FL function 1522 responds to the Model Training Preparation Request to the NEF 1550 including the available samples and/or features for the VFL process.

[0158] In step 1579, the NEF 1550 forwards the response to the AF 1542.

[0159] Figure 15b is a signalling diagram for a vertical federated learning (VFL) system, indicated generally by reference numeral 1501, according to one or more embodiments. The VFL system 1501 may comprise the following entities: an Application Function (AF) (Federated Learning (FL) function) 1542, AF (FL clients) 1544, a Network Exposure Function (NEF) 1550, a Network Repository Function (NRF) 1560, an ADRF 1562, one or more FL Function(s) 1520, 1521 and one or more Data Provider Network Function (NF)/ADRF 1510.

[0160] The signalling diagram may be for a VFL procedure, for example following the VFL preparation process described above in relation to VFL system 1501 in Figure 15a. In operation, the VFL system 1501 performs the following steps.

[0161] In step 1580, the AF 1542 starts the VFL process.

[0162] In step 1581, the AF 1542 sends a Federated Learning Training Request to the NEF 1550 including the Analytic ID/Model ID/Service ID and Data set requirements (statistics/features).

[0163] In step 1582a, the FL function 1522 may collect data according to the data set requirements and/or analytic ID/service ID/Model ID to train the data.

[0164] In step 1583a, alternatively if the FL process requires assistance from other FL functions 1520, 1521 the FL function 1522 sends a Federated Learning Training Request to the selected FL functions 1520, 1521 including Analytic ID/Model ID/Service ID and Data Set Requirements.

[0165] In step 1583b, the FL functions 1520, 1521 train the model by collecting the required data.

[0166] In step 1583c, the FL functions 1520, 1521 provide updated FL parameters to the FL function 1522 in the Model Training Response.

[0167] In step 1584, the FL function 1522 may train the model based on the data (received in step 1582a) or FL parameters received from the FL functions 1520, 1521.

[0168] The FL function 1522 may perform further model training iterations to the FL functions 1520, 1521 in order to improve the accuracy of the ML model.

[0169] In step 1585, when the aggregated model accuracy/confidence is high enough the FL function 1522 provides the VFL parameters to the NEF 1550 by responding to the request in step 1583. The VFL parameters may be intermediate results to FL functions of the AF domain or may be gradients/losses that are sent to a FL function acting as a coordinator. In an alternative embodiment, the FL function 1522 instead of providing VFL parameters in the response may trigger a new SBI request to provide intermediate results or gradients/losses. A separate container within VFL parameters or separate containers may be defined to convey intermediate results and gradients/losses for model training.

[0170] In step 1586, the NEF 1550 forwards the local model parameters to the AF 1542 by responding to the request of step 1581.

[0171] In step 1587, the AF 1542 may receive VFL parameter information from FL clients 1544 in the AF domain (out of scope of 3GPP).

[0172] In step 1588, the AF 1542 performs a VFL process.

[0173] In step 1589, the AF 1542 provides updated VFL parameters and /or trained models to the FL function by repeating step 1581-1586 until the model is accurate enough or the target time for the model training is up.

[0174] If NEF 1550 acts as an FL coordinator, then step 1580 is initiated by the NEF 1550. NEF 1550 sends model training requests to both FL functions in the 5GC 1522 and FL functions in the AF 1542 and collects gradient/losses and intermediate results. The

NEF 1550 then provides updated ML models to each FL function in each domain. The NEF 1550 then repeats step 1589 if more training is needed.

[0175] If the FL function 1522 in 5GC acts as an FL coordinator, then step 1580 is initiated by the FL function 1522. NEF 1550 sends model training requests to both FL functions in the 5GC 1522 and FL functions in the AF 1542 and collects gradient/losses and intermediate results. The FL function 1522 then provides updated ML models to each FL function in each domain. The NEF 1550 then repeats step 1589 if more training is needed.

[0176] Figure 16 is a schematic diagram of a vertical federated learning system, indicated generally by reference numeral 1600, according to one or more embodiments.

[0177] In the VFL system 1600, a Network Exposure Function (NEF) 1650 (in a mobile communications network) initiates VFL request to a 3rd party FL function in a third-party Application Function (AF) 1642 (which may be outside of the mobile communications network). The mobile communications network may be a 5G core network.

[0178] The main entities affected by the VFL (vertical federated learning) system 1600 and their operations are shown in Figure 16. The AF 1642 communicates with NEF 1650 to request support to train a model. An MTLF (FL Function) 1620 may perform VFL discovery with a Network Repository Function (NRF) 1660. The NEF 1650 may exchange FL requests with one or more first Model Training Logical Function(s) (MTLF(s)) 1620 which may be FL functions. The first MTLF 1620 may exchange data with a second MTLF 1621, a third MTLF 1622 and a fourth MTLF 1623. The first MTLF 1620 may receive a first data set from one or more first Data Producer Network Functions (NFs) 1610. The second MTLF 1621, third MTLF 1622 and fourth MTLF 1623 may each receive data from one or more Data Producer NF(s) 1612, 1613, 1614.

[0179] The VFL process may be initiated from the 5GC to 3rd party AF when the VFL process (i.e. model parameter aggregation) is taking place in the 5G core.

[0180] In some embodiments, a FL function 1620 may need VFL parameters related to data (features) that are not available in the core network.

[0181] In some embodiments, the FL function 1620 then finds a 3rd party AF 1642 that is able to provide VFL parameters for an analytic ID/model ID/service ID requiring model training using federated learning.

