Service-based Slice Selection Function for 5G

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***Abstract*—Through successive technological innovation, mobile networks have been able to cope with traffic growth and the changing nature of services. However, there is still a gap between the possible transformation in terms of performance and efficiency, and the emerging new service requirements. This paper presents the ongoing mobile network evolution towards 5G, with a focus on the emerging network slicing concept, supposed to cope with the disparate requirements of future services and applications. Network slicing allows for the coexistence of different architectures to address disparate service requirements in a more efficient way. A slice selection function is a key element in the future core network architecture, enabling the UE to be allocated to a proper slice. We proposed a new slice selection mechanism allowing the UE to connect to multiple slices based on service type. The standardization status on this matter and the technical aspects of the proposed selection function are discussed.**

Keywords*—*Network slicing, Décor, 5G, CIoT, CUPS, NFV, SDN, NextGen and Slice Selection Function.

I. Introduction

Mobile networks have experienced a constant evolution, from the circuit-switched based analogue voice system to supporting a wide variety of millions of applications and billions of users generating huge amounts of data traffic. We are witnessing an unprecedented mobile data traffic growth, which has reached 3.7 exabytes per month at the end of 2015 and is expected to reach 30.6 exabytes per month by 2020 [1]. The reasons behind this explosion are manifold; we list the most relevant here:

- **Innovation in the mobile terminal:** User Equipment (UE) capabilities have been progressing at high pace. 2G UEs started out as simple devices with voice and messaging services. This evolved to UEs capable of receiving data over a packet switching network on top of a circuit switching network. Advancement in UE technology enable now of more and more complex and data intensive mobile applications (e.g. context-awareness applications, online-games, health care and social media). This has dramatically increased data traffic usage. In fact, everyday a new use case is emerging that can easily challenge the network's capabilities.
- **Innovation in the mobile network:** growing mobile data traffic is one of the main drivers of the dramatic and fundamental technological changes in the mobile network. Long Term Evolution (LTE) has helped the network operators to keep up with the traffic growth by increasing the radio access capacity, while lowering the cost per bit. However, the mobile network transformation must continue to keep up with innovation in mobile terminals and their service requirements.

Emerging services with a wide variety of needs impose stringent requirements on the mobile network. For example, moving an object on a touchscreen in real time (i.e. tactile Internet) produces approximately $1mm$ differential displacement between pressing the screen and the reaction if the finger is moving at a speed of $1m/s$ with $1ms$ latency [2]. Similarly, the expected required latency for a vehicular communication (i.e. V2X services) is less than $10ms$. Service requirements from a wide range of devices (e.g., smartphone, wearables, sensors) and applications (e.g. tactile Internet, mission critical machine type communication) impose unprecedented requirements to the current *"one-size-fits-all"* mobile network architecture. To cope with these extreme service requirements, the current EPC (Evolved Packet Core) needs to be revisited. EPC architecture is the result of a *"one-size-fits-all"* approach, in which all services are similarly treated by the EPC network entities such as Serving Gateway (SGW) and PDN Gateway (PGW). This is an efficient approach when requirements for different services are mostly similar, as it was the case when EPC was designed, but can easily reach its limits when required difference strongly.

EPC network entities are tightly coupled in two dimensions: (i) control and user plane, and (ii) hardware and software. As a result, it is difficult to roll-out the new functions and services due to vendor lock-in, and flexibly allocate the required resources in a cost-effective manner to cope with future service requirements and the associated data volumes.

On these grounds, emerging technologies such as Network Functions Virtualization (NFV) and Software Defined Networking (SDN) enable improvements in network efficiency, programmability and flexibility. SDN separates the control and user plane of the network elements, and logically centralizes the network intelligence in the controller [3]. Such a centralized controller enables the network operator to steer the data traffic during run-time, and enables the automation of tasks such as configuration and policy management. NFV moves away from the principle of dedicated proprietary hardware for network functions by leveraging on virtualization technology. NFV decouples the network function (e.g., gateways or firewall) from hardware, making it possible to implement the network function on standard high-volume commodity servers, switches, and storage [4]. It does not only promise a cost reduction, but also enables a fast time to deploy new services and quickly scaling the network functions as needed.

This paper is structured as follows. In section II we introduce briefly the Mobile Network evolution. The emerging slicing concepts to cope with the disparate requirements of future services and applications are introduced in Section III. A slice selection function appears then as a key function in

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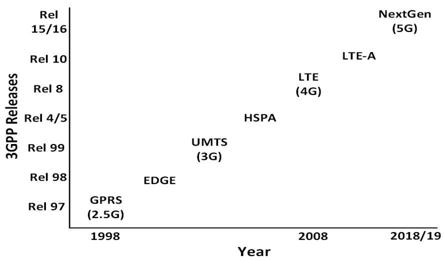

Fig. 1. Cellular system technology revolution [7].

the future Core Network architecture. We discuss a proposed new selection function based on terminal and service type in Section IV. This proposed function allows multipurpose terminals to select separate slices for different services. The technical aspects of the proposed solution are discussed and the current standardization status and impacts are given.

II. Mobile Network Architecture Evolution

Mobile networks have evolved from analog to digital services and from a circuit switching to a packet switching network. Within 25 years mobile subscriber numbers worldwide grow from 0 to over 4.7 billion [5]. This enormous success is backed up by the mobile operator's commitment to provide best communication services and technology to the end-users.

A. Standardization Activities on Architecture evolution

3rd Generation Partnership Project (3GPP) is a telecommunications standard development organization which provides their worldwide members with a stable environment to produce the specifications that define the mobile network architecture and related technologies [6]. Standardization activities are the key for interoperability and worldwide network operation and evolution.

Fig. 1 shows the mobile network technology evolution from the 2.5G networks up to the upcoming NextGen (5G) networks being discussed within 3GPP. Packet data over cellular system became a reality during the second half of the 1990s with General Packet Radio Services (GPRS). 3G and 4G technologies are available in early 2001s and 2010s, respectively. Recently, the Fifth Generation (5G) core network design study item started a *"NextGen"* in 3GPP. The first 5G release is expected to be Rel-15, which will address only a subset of the requirements of IMT-2020 [8] while Rel-16 will address the full requirements.

*1) **LTE/EPC Architecture**:* 3GPP LTE/EPC (i.e. 4G) architecture has been first introduced in 3GPP release 8 in 2008, in which EPC is a flat IP-based network with separation of control and data plane. The architecture is composed of the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the EPC core as shown in Fig. 2.

The four major network entities of EPC that are of interest here are Mobility Management Entity (MME), Serving Gateway (SGW), PDN Gateway (PGW), and Home Subscriber