CCF: Redesign a simple and flexible control plane for mobile network

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Content

1. Introduction ..................................................................................... 01
2. Challenges of Current Network Architecture ............ 02
   2.1 State of the art ............................................................... 02
   2.2 Summary ........................................................................ 03
3. Introduction of CCF solution ............................................. 04
   3.1 Logical architecture overview .................................... 04
   3.2 Control Function Design ............................................. 05
   3.3 Signaling Delivery Function ......................................... 07
   3.4 Unified Database .......................................................... 08
4. Conclusion .................................................................................... 09
Abbreviations

AAA Authentication, Authorization, and Accounting
ANDSF Access Network Discovery and Selection Function
CCF Composable Control Function
CP Control Plane
CPCS Control Plane Component Service
CUPS Control/User Plane Separation
DHCP Dynamic Host Configuration Protocol
EPS Evolved Packet System
GW-C Gateway Control Plane
GW-U Gateway User Plane
HSS Home Subscriber Server
IoT Internet of Things
LCS Location Service
MCPTT Mission Critical Push to Talk
MM Mobility Management
MME Mobility Management Entity
NFV Network Function Virtualization
OFCS Offline Charging System
OCS Online Charging System
PCRF Policy and Charging Rule Function
ProSe Proximity Services
QoE Quality of Experience
SCTP Stream Control Transmission Protocol
SDN Software Defined Network
SM Session Management
SoC Service Oriented Core
SPR Subscription Profile Repository
TCO Total Cost of Ownership
TDF Traffic Detection Function
TTM Time to Market
UDB Unified Database
RAN Radio Access Network
Introduction

The industry is investigating the next generation mobile network to satisfy the potential demands from mobile ecosystem for next decade. Currently, the mobile operators are enduring high TCO and long TTM of new services caused by the increasing complexity of the network. The future mobile network is expected to be simplified and provide inherent high flexibility to enhance the competitiveness of the operators.

Most of the complex logics are concentrated in the control plane of the mobile network. How to design a simplified and flexible control plane is one of the key issues in the network architecture evolvement. In this article, a novel control plane of the future mobile network, named CCF (Composable Control Function), is introduced. As introduced in [1], CCF acts as the control plane of the SoC architecture to meet the requirements on both simplification and flexibility.

Simplification does not mean weakness of the network. On the contrary, the future network will be of more advanced features to enhance user’s QoE and explore new services. Hence, the network must be flexible enough to fulfill the abundant features in one unified architecture and keep the simplicity of the network.

The requirements on simplicity and flexibility, bring huge challenges to traditional proprietary hardware-based network. Recently, some new technologies, e.g. Software-Defined Network (SDN), Network Function Virtualization (NFV), and cloud, have been introduced as the enablers of next generation mobile network [1], which bring a possibility to re-design the mobile network architecture towards the targets of simplicity and flexibility.

The network restructure with SDN principle have been initiated in some organizations, e.g. NGMN, IETF, ONF and 3GPP. A FS_CUPS study item has been established in 3GPP SA2 to consider the architecture enhancement by Control and User Plane Separation (CUPS) of mobile gateway and TDF [2]. Current CUPS focuses on the gateway side. However, the splitting of control functions of mobile gateway will potentially trigger further evolvement of control plane to re-organize the functionalities based on their affinities.

In this article, the challenges of current control plane of network architecture are analyzed in chapter 2. Chapter 3 describes the design of control functions in converged and service-oriented modes, signal delivery and unified database in the CCF architecture. The various control functionalities and logics are decomposed and reorganized to satisfy the requirements on simplification and flexibility of next generation mobile network.


2 Challenges of Current Network Architecture

2.1 State of the art

The current Evolved Packet System (EPS) network architecture was implemented based on the proprietary hardware. Due to the tight coupling of software and vendor-specific hardware, the functionalities of each network entity are rather rigid. Extending new features usually falls into a long-time and hard struggle especially in multi-vendor environment.

When expanding the functions of existing network entities, normally new entities have to be introduced when new features are requested. As shown in the above figure, current 3GPP EPS has introduced many additional entities besides basic architecture to support various features such as ProSe, MCPTT [3].