[0182] In some embodiments, the FL function 1620 performs the following steps:

- Determines the available sample range of data and features that can be used in the 5GC to train a model.
- Discovers an NEF 1650 that interfaces with the AF 1642 that support federated learning for the Analytic ID/Model ID/Service ID of the model that requires federated learning
- Sends a request for model training/data alignment to the AF 1642 via NEF 1650 where the request includes:
    - Analytic ID or Model ID or an general identifier (Service ID) denoting the details of the ML model and the data required to train such model
    - A federated learning indicator or an indicator indicating vertical federated learning (e.g. a vertical federated learning indication).
    - Model Parameters (e.g. model algorithm or address where local model parameters can be retrieved)
    - Data Set Requirements which contain information (statistics) on the data and features required to train the ML model. Data Set requirements may contain one or more of the following information:
        - A (list of) Event ID(s) (features) required to train the local model
        - The sample ID range where VFL must be performed. For example, the sample range may be a list of UEs (identified by an application identifier or 3GPP subscription (GPSI, SUPI), a location area, a time range or a combination of).
- The AF 1642 trains local model ensuring that same sample range is used for the features requested by the NWDAF.

[0183] In some embodiments, the FL function 1620 sends to the NEF 1650 a request for model training and/or federated learning including a data set requirement and the NEF finds a candidate lists of AF (supporting FL functions) that meet the data set requirements criteria. The FL function 1620 sends a request to the NEF 1650 and the NEF 1650 may invoke requests to multiple AF whether FL can be supported. The NEF creates a candidate lists of AF and provides the list to the FL function.

[0184] In some embodiments, the NEF 1650 may act as FL coordinator collecting VFL parameters from FL functions of each domain and providing updated trained ML models based on the VFL parameters to each FL function in each domain.

[0185] The capability of each NF to support VFL may be based on the Analytic ID/Service ID/Model ID of the ML model which is stored in the NRF 1660. In some embodiments, a specific VFL capability may be stored in the NRF 1660. In some embodiments, a FL function supporting FL coordinator capability may be stored in the NRF 1660.

[0186] When NEF 1650 or FL function 1620 sends to NRF 1660 a discovery request to discover other FL functions that support VFL the FL function identifies that VFL is supported based on specific VFL capability indication or based on the analytic ID/Model ID/Service ID.

[0187] Figure 17a is a signalling diagram for a vertical federated learning (VFL) system, indicated generally by reference numeral 1700, according to one or more embodiments. The VFL system 1700 may comprise the following entities: an Application Function (AF) (Federated Learning (FL) function) 1742, AF (FL function) 1742, a Network Exposure Function (NEF) 1750, a Network Repository Function (NRF) 1760, a FL function 1722, one or more FL Function(s) 1720, 1721 and one or more Data Provider Network Function (NF)/ADRF 1710. In operation, the VFL system 1700 performs VFL preparation according to the following steps.

[0188] In step 1771, the FL function 1722 is triggered to train a model and determines model requires federated learning. The request may include data set requirements and analytic ID/model ID/service ID.

[0189] In step 1772, the FL function 1722 determines the sample range and features available within the mobile operator network to train the model based on the data (Event IDs) required to be collected to train the model by interface with the ADRF or Data Producer NF(s).

[0190] In step 1773, alternatively, if the FL function 1722 requires assistance from other FL function 1720, 1721, the FL function 1722 interfaces with the NRF 1760 to retrieve a list of candidate client FL function based on the Analytic ID/Service ID/Model ID requested and the data set requirements.

[0191] In step 1774a, the FL function 1722 sends a request for model training where the request may include a federated learning indication, an identifier identifying the type of model training required (analytic ID, model ID or service ID) and data set requirements including the data needed to be collected to train a model (in one embodiment identified by an Event ID(s)).

[0192] In step 1774b, the FL functions 1720, 1721 determine if they can participate in the FL process by checking whether the data are available (or can be retrieved) and other factors (e.g., load of NF or latency).

[0193] In step 1774c, the FL functions 1720, 1721 responds if they can join or not and may include the Available/Matched Sample range if they can join the FL process.

[0194] In step 1775, the FL function 1722 determines the available sample range.

[0195] In step 1776, the FL function 1722 sends request to the NRF 1760 to discover NEF 1750 that interfaces with AF 1742 able to support federated learning for the model identified by an analytic ID or model ID.

[0196] In step 1777, the FL function 1722 sends a model training preparation request to the NEF 1750 and includes Analytic ID/Model ID and Data Set Requirements.

[0197] In step 1778, in some embodiments, the NEF 1750 may be triggered to find candidate list of AFs (that can interface with this NEF 1750) that support the data set requirements.

[0198] In step 1779, the NEF 1750 forwards the request to the AF 1742 or sends requests to multiple AF (that can interface with this NEF 1742).

[0199] In step 1780, the AF 1742 identifies the available sample range and features (or may simply respond back with its own sample range).

[0200] In step 1781, the AF 1742 responds providing matched/available sample range or may simply include its sample range.

[0201] In step 1782, in some embodiments, the NEF 1750 may find a candidate list of AF supporting FL functions that meet the data set requirement.

[0202] In step 1783, the NEF 1750 forwards the response to the FL function 1722 and may include a candidate list of AF(s).

[0203] In step 1784, in some embodiments the FL function 1722 performs entity alignment by determining the available sample range for the VFL process.

[0204] Figure 17b is a signalling diagram for a vertical federated learning (VFL) system, indicated generally by reference numeral 1701, according to one or more embodiments. The VFL system 1701 may comprise the following entities: an Application Function (AF) (Federated Learning (FL) function) 1742, AF (FL function) 1742, a Network Exposure Function (NEF) 1750, a Network Repository Function (NRF) 1760, a FL function 1722, one or more FL Function(s) 1720, 1721 and one or more Data Provider Network Function (NF)/ADRF 1710.

