**3GPP TSG-WG SA2 Meeting #164S2-2408888**

**Maastricht, NL, 19th Aug – 23rd Aug, 2024 (revision of S2-2408659)**

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| *CR-Form-v12.3* |
| **CHANGE REQUEST** |
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|  | **23.288** | **CR** | **1185** | **rev** | **1** | **Current version:** | **18.6.0** |  |
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| *For* [***HE******LP***](http://www.3gpp.org/3G_Specs/CRs.htm#_blank)*on using this form: comprehensive instructions can be found at* [*http://www.3gpp.org/Change-Requests*](http://www.3gpp.org/Change-Requests)*.* |
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| ***Proposed change affects:*** | UICC apps |  | ME |  | Radio Access Network |  | Core Network | **X** |

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|  |
| ***Title:***  | High level feature description for VFL |
|  |  |
| ***Source to WG:*** | Interdigital, LG Electronics, ICS, Futurewei |
| ***Source to TSG:*** | SA2 |
|  |  |
| ***Work item code:*** | AIML\_CN |  | ***Date:*** | 2024-08-09 |
|  |  |  |  |  |
| ***Category:*** | **B** |  | ***Release:*** | Rel-19 |
|  | *Use one of the following categories:****F*** *(correction)****A*** *(mirror corresponding to a change in an earlier release)****B*** *(addition of feature),* ***C*** *(functional modification of feature)****D*** *(editorial modification)*Detailed explanations of the above categories canbe found in 3GPP [TR 21.900](http://www.3gpp.org/ftp/Specs/html-info/21900.htm). | *Use one of the following releases:Rel-8 (Release 8)Rel-9 (Release 9)Rel-10 (Release 10)Rel-11 (Release 11)…Rel-17 (Release 17)Rel-18 (Release 18)Rel-19 (Release 19) Rel-20 (Release 20)* |
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| ***Reason for change:*** | Based on TR 23.700-84 conclusions, Vertical Federated Learing is agreed to be supported in 5GC, as per clause 8.2. This contribution provides a general description as to how Vertical Federated Learning is to be supported in 5GC.For Horizontal Federated Learning in 5GC, the entities involved are within the same operator’s control. Therefore, it can be assumed that for each Analytic service, which is identified by Analytic ID, NWDAFs are preconfigured with supported ML models by operators and NWDAF supporting same Analytic ID shall be able to support same ML model. For Vertical Federated Learning, however, in 5GC, AFs and NWDAFs involved in the VFL process, may support different ML models per Analytic ID. Furthermore, for same analytic ID and same global ML model, different VFL operation may be possible according to the design of different local ML model (e.g., input, output features) which depends on VFL client’s capability. Therefore, for discovery and selection of VFL clients supporting the same ML model for requested analytic ID, VFL clients need to register its capability for supported ML model and interoperatbility information. |
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| ***Summary of change:*** | 1. New clause for high level description for VFL.
2. Update on NWDAF discovery and selection for VFL.
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| ***Consequences if not approved:*** | Vertical Federated Learning (VFL) cannot be supported in 5GC. |
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| ***Clauses affected:*** | 5.2, 5.X |
|  |  |
|  | **Y** | **N** |  |  |
| ***Other specs*** |  | **X** |  Other core specifications  | TS/TR ... CR ...  |
| ***affected:*** |  | **X** |  Test specifications | TS/TR ... CR ...  |
| ***(show related CRs)*** |  | **X** |  O&M Specifications | TS/TR ... CR ...  |
|  |  |
| ***Other comments:*** |  |
|  |  |
| ***This CR's revision history:*** |  |

\* \* \* \* First change \* \* \* \*

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1], TS 23.501 [2] and TS 23.503 [4] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

DCAF Data Collection Application Function

RE-NWDAF Roaming Exchange Network Data Analytics Function

VFL Vertical Federated Learning

\* \* \* \* Next change \* \* \* \*

## 4.1 General

The NWDAF (Network Data Analytics Function) is part of the architecture specified in TS 23.501 [2] and uses the mechanisms and interfaces specified for 5GC in TS 23.501 [2] and OAM services (see clause 6.2.3.1).

The NWDAF may support the following functionalities:

- Data collection based on subscription to events provided by AMF, SMF, UPF, PCF, UDM, NSACF, AF (directly or via NEF) and OAM;

- Analytics and Data collection using the DCCF (Data Collection Coordination Function);

- Retrieval of information from data repositories (e.g. from UDR via UDM for subscriber-related information or optinally via NEF(PFDF) for PFD information);

- Data collection of location information using LCS (finer granularity location information determined by LMF);

- Storage and retrieval of information from ADRF (Analytics Data Repository Function);

- Analytics and Data collection from MFAF (Messaging Framework Adaptor Function);

- Retrieval of information about NFs (e.g. from NRF for NF-related information);

- On demand provision of analytics to consumers, as specified in clause 6.