Increasing network entities cause policy decision more sophisticated. In EPS, MME and PCRF are two control centers. More other entities, e.g. HSS, SPR, OCS, OFCS, ANDSF, and AAA, are also involved in the policy decision or context maintaining. The distributed control logic and contexts may lead to potential inconsistency.

The keeping growth of network entities also leads to more interfaces and protocols, which causes not only a complex network topology and long time to market (TTM) of new features, but also difficulties for network integration and operation, which eventually raises TCO of the operators.

Another problem caused by proprietary hardware platform is lack of dynamic scaling of capacity. Currently, the capacity of the network entity relies on the performance of the hardware. It's difficult for the whole network to support dynamic scale in and scale out based on the real-time resource demand. The network has to be planed and deployed based on the peak required capacity, thus usually causes waste of resource and energy.

### 2.2 Summary

Due to the limitations of vendor-specific hardware-based mobile network entities, current EPS network is lack of flexibility and scalability to meet diverse requirements of future services. And the increasing complexity of the whole network causes network operation to be unsustainable.

NFV and cloud are changing the foundation and implementation of mobile network. Based on these new emerging technologies, the industry could have the chance to redesign next generation mobile network to overcome the above limitations. As one of the key evolving directions, a new control plane should be considered to keep network simplified as well as enhance its flexibility.
3. Introduction of CCF solution

3.1 Logical architecture overview

Figure 3-1 shows the logic view of the target architecture of CCF, which comprises of three key elements:

• Control Function design: Reconstructs existing control plane, simplifies the complexity of interworking and provides flexibility to support diverse control functions.

• Signaling Delivery Function: Aggregates the control signaling from multiple interfaces and delivers the signaling to the appropriate control function. With SDF, the dynamic changing of control plane functions can be transparent to other network entities.

• Unified Database: Separates the state information from the control functions, implements state information migration after resource scale in/out, improves the reliability of the control plane.

![Logical architecture of Control Plane](image-url)
3.2 Control Function Design

3.2.1 Converged Control function

Control plane should be able to offer new services in a very short time-to-market manner which requires fewer control function types and interfaces to simplify the work of interworking. Massive number of connections requires less signaling interaction and higher signaling efficiency to reduce the control plane load.

Network function virtualization only realizes hardware and software decoupling for network entity without changing the existing logical architecture. If only the virtualized network entities are considered the complex interoperability does not reduce and still requires long time to add new features. The control and user plane separation of mobile gateway further increases functionality redundancy with existing control plane entities such as MME, PCRF.

The converged control function reassembles the logic functions from the existing control entities (e.g., MME, PCRF, GW-C) to reduce types of network entities. Process logics between new network functions will be converged to eliminate redundancy. Optimized procedure design reduces the signaling interactions and processing delay to avoid signaling storm.

![Figure 3-2 Implementation options of Converged Control Function](image)

3.2.2 Service-oriented control plane

The future services such as critical communication, Massive IoT, V2X introduce the diverse needs on control plane functions. It is much complex and costly if one general control plane is to serve these diverse services. The control plane shall be flexibly customized and provisioned to address the service requirements in an efficient manner.

The legacy system design tightly integrates the logic functions, and it is difficult to flexibly customize and provide the control plane functions based on service requirements. When introducing new service feature in the legacy system, the existing logic functions are often impacted and need upgrade due to the tight coupling
among the logic functions. Thus it is often inefficient and costly when introducing the new service feature into the legacy system.

By service oriented approach, CCF abstracts the logic functions into the independent service component(s), and these service components are flexibly composed to support multiple network services.

![Figure 3-3 Service-Oriented Control Function](image)

As depicted in the figure, there are the following main elements in Service-Oriented Control Function architecture:

- **External Interface Function**: It realizes the standardized interface towards the external entities/domains.
- **Control Plane Component Service**: It realizes the self-contained functions and exposes its service via light weight interface.
- **Composed Control Plane Service**: It specifies the workflow to realize the network service via composing the related service components.
- **Control Plane Service Controller**: Service Controller is responsible for service invoking.
- **Service Management Framework**: It provides the service management function such as service communication, monitoring, and etc. The service consumer and the service provider may directly interwork via the lightweight and high-performance protocol.

In the architecture, Composed CP Services are customized and provisioned to support the diverse network service requirements via the service orchestration and composition, and the Control Plane Component Service can be added and updated without impacting other component services. Thus the service feature is able to flexibly provision and initiate in the architecture.