[0205] The signalling diagram may be for a VFL procedure/process, for example following the VFL preparation process described above in relation to VFL system 1701 in Figure 17a. In operation, the VFL system 1701 performs the following steps.

[0206] In step 1785, the FL function 1722 starts collecting data from Data Producer NFs 1710 or if the training requires assistance from other FL functions 1720, 1721 sends a model training request to selected FL function 1720, 1721 based on the data set requirement (as in Steps 1582a-1584 of Figure 15b).

[0207] In step 1786, the FL function 1722 sends a Model Training Request including Analytic ID/Service ID/Model ID and the Data Set requirements (based on the alignment) to the NEF 1750/AF 1742.

[0208] In step 1787, the NEF 1750 forwards the request to the AF 1742.

[0209] In step 1788, the AF 1742 performs VFL process.

[0210] In step 1789, the AF 1742 responds to the NEF 1750 including VFL parameters.

[0211] In step 1790, the NEF 1750 forwards the response to the FL function 1722.

[0212] In step 1791, the FL function 1722 performs VFL and provide updated VFL parameters to FL functions (either in core network or AF) by repeating steps 1783-1788. The VFL parameters may be intermediate results, gradients or updated ML model.

[0213] If NEF 1750 acts as an FL coordinator, then step 1786 is initiated by the NEF 1750. NEF 1750 sends model training requests to both FL functions 1722 in the 5GC and FL functions in the AF 1742 and collects gradient/losses and intermediate results. The NEF 1750 then provides updated ML models to each FL function in each domain. The NEF 1750 then repeats step 1791 if more training is needed.

[0214] In an aspect there is provided a first network function in a mobile communications network, the first network function comprising: at least one memory; and at least one processor coupled with the at least one memory and configured to cause the first network function to: receive, from a second network function, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determine a data set available in the mobile communications network that matches the data set requirement; and send the data set to the second network function.

[0215] The first network function enables initiation of model training based on a vertical federated learning indication from a second network function. The first network function enables determination of a data set available in the mobile communications network that matches the data set requirement. The model training may only be supported when the data set matches the data set requirement.

[0216] The first network function may be part of a first domain. The first domain may be a mobile communications network. The second network function may be part of a second domain. The second domain may be a third-party service provider. The first network function may enable training of a model in the second domain using federated learning functions in the first domain. For example, the first network function in a mobile communications network may enable training of a third-party model.

[0217] The first network function may be a Network Exposure Function. The first network function may be part of a first domain of the mobile communications network. The first domain may be a 5G Core.

[0218] The second network function may be a third-party network function. The second network function may be part of a third-party network function. The second network function may be a third-party application function. The third-party application function may be a banking application function. The second network function may be part of a third-party cloud. The second network function may be in the mobile communications network. The second network function may be in the 5G core. The second network function may be outside the mobile communications network. The second network function may not be in the mobile communications network. The second network function may not be part of the mobile communications network. The second network function may be a federated learning function. The second network function may be a vertical federated learning function. The second network function may be an Application Function. The application function may not be a third-party network function. The application function may be outside the mobile communications network. The application function may not be in the mobile communications network. The application function may not be part of the mobile communications network. The second network function may be a model training logical function. The second network function may be a model training logical function in a 5G Core.

[0219] The data set available in the mobile communications network may be part of a first sample space. The data set available in the mobile communications network may be for a first user. The data set available in the mobile communications network may be for a first set of users.

[0220] A second data set for a user may be available at the second network function. The second data set may be part of the first sample space. The second data set may be for the first user. The second data set may be for the first set of users. The data set requirement may be determined based on the second data set.

[0221] The data set available in the mobile communications network may be part of a different feature space to the second data set. The data set available in the mobile communications network may be part of a different data space to the second data set. The data set available in the mobile communications network may not be aligned with the second data set.

[0222] The vertical federated learning indication may indicate that vertical federated learning is required to support the model training. Vertical federated learning may be used for model training using the data set available in the mobile communications network and/or the second data set available to the second network function.

[0223] The first request may be a data alignment request. The data alignment may be to align the data set available in the mobile communications network with the second data set. The first request may be a model training request. The first request may be a request to train the model. The first request may comprise a federated learning indication. The first request may comprise a vertical federated learning indication. The first request may not be a request to train a model based on an analytic identifier. The first request may be to train a model based on a vertical federated learning indication. The vertical federated learning indication may be identified by one or more of a model identifier, a service identifier, analytic identifier or an application identifier.

[0224] The model may be a machine learning model. The model may be a neural network. The model may be an artificial intelligence model. The model may be part of a third-party application. The model may be owned by a third-party application. The model may not be part of the mobile communications network.

[0225] A third-party application may be a third-party service provider. A third-party service provider may be a banking application.

[0226] The model training may comprise a vertical federated learning process. Training the first model may comprise federated learning. Training the model may comprise vertical federated learning.

[0227] Federated learning may only be supported when the data set is identical to the data set requirement. Vertical federated learning may only be supported when the data set is identical to the data set requirement.

[0228] The vertical federated learning indication may comprise one or more of a model identifier, a service identifier, a vertical federated learning identifier, an application identifier, an analytic identifier or a vertical federated learning service identifier. In some embodiments, a vertical federated learning identifier may be determined based on one or more of a model identifier, service identifier, or an analytic identifier.