- Provision of bulked data related to Analytics ID(s).

- Provision of Accuracy information about Analytics ID(s).

- Provision or retrieval of ML Model Accuracy Information or ML Model accuracy degradation about a ML Model.

- Verftical Federated Learning

5.2 NWDAF Discovery and Selection

The NWDAF service consumer selects an NWDAF that supports requested analytics information and required analytics capabilities and/or requested ML Model Information by using the NWDAF discovery principles defined in clause 6.3.13 of TS 23.501 [2].

Different deployments may require different discovery and selection parameters. Different ways to perform discovery and selection mechanisms depend on different types of analytics/data (NF related analytics/data and UE related analytics/data). NF related refers to analytics/data that do not require a SUPI nor group of SUPIs (e.g. NF load analytics). UE related refers to analytics/data that requires SUPI or group of SUPIs (e.g. UE mobility analytics).

In order to discover an NWDAF containing AnLF using the NRF:

- If the analytics is related to NF(s) and the NWDAF service consumer (other than an NWDAF) cannot provide an Area of Interest for the requested data analytics, the NWDAF service consumer may select an NWDAF with large serving area from the candidate NWDAFs from discovery response. Alternatively, in case the consumer receives NWDAF(s) with aggregation capability, the consumer preferably selects an NWDAF with aggregation capability with large serving area.

NOTE 1: If the selected NWDAF cannot provide the requested data analytics, e.g. due to the NF(s) to be contacted being out of serving area of the NWDAF, the selected NWDAF might reject the analytics request/subscription or it might query the NRF with the service area of the NF to be contacted to determine another target NWDAF.

- If the analytics is related to UE(s) and the NWDAF service consumer (other than an NWDAF) cannot provide an Area of Interest for the requested data analytics, the NWDAF service consumer may select an NWDAF with large serving area from the candidate NWDAFs from discovery response. Alternatively, in case the consumer receives NWDAF(s) with aggregation capability, the consumer preferably selects an NWDAF with aggregation capability with large serving area.

NOTE 2: If a selected NWDAF cannot provide analytics for the requested UE(s) (e.g. the NWDAF serves a different serving area), the selected NWDAF might reject the analytics request/subscription or it might determine the AMF serving the UE as specified in clause 6.2.2.1, request UE location information from the AMF and query the NRF with the tracking area where the UE is located to discover another target NWDAF serving the area where the UE(s) is located.

- If the analytics are related to UE(s) and if NWDAF instances indicate weights for TAIs in their NF profile (see clause 6.3.13 of TS 23.501 [2]), the NWDAF service consumer may use the weights for TAIs to decide which NWDAF to select.

- If the NWDAF service consumer needs to discover an NWDAF containing an AnLF with analytics accuracy checking capability, the consumer may query NRF providing also the analytics accuracy checking capability in the discovery request.

If the NWDAF service consumer needs to discover an NWDAF that is able to collect data from particular data sources identified by their NF Set IDs or NF types or to collect data from particular NWDAF Serving Area, the consumer may query NRF providing the NF Set IDs or NF types or Area of Interest in the discovery request.

NOTE 3: The NF Set ID or NF Type of a data source serving a particular UE, can be determined as indicated in Table 5A.2-1.

In order to discover an NWDAF that has registered in UDM for a given UE:

- NWDAF service consumers or other NWDAFs interested in UE related data or analytics, if supported, may make a query to UDM to discover an NWDAF instance that is already serving the given UE.

If an NWDAF service consumer needs to discover NWDAFs with data collection exposure capability, the NWDAF service consumer may discover via NRF the NWDAF(s) that provide the Nnwdaf\_DataManagement service and their associated NF type of data sources or their associated NF Set ID of data sources or NWDAF Serving Area information as defined in clause 6.3.13 of TS 23.501 [2].