Compared with the legacy system which tightly integrates the logic functions, the architecture is beneficial to simplify network service development and provisioning, and to efficiently enable the flexibility and simplicity required by the future network such as Network Slice. The complexity and cost on introducing new service features can be greatly reduced for operators.
3.3 Signaling Delivery Function

Control plane will become more flexible and dynamic:

- Multiple slices for different user cases (e.g., mission critical, massive connection, mobile broadband)
- Multiple entities for different administrative domains (e.g., enterprises, industries, virtual operators)
- A variable number of control function to implement resource scale in/out

All of this requires a simple and flexible signaling delivery mechanism to deliver the control signaling to the appropriate slice, control function.

Existing control entity is generally selected by the surrounding network entities such as RAN, the connection relationship is statically configured which requires complex maintenance operation to adapt to the dynamic changes in the number of network entities. Some virtualized network entities implement resource scaling in/out via the internal signaling delivery component. The inner parameters of each signaling from multiple interfaces are resolved which results in complex signaling process and degraded performance. Independent control function selection results in duplication of signaling process and is difficult to enforce flexible delivery policies.

An independent signaling delivery function is introduced to aggregate control signaling, select the corresponding control function in the appropriate slice and deliver the signaling of the same user from multi interfaces to the processing control function. The control signaling is optimized and adapted, only the parameters of the very first signaling are needed to be resolved to implement signaling delivery. A new and unified signaling transport protocol is defined between the signaling delivery function and the control function which avoids repeatedly handling multiple signaling transport protocol, such as SCTP, TCP, UDP, etc.

As a unified and single signal entrance, the signaling delivery function hides the flexibility and dynamics of control plane, simplifies the configuration and management complexity of the surrounding network entities (e.g. RAN, user plane, DHCP server), reduces the delay of signaling processing and improves the efficiency of signaling delivery. Based on user profile, device, location, access and load information, the signaling delivery function can flexibly adjust the delivery policy without interrupting the control procedure.

Figure 3-4 Signaling Delivery Function in CCF
3.4 Unified Database

In order to meet the reliability requirements after control plane virtualization, the state information backup across data centers should be supported for fast failover. The elastic control plane has the capabilities to dynamically scale-in/out resources as traffic demands increase/decrease which requires flexible data synchronization across any control functions.

Traditional 1+1 or N+1 backup mechanism relies on private signaling interaction to synchronize state information across entities or components, implementation specific synchronization mechanism leads to complex and inefficient, limits the interoperability across the products of different vendors. The synchronization relationship is statically configured which makes it difficult to flexibly synchronize state information.

By separating data and processing logic, the data can be stored in a unified database. The state information can be accessed from the database via a unified interface and data model which facilitates the data sharing across any functions. After scaling or fault, the database can proactively push batch data to the target function to reduce the signaling and time required for state synchronization. With the help of the distributed database synchronization technologies, the state information can be backed up across data centers in a real-time and reliable manner.

The unified data access interface simplifies state information acquisition process and reduces required signaling for synchronization. By interacting with the management system, the data can be flexibly synchronized according to the load or failure information without manual participation. The unified database will further contain other context information, such as terminal, radio and application. Centralized data management facilitates data analysis and openness.

Figure 3-5 Distributed database for data sharing
The future network will focus on the operation efficiency and flexibility to address the diverse business applications and user experience other than just the pursuit of the greater bandwidth and volume. In this article, a control plane of future mobile network is introduced which includes three aspects:

For control function design, the logic control functions are converged to reduce the types of network entity and the number of interfaces, simplify the interworking and improve the efficiency of control plane. Furthermore, the logic control functions can be composable through service oriented approach to support the flexible control plane required by diverse services. All of these characteristics accelerate the TTM of new features.

Signaling Delivery Function shields the impact on other network entities introduced by control plane cloud-lization, simplifies the signaling resolution complexity, implements flexible control entity selection and automated signaling delivery after scaling in/out.

Unified Database facilitates the data sharing across control functions and third parties, reduces redundant state information and simplifies data synchronization and backup for faster fault recovery and dynamic scaling in/out.

With above functions, the control plane supports to build a service oriented network to flexibly and efficiently respond to the user needs, and offer consistent and high-quality services for different business requirements.

Conclusion
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