[0229] The data set requirement may be a data sample requirement. The data set requirement may comprise information on the data required to train the model. The data set requirement may comprise an indication of the data needed to be collected to train the model. The data set requirement may comprise statistics corresponding to the data needed to be collected to train the model. The data set requirement may comprise features corresponding to the data needed to be collected to train the first model. The data set requirement may comprise one or more sample range requirement. The one or more sample range requirement may be identified by one or more of: one or more user equipment identifiers; one or more location areas; and/or one or more time ranges. The one or more user equipment identifiers may include one or more of: a Subscription Permanent Identifier (SUPI), Global Public Subscriber Identity (GPSI) or user application identifier. The data set requirement may comprise one or more event identification(s).

[0230] The data set may comprise one or more sets of data. The data set may comprise features. The features may be one or more of a user equipment mobility, a user equipment communication pattern or a list of application used over the mobile communications network. The features may be one or more of a number of transactions in a particular area, a number of purchases in a particular area, a number of cash withdrawals, shopping trends.

[0231] In some embodiments, the at least one processor coupled with the at least one memory may be further configured to cause the first network function to: determine a first list comprising one or more third network functions in the mobile communications network that are available to support the model training according to the vertical federated learning indication.

[0232] One or more of the one or more third network functions may be part of a second domain of the mobile communications network. One or more of the one or more third network functions may be a federated learning function. One or more of the one or more third network functions may support federated learning. One or more of the one or more third network functions may be a vertical federated learning function. One or more of the one or more third network functions may support vertical federated learning. One or more of the one or more third network functions may be an application function.

[0233] Federated Learning may allow the local model training functions (e.g. one or more third network functions, first network function and the second network) to exchange model parameters and aggregate trained model and/or intermediate training results instead of centrally training models by collecting raw data. Horizontal federated learning, or sample-based federated learning, may be introduced in the scenarios that data sets share the same feature space but have different samples. Vertical federated learning or feature-based federated learning may be applicable to the cases that two data sets share the same sample space but differ in feature space. In both horizontal and vertical federated learning model parameters from each local model training function may be sent to a model aggregator to calculate an aggregate model. The model aggregator may provide updated model parameters to each MTLF that each MTLF may use to re-train its own model thus allowing one or more local model training function to have a trained model using data from multiple sources.

[0234] The capability of each of the one or more third network functions to support the training of the model may be based on the vertical federated learning indication. The capability of each of the one or more third network functions to support the training of the model may be based on an identifier in the vertical federated learning indication. The capability of each of the one or more third network functions to support the training of the

model may be based on one or more of an analytic identifier, service identifier or model identifier in the vertical federated learning indication. The first network function may store one or more of an analytic identifier, service identifier or model identifier.

[0235] In some embodiments, the at least one processor coupled with the at least one memory is further configured to cause the first network function to: send the first list to the second network function.

[0236] In some embodiments, the first list corresponds to a list of network functions that support vertical federated learning based on a data set alignment.

[0237] The first list may be a list of Network Functions that support model training for the available data set (or based on the data set alignment).

[0238] In some embodiments, the at least one processor coupled with the at least one memory is further configured to cause the first network function to: determine whether the data set matches the data set requirement based on a data set alignment.

[0239] The data set alignment of a data set available in the mobile communications network that matches the vertical federated learning indication.

[0240] The data set alignment may comprise checking which data in the data set matches the data set requirement. The data set alignment may comprise determining which data in the data set are aligned with the data set requirement. The data set may comprise one or more data sets. The data set alignment may comprise determining which data set in the one or more data set matches the data set requirement. The data set alignment may comprise determining which data set in the one or more data set are aligned with the data set requirement.

[0241] In some embodiments, data set alignment is performed by the first network function.

[0242] The first network function may be a Network Exposure Function. The Network Exposure Function may perform the data set alignment.

[0243] In some embodiments, the data set alignment is performed by one or more of the third network functions.

[0244] One or more of the one or more third network functions may be a federated learning function. One or more of the federated learning functions may perform the data set alignment.

[0245] In some embodiments, the second network function is not part of the mobile communication network.

[0246] In some embodiments, the vertical federated learning indication comprises one or more of a model identifier, a service identifier, a vertical federated learning identifier, an application identifier, analytics identifier or a vertical federated learning service identifier.

[0247] The model training may be based on the vertical federated learning indication.

[0248] In some embodiments, the data set requirement comprises one or more of an event identifier or a sample range.

[0249] The data set requirement may comprise information on the data required for the model training.

[0250] The data set requirement may comprise an event identifier required to train the model. The data set requirement may comprise an event identifier required for model training. The data set requirement may comprise a list of event identifiers required to train the model. The data set requirement may comprise a list of event identifiers required for model training.

[0251] The data set requirement may comprise a feature required to train the model. The data set requirement may comprise a feature required for model training. The data set requirement may comprise a list of features required to train the model. The data set requirement may comprise a list of features required for model training.

[0252] The data set requirement may comprise a sample range where model training is performed. The data set requirement may comprise a sample range where federated learning of the model is performed. The data set requirement may comprise a sample range where vertical federated learning of the model is performed. The sample range may be a list of one or more user equipment. The one or more user equipment may be identified by a list of one or more application identifiers. The one or more user equipment may be

identified by a list of one or more 3rd Generation Partnership Project (3GPP) subscriptions. The one or more user equipment may be identified by one or more of: a Subscription Permanent Identifier (SUPI), Global Public Subscriber Identity (GPSI) or user application identifier. The sample range may be a list of one or more location areas. The sample range may be a list of one or more time ranges. The sample range may be one or more of: a list of one or more application identifiers; a list of one or more 3GPP subscription; a list of one or more location areas; a list of one or more time ranges; or a combination thereof.