In order to discover an NWDAF containing MTLF via NRF:

- When one or more trained ML Models are available for one or more Analytics ID(s) the NWDAF containing MTLF shall include the Analytics ID(s) that is(are) supported per service in the registration towards NRF. The NWDAF containing MTLF may wait to register in NRF the above services until at least one trained model is available. The NWDAF containing MTLF may provide to the NRF a list of Analytics IDs corresponding to the trained ML Models and possibly the ML Model Filter Information for the trained ML Model per Analytics ID(s), if available. In this Release of the specification, only the S-NSSAI(s) and Area(s) of Interest from the ML Model Filter Information for the trained ML Model per Analytics ID(s) may be registered into the NRF during the NWDAF containing MTLF registration. If the NWDAF containing MTLF supports ML Model interoperability, the NWDAF containing MTLF includes, in the registration to the NRF, an ML Model Interoperability indicator for each Analytics ID.

- The ML Model Interoperability indicator comprises a list of NWDAF providers (vendors) that are allowed to retrieve ML Models from this NWDAF containing MTLF. It also indicates that the NWDAF containing MTLF supports the interoperable ML Models requested by the NWDAFs from the vendors in the list.

NOTE 4: The S-NSSAI(s) and Area(s) of Interest from the ML Model Filter Information are within the indicated S-NSSAI and NWDAF Serving Area information in the NF profile of the NWDAF containing MTLF, respectively.

- During the discovery of NWDAF containing MTLF, a consumer (e.g. an NWDAF containing AnLF, an NWDAF containing MTLF as FL server or FL client) may include in the request the target NF type (i.e. NWDAF), the Analytics ID(s), the S-NSSAI(s), Area(s) of Interest of the Trained ML Model required, ML Model Interoperability indicator and NF consumer information. The NRF returns one or more candidate instances of NWDAF containing MTLF to the NF consumer and each candidate instance of NWDAF containing MTLF includes the Analytics ID(s), possibly the ML Model Filter Information for the available trained ML Models and ML Model Interoperability indicator, if available.

NOTE 5: NF consumer information such as Vendor ID is defined in stage 3.

- If the NWDAF service consumer needs to discover an NWDAF containing an MTLF with ML Model accuracy checking capability, the consumer may query NRF also providing the ML Model accuracy checking capability in the discovery request.

In order to discover an NWDAF containing MTLF with Federated Learning (FL) capability via NRF, in addition to the procedures described above for discovering NWDAF containing MTLF:

- An NWDAF containing MTLF supporting FL as a server shall additionally include FL capability type (i.e. FL server) and may include Time interval supporting FL as FL capability information during the registration in NRF.

- An NWDAF containing MTLF supporting FL as a client shall additionally include FL capability type (i.e. FL client) and may include Time interval supporting FL as FL capability information during the registration in NRF, and it may also include, NF type(s) and NWDAF Serving Area information and/or NF set ID(s) of the data source(s) where data can be collected as input for local model training.

NOTE 6: An NWDAF containing MTLF may indicate to support both FL server and FL client in the FL capability for specific Analytics ID.

- During the discovery of NWDAF containing MTLF as FL server, a consumer (e.g. a NWDAF containing MTLF) may include in the request the FL capability type as FL server and may include Time Period of Interest and ML Model Filter information for the trained ML Model(s) per Analytics ID(s), if available. The NRF returns one or more NF profiles of candidate instances of NWDAF satisfying the query parameters.

- During the discovery of NWDAF containing MTLF as FL client, a consumer (e.g. an FL server) may include in the request FL capability type as FL client and may include Time Period of Interest, a list of NF type(s) and/or NF set ID(s) of the data source(s). The NRF returns one or more NF profiles of candidate instances of NWDAF satisfying the query parameters.

NOTE 7: The service consumer to discover an NWDAF containing MTLF with FL capability is limited to NWDAF containing MTLF in this Release.

A PCF may learn which NWDAFs being used by AMF, SMF and UPF for a specific UE, via signalling described in clause 4.16 of TS 23.502 [3]. This enables a PCF to select the same NWDAF instance that is already being used for a specific UE.

In the roaming architecture, the NWDAF with roaming exchange capability (RE-NWDAF) to request analytics or input data is discovered via the NRF. A consumer in the same PLMN as the RE-NWDAF discovers the RE-NWDAF(s) by querying for NWDAF(s) where the roaming exchange capability is indicated in its (their) NF profile. A consumer in a peer PLMN (i.e. RE-NWDAF) discovers the RE-NWDAF(s) by querying for NWDAF(s) in the target PLMN that is (are) supporting the specific services defined for roaming. A RE-NWDAF discovers the RE-NWDAF(s) in a different PLMN (i.e. HPLMN or VPLMN) using the procedure defined in clause 4.17.5 (if delegated discovery is not used) or clause 4.17.10 (if delegated discovery is used) of TS 23.502 [3], where the detailed parameters are determined based on the analytics request or subscription from the consumer 5GC NF, operator policy, user consent and/or local configuration.