[0253] In some embodiments, the at least one processor coupled with the at least one memory is further configured to cause the first network function to: send, to a fourth network function, a second request for the model training, wherein the second request comprises the vertical federated learning indication and the data set requirement.

[0254] The second request may be a model training preparation request. The second request may be a model training preparation request using federated learning. The second request may be a model training preparation request using vertical federated learning. The second request may comprise one or more of a federated learning indicator, analytic identifier, model identifier or service identifier.

[0255] The fourth network function may be federated learning function. The fourth network function may be vertical federated learning function.

[0256] In some embodiments, the at least one processor coupled with the at least one memory is further configured to cause the first network function to: receive, from the fourth network function, a response message, wherein the response message comprises an indication of available samples for the model training.

[0257] The fourth network function may determine whether it can participate in the model training according to the data set requirement. The fourth network function may determine whether it can participate in federated learning for the model training according to the data set requirement. The fourth network function may determine whether it can participate in vertical federated learning for the model training according to the data set requirement. The fourth network function may determine whether data according to the data set requirement is available. The fourth network function may determine whether

vertical federated learning is required based on one or more of an analytic identifier, service identifier, model identifier or a specific trigger in the second request.

[0258] In some embodiments, the second request may be received by the first network function, from the fourth network function. In these embodiments, the response message may be sent from the first network function to the fourth network function.

[0259] In an aspect there is provided a method performed by a first network function in a mobile communications network, the method comprising: receiving, from a second network function, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determining a data set available in the mobile communications network that matches the data set requirement; and sending the data set to the second network function.

[0260] The method enables initiation of model training based on a vertical federated learning indication from a second network function. The method enables determination of a data set available in the mobile communications network that matches the data set requirement. The model training may only be supported when the data set matches the data set requirement.

[0261] In an aspect there is provided a second network function comprising: at least one memory; and at least one processor coupled with the at least one memory and configured to cause the second network function to: send, to a first network function in a mobile communications network, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; receive, from the first network function, a data set that matches the data set requirement, wherein the first network node determined the data set to be available in the mobile communications network.

[0262] The method enables initiation of model training based on a vertical federated learning indication from a second network function. The method enables determination of a data set available in the mobile communications network that matches the data set requirement. The model training may only be supported when the data set matches the data set requirement.

[0263] In some embodiments, the at least one processor coupled with the at least one memory is further configured to cause the second network function to: receive, from the first network function, a first list comprising one or more third network functions in the mobile communications network that are available to support the model training according to the vertical federated learning indication.

[0264] One or more of the one or more third network functions may be part of a second domain of the mobile communications network. One or more of the one or more third network functions may be a federated learning function. One or more of the one or more third network functions may support federated learning. One or more of the one or more third network functions may be a vertical federated learning function. One or more of the one or more third network functions may support vertical federated learning. One or more of the one or more third network functions may be an application function.

[0265] In an aspect there is provided a method performed by a second network function, the method comprising: sending, to a first network function in a mobile communications network, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; receiving, from the first network function, a data set that matches the data set requirement, wherein the first network function determined the data set to be available in the mobile communications network.

[0266] The method enables initiation of model training based on a vertical federated learning indication from a second network function. The method enables determination of a data set available in the mobile communications network that matches the data set requirement. The model training may only be supported when the data set matches the data set requirement.

[0267] Figure 18 illustrates an example of a UE 1800 in accordance with aspects of the present disclosure. The UE 1800 may include a processor 1802, a memory 1804, a controller 1806, and a transceiver 1808. The processor 1802, the memory 1804, the controller 1806, or the transceiver 1808, or various combinations thereof or various components thereof may be examples of means for performing various aspects of the present disclosure as described herein. These components may be coupled (e.g.,

operatively, communicatively, functionally, electronically, electrically) via one or more interfaces.

[0268] The processor 1802, the memory 1804, the controller 1806, or the transceiver 1808, or various combinations or components thereof may be implemented in hardware (e.g., circuitry). The hardware may include a processor, a digital signal processor (DSP), an application-specific integrated circuit (ASIC), or other programmable logic device, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure.

[0269] The processor 1802 may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, a CPU, an ASIC, an FPGA, or any combination thereof). In some implementations, the processor 1802 may be configured to operate the memory 1804. In some other implementations, the memory 1804 may be integrated into the processor 1802. The processor 1802 may be configured to execute computer-readable instructions stored in the memory 1804 to cause the UE 1800 to perform various functions of the present disclosure.

[0270] The memory 1804 may include volatile or non-volatile memory. The memory 1804 may store computer-readable, computer-executable code including instructions when executed by the processor 1802 cause the UE 1800 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as the memory 1804 or another type of memory. Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer.

[0271] In some implementations, the processor 1802 and the memory 1804 coupled with the processor 1802 may be configured to cause the UE 1800 to perform one or more of the functions described herein (e.g., executing, by the processor 1802, instructions stored in the memory 1804). For example, the processor 1802 may support wireless communication at the UE 1800 in accordance with examples as disclosed herein. The UE 1800 may be configured to support a means for receiving, from a second network function, a first request

for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determining a data set available in the mobile communications network that matches the data set requirement; and sending the data set to the second network function.

[0272] The controller 1806 may manage input and output signals for the UE 1800. The controller 1806 may also manage peripherals not integrated into the UE 1800. In some implementations, the controller 1806 may utilize an operating system such as iOS®, ANDROID®, WINDOWS®, or other operating systems. In some implementations, the controller 1806 may be implemented as part of the processor 1802.

[0273] In some implementations, the UE 1800 may include at least one transceiver 1808. In some other implementations, the UE 1800 may have more than one transceiver 1808. The transceiver 1808 may represent a wireless transceiver. The transceiver 1808 may include one or more receiver chains 1810, one or more transmitter chains 1812, or a combination thereof.

[0274] A receiver chain 1810 may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receiver chain 1810 may include one or more antennas for receiving the signal over the air or wireless medium. The receiver chain 1810 may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receiver chain 1810 may include at least one demodulator configured to demodulate the received signal and obtain the transmitted data by reversing the modulation technique applied during transmission of the signal. The receiver chain 1810 may include at least one decoder for decoding and/or processing the demodulated signal to receive the transmitted data.

[0275] A transmitter chain 1812 may be configured to generate and transmit signals (e.g., control information, data, packets). The transmitter chain 1812 may include at least one modulator for modulating data onto a carrier signal, preparing the signal for transmission over a wireless medium. The at least one modulator may be configured to support one or more techniques such as amplitude modulation (AM), frequency modulation (FM), or digital modulation schemes like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). The transmitter chain 1812 may also include at least one power

amplifier configured to amplify the modulated signal to an appropriate power level suitable for transmission over the wireless medium. The transmitter chain 1812 may also include one or more antennas for transmitting the amplified signal into the air or wireless medium.

[0276] Figure 19 illustrates an example of a processor 1900 in accordance with aspects of the present disclosure. The processor 1900 may be an example of a processor configured to perform various operations in accordance with examples as described herein. The processor 1900 may include a controller 1902 configured to perform various operations in accordance with examples as described herein. The processor 1900 may optionally include at least one memory 1904, which may be, for example, an L1/L2/L3 cache. Additionally, or alternatively, the processor 1900 may optionally include one or more arithmetic-logic units (ALUs) 1906. One or more of these components may be in electronic communication or otherwise coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces (e.g., buses).

[0277] The processor 1900 may be a processor chipset and include a protocol stack (e.g., a software stack) executed by the processor chipset to perform various operations (e.g., receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) in accordance with examples as described herein. The processor chipset may include one or more cores, one or more caches (e.g., memory local to or included in the processor chipset (e.g., the processor 1900)) or other memory (e.g., random access memory (RAM), read-only memory (ROM), dynamic RAM (DRAM), synchronous dynamic RAM (SDRAM), static RAM (SRAM), ferroelectric RAM (FeRAM), magnetic RAM (MRAM), resistive RAM (RRAM), flash memory, phase change memory (PCM), and others).

[0278] The controller 1902 may be configured to manage and coordinate various operations (e.g., signalling, receiving, obtaining, retrieving, transmitting, outputting, forwarding, storing, determining, identifying, accessing, writing, reading) of the processor 1900 to cause the processor 1900 to support various operations in accordance with examples as described herein. For example, the controller 1902 may operate as a control unit of the processor 1900, generating control signals that manage the operation of various components of the processor 1900. These control signals include enabling or disabling

functional units, selecting data paths, initiating memory access, and coordinating timing of operations.

[0279] The controller 1902 may be configured to fetch (e.g., obtain, retrieve, receive) instructions from the memory 1904 and determine subsequent instruction(s) to be executed to cause the processor 1900 to support various operations in accordance with examples as described herein. The controller 1902 may be configured to track memory address of instructions associated with the memory 1904. The controller 1902 may be configured to decode instructions to determine the operation to be performed and the operands involved. For example, the controller 1902 may be configured to interpret the instruction and determine control signals to be output to other components of the processor 1900 to cause the processor 1900 to support various operations in accordance with examples as described herein. Additionally, or alternatively, the controller 1902 may be configured to manage flow of data within the processor 1900. The controller 1902 may be configured to control transfer of data between registers, arithmetic logic units (ALUs), and other functional units of the processor 1900.

[0280] The memory 1904 may include one or more caches (e.g., memory local to or included in the processor 1900) or other memory, such as RAM, ROM, DRAM, SDRAM, SRAM, MRAM, flash memory, etc.). In some implementations, the memory 1904 may reside within or on a processor chipset (e.g., local to the processor 1900). In some other implementations, the memory 1904 may reside external to the processor chipset (e.g., remote to the processor 1900).

[0281] The memory 1904 may store computer-readable, computer-executable code including instructions that, when executed by the processor 1900, cause the processor 1900 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as system memory or another type of memory. The controller 1902 and/or the processor 1900 may be configured to execute computer-readable instructions stored in the memory 1904 to cause the processor 1900 to perform various functions. For example, the processor 1900 and/or the controller 1902 may be coupled with or to the memory 1904, the processor 1900, the controller 1902, and the memory 1904 may be configured to perform various functions described herein. In some examples, the

processor 1900 may include multiple processors and the memory 1904 may include multiple memories. One or more of the multiple processors may be coupled with one or more of the multiple memories, which may, individually or collectively, be configured to perform various functions herein.

[0282] The one or more ALUs 1906 may be configured to support various operations in accordance with examples as described herein. In some implementations, the one or more ALUs 1906 may reside within or on a processor chipset (e.g., the processor 1900). In some other implementations, the one or more ALUs 1906 may reside external to the processor chipset (e.g., the processor 1900). One or more ALUs 1906 may perform one or more computations such as addition, subtraction, multiplication, and division on data. For example, one or more ALUs 1906 may receive input operands and an operation code, which determines an operation to be executed. One or more ALUs 1906 may be configured with a variety of logical and arithmetic circuits, including adders, subtractors, shifters, and logic gates, to process and manipulate the data according to the operation. Additionally, or alternatively, the one or more ALUs 1906 may support logical operations such as AND, OR, exclusive-OR (XOR), not-OR (NOR), and not-AND (NAND), enabling the one or more ALUs 1906 to handle conditional operations, comparisons, and bitwise operations.

[0283] The processor 1900 may support wireless communication in accordance with examples as disclosed herein. The processor 1900 may be configured to or operable to support a means for receiving, from a second network function, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determining a data set available in the mobile communications network that matches the data set requirement; and sending the data set to the second network function.

[0284] Figure 20 illustrates an example of a NE 2000 (which may be a Network Function or perform a Network Function) in accordance with aspects of the present disclosure. The NE 2000 may include a processor 2002, a memory 2004, a controller 2006, and a transceiver 2008. The processor 2002, the memory 2004, the controller 2006, or the transceiver 2008, or various combinations thereof or various components thereof may be examples of means for performing various aspects of the present disclosure as described

herein. These components may be coupled (e.g., operatively, communicatively, functionally, electronically, electrically) via one or more interfaces.

[0285] The processor 2002, the memory 2004, the controller 2006, or the transceiver 2008, or various combinations or components thereof may be implemented in hardware (e.g., circuitry). The hardware may include a processor, a digital signal processor (DSP), an application-specific integrated circuit (ASIC), or other programmable logic device, or any combination thereof configured as or otherwise supporting a means for performing the functions described in the present disclosure.

[0286] The processor 2002 may include an intelligent hardware device (e.g., a general-purpose processor, a DSP, a CPU, an ASIC, an FPGA, or any combination thereof). In some implementations, the processor 2002 may be configured to operate the memory 2004. In some other implementations, the memory 2004 may be integrated into the processor 2002. The processor 2002 may be configured to execute computer-readable instructions stored in the memory 2004 to cause the NE 2000 to perform various functions of the present disclosure.

[0287] The memory 2004 may include volatile or non-volatile memory. The memory 2004 may store computer-readable, computer-executable code including instructions when executed by the processor 2002 cause the NE 2000 to perform various functions described herein. The code may be stored in a non-transitory computer-readable medium such as the memory 2004 or another type of memory. Computer-readable media includes both non-transitory computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A non-transitory storage medium may be any available medium that may be accessed by a general-purpose or special-purpose computer.

[0288] In some implementations, the processor 2002 and the memory 2004 coupled with the processor 2002 may be configured to cause the NE 2000 to perform one or more of the functions described herein (e.g., executing, by the processor 2002, instructions stored in the memory 2004). For example, the processor 2002 may support wireless communication at the NE 2000 in accordance with examples as disclosed herein. The NE 2000 may be configured to support a means for receiving, from a second network function, a first request

for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; determining a data set available in the mobile communications network that matches the data set requirement; and sending the data set to the second network function. In some embodiments, the NE 2000 may be configured to support a means for sending, to a first network function in a mobile communications network, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement; and receiving, from the first network function, a data set that matches the data set requirement, wherein the first network function determined the data set to be available in the mobile communications network.

[0289] The controller 2006 may manage input and output signals for the NE 2000. The controller 2006 may also manage peripherals not integrated into the NE 2000. In some implementations, the controller 2006 may utilize an operating system such as iOS®, ANDROID®, WINDOWS®, or other operating systems. In some implementations, the controller 2006 may be implemented as part of the processor 2002.

[0290] In some implementations, the NE 2000 may include at least one transceiver 2008. In some other implementations, the NE 2000 may have more than one transceiver 2008. The transceiver 2008 may represent a wireless transceiver. The transceiver 2008 may include one or more receiver chains 2010, one or more transmitter chains 2012, or a combination thereof.

[0291] A receiver chain 2010 may be configured to receive signals (e.g., control information, data, packets) over a wireless medium. For example, the receiver chain 2010 may include one or more antennas for receiving the signal over the air or wireless medium. The receiver chain 2010 may include at least one amplifier (e.g., a low-noise amplifier (LNA)) configured to amplify the received signal. The receiver chain 2010 may include at least one demodulator configured to demodulate the received signal and obtain the transmitted data by reversing the modulation technique applied during transmission of the signal. The receiver chain 2010 may include at least one decoder for decoding and/or processing the demodulated signal to receive the transmitted data.

[0292] A transmitter chain 2012 may be configured to generate and transmit signals (e.g., control information, data, packets). The transmitter chain 2012 may include at least

one modulator for modulating data onto a carrier signal, preparing the signal for transmission over a wireless medium. The at least one modulator may be configured to support one or more techniques such as amplitude modulation (AM), frequency modulation (FM), or digital modulation schemes like phase-shift keying (PSK) or quadrature amplitude modulation (QAM). The transmitter chain 2012 may also include at least one power amplifier configured to amplify the modulated signal to an appropriate power level suitable for transmission over the wireless medium. The transmitter chain 2012 may also include one or more antennas for transmitting the amplified signal into the air or wireless medium.

[0293] Figure 21 illustrates a flowchart of a method in accordance with aspects of the present disclosure. The operations of the method may be implemented by a first network function (or first network Equipment) as described herein. In some implementations, the first network function may execute a set of instructions to control the function elements of the first network function to perform the described functions.

[0294] At 2102, the method may include receiving, from a second network function, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement. The operations of 2102 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 2102 may be performed by a first network function as described with reference to Figure 20.

[0295] At 2104, the method may include determining a data set available in the mobile communications network that matches the data set requirement. The operations of 2104 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 2104 may be performed by a first network function as described with reference to Figure 20.

[0296] At 2106, the method may include sending the data set to the second network function. The operations of 2106 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 2106 may be performed by a first network function as described with reference to Figure 20.

[0297] It should be noted that the method described herein describes A possible implementation, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible.

[0298] Figure 22 illustrates a flowchart of a method in accordance with aspects of the present disclosure. The operations of the method may be implemented by a second network function (or second network Equipment) as described herein. In some implementations, the second network function may execute a set of instructions to control the function elements of the second network function to perform the described functions.

[0299] At 2202, the method may include sending, to a first network function in a mobile communications network, a first request for model training, wherein the first request comprises a vertical federated learning indication and a data set requirement. The operations of 2202 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 2202 may be performed by a second network function as described with reference to Figure 20.

[0300] At 2204, the method may include receiving, from the first network function, a data set that matches the data set requirement, wherein the first network function determined the data set to be available in the mobile communications network. The operations of 2204 may be performed in accordance with examples as described herein. In some implementations, aspects of the operations of 2204 may be performed by a second network function as described with reference to Figure 20.

[0301] It should be noted that the method described herein describes A possible implementation, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible.

[0302] The description herein is provided to enable a person having ordinary skill in the art to make or use the disclosure. Various modifications to the disclosure will be apparent to a person having ordinary skill in the art, and the generic principles defined herein may be applied to other variations without departing from the scope of the disclosure. Thus, the disclosure is not limited to the examples and designs described herein but is to be accorded the broadest scope consistent with the principles and novel features disclosed herein.

[0303] As part of Release 19 study on AI/ML one of the objectives is to provide solutions to support vertical federated learning enabling the 5GS to assist in collaborative AI/ML operation involving the 5GC/NWDAF or AF.

[0304] One of the use cases is the scenario where a 3rd party application provider needs to combine data available from the application with data available from a network operator in order to train an ML model.

[0305] One use case for vertical federated learning is when the 3rd party application/3rd party service provider (e.g., a bank application) needs a model to identify the user purchasing behaviour against its mobility trends. The user can be identifiable by an application ID or by a 3GPP subscription. However, the data (features) available for the same user will be different in the 3rd party and operator network since the 3rd party will have transaction details for the user whereas the core network will have network information, e.g., mobility / location information, for the same user. Vertical Federated Learning can support model training when different domains have the same sample data, e.g., for the same users, but have different feature space.

[0306] The following points are addressed in order to support cross domain vertical federated learning:

- How an AF and 5GC ensure that both AF and 5GC have an aligned sample range, e.g., the same users, to support vertical federated learning (Data Alignment between NWDAF and AF).
- How an AF and 5GC discover what features are available between domains (for the same sample range) in order to support vertical federated learning (Feature Alignment between NWDAF and AF).
- General procedure to support vertical federated learning between AF and NWDAF/5GC.

[0307] The solution proposes a novel method to perform data alignment between the AF domain and 5GC domain during the federated learning process. The 5GC assist in

determining how available samples at the AF matches available samples at the 5GC and ensures that vertical federated learning can be supported.

[0308] A method for the NWDAF to support horizontal federated learning is known. In known horizontal federated learning methods there is no requirement for the samples between each function to be the same.

[0309] Figures 12, 13a and 13b describe one or more embodiments where NEF performs Data Alignment and FL client selection based on Federated Learning request initiated by 3rd party AF.

[0310] Figures 14, 15a and 15b describe one or more embodiments where FL Function performs data Alignment and Federated Learning request initiated by 3rd party AF.

[0311] Figures 16, 17a and 17b describe one or more embodiments where 5GC initiates VFL request to a 3rd party FL function.

[0312] There is provided a first network function performing entity alignment, which may include a VFL preparation/process.

[0313] In an aspect there is provided an apparatus comprising a first transceiver that communicates with a mobile communication network located in a first domain and a processor that: receives a first request from a first domain (e.g. AF or NEF or MTLF in 5GC) for model training wherein the request includes an identifier corresponding to the model requiring training and data sample requirements; determines a first list of Network Function supporting model training that meets the data sample requirements in a second domain; sends a second request to the (first list) of Network Functions in the second domain to initiate model training including an identifier and data sample requirements; in response to receiving from the (first list) of Network Function an indication to join the model training process responds to the first request including a second list of Network Function that can participate in the model training process based on the data sample requirements.

[0314] In some embodiments, the data sample requirements include a UE identifier (GPSI, SUPI, application id), location area, time range or a combination of.

[0315] In some embodiments, the sample range corresponds to a list of UEs, time, area or a combination of the above.

[0316] In some embodiments, the apparatus, in response to the second request, identifies a second list of FL functions that can participate in the FL process based on the available sample range.

[0317] In an aspect there is provided, for a VFL model training initiation process an apparatus comprising a first transceiver that communicates with a mobile communication network located in a first domain and a processor that: receives a first request from a first domain (e.g. AF or NEF) for model training wherein the request includes an identifier corresponding to the model requiring training and data sample requirements.

[0318] In some embodiments, the apparatus sends a second request for model training to a first list of functions supporting model training in the second domain supporting the data sample requirements.

[0319] In some embodiments, in response to receiving model training parameters, the apparatus trains the model or updates gradient/losses of the model.

[0320] In some embodiments, the apparatus sends updated trained model or updated gradient losses parameters to a first list of functions.

[0321] The following abbreviations are relevant in the field addressed by this document: ADRF, Analytics Data Repository Function; AF, Application Function; AnLF, Analytics Logical Function; DCCF, Data Collection Coordination Function; DNAI, Data Network Access Identifier; DNN, Data Network Name; ML model, Machine Learning Model; MTLF, Model Training Logical Function; NF, Network Function; NWDAF, Network Data Analytics Function; UE, User Equipment; VFL, Vertical Federated Learning.