To discover an FL server or an FL client with Vertical Federated Learning functionality, via NRF, an NWDAF/AF:

- Acting as FL server shall include its FL capability information including FL capability type (i.e. FL server), FL type (i.e., VFL), Vendor ID, Time interval supporting FL and Analitic ID, during the registration in NRF.

- Acting as FL client shall include its FL capability information including FL capability type (i.e. FL client), FL type (i.e., VFL), Vendor ID, Time interval supporting FL, and Analytic ID, during the registration in NRF.

- For an untrusted AF acting asFL client, the NEF registers in the NRF, within its NF profile, information about AF, as specified in clause 6.2.2.3. The AF information is based on configuration (i.e., via OAM).

When an AF register its capability as a FL server or as a FL client, NEF may register AF’s capability at NRF on behalf of AF. When NEF registers AF’s capability for VFL at NRF, NEF may include Analytic ID which is translated by NEF based on supported analytics service information from AF.

Editor’s note:Details of ML Model handling, supported features, Feature alignment and Sample alignment are FFS.

Editor’s note: Exact wording to tell apart VFL from HFL (e.g., FS type) is FFS

\* \* \* \* Next change \* \* \* \*

5.X Vertical Federated Learning (VFL)

Vertical Federated learning is a machine learning techinique without exchanging/sharing local data set, while maintaining some level of coordination amongst VFL participants, when training and inference are performed on local ML Models, wherein the local data set in different VFL Participant for local model training have different feature spaces for the same samples (e.g. UE IDs). Vertical Federated Learning may involve multiple NWDAFs and AF.

For Vertical Federated Learning, there may be one NWDAF or one AF acting as a FL server and one or multiple NWDAF(s) and/or one or multiple AF(s) acting as FL Client(s). Vertical Federated Learning is available among NWDAFs within a single PLMN or between an AF and NWDAF(s) in a single PLMN.

The main functionalities of FL server and FL client for Vertical Federated Learning, include:

**FL server:**

- discovers and selects FL client(s) (NWDAF(s) and/or AF(s)) to participate in a VFL procedure. The NWDAF may support AnLF functionality, MTLF functionality or both.

- requests FL clients to do local model training and to report intermediate results.

- triggers sample alignment and selects samples to be used in the training process

- aggregates intermediate results from FL client(s) and computes intermediate training information (e.g. gradient information, loss information) for updating its own local ML Model and the ML Models of FL clients during the VFL training process and sends the intermediate training information towards FL clients involved in the joint VFL training process.

- In VFL inference process, it aggregates local inference result from FL clients and generates the final VFL inference result

- It sends the final VFL inference result to the consumer.

**FL client:**

- locally trains ML Model with the available local data set, which includes the data that may not be allowed to be shared with other FL clients due to e.g. data privacy, data security, data access rights.

- computes the intermediate results for their local ML Models involved in the VFL training and provide reports with the intermediate results to the AF or NWDAF acting as FL server.

- receives the updated local ML Model from FL server (e.g. gradient information, loss information) and perform an additional training iteration if needed.

When receiving a request for analytic service for an analytic ID, the NWDAF acting as a FL Server may determine to perform VFL training of models for the analytic ID or VFL inference for the analytic ID. A NWDAF as a FL server may discover and select NWDAF(s) and AF(s) as FL client(s), as described in 5.2.

An AF acting as an FL server may be initiated to perform VFL training of models for internal AF process or VFL inference for internal AF process, an AF acting as an FL server may be triggered to perform VFL training of models and/or process of VFL inference by an NWDAF. An AF acting as a FL server may discover and select NWDAF(s) acting as FL clients for an analytic service via NEF which may translate the requested analytic service information to a requested analytic ID.

When VFL training is performed, a transaction ID is assigned by FL server which will correlate the participants and an VFL based analytic service with ML models during the VFL training and subsequent VFL inference process. The detail operation of VFL training is described in clause 6.2X.

A FL server may initiate VFL inference process for an analytic ID using available trained VFL ML model for an analytic ID which is associated with a transaction ID. If there is no available VFL ML model for VFL inference for an analytic ID, the FL server may initiate VFL training procedure which may include discovery and selection of FL clients. The detail operation of VFL inference is described in clause 6.2X.

Editor’s note: Details regarding Sample alignment and features alignment functionality or whether the functionality needs to be specified are FFS.

\* \* \* \* End of changes \* \* \* \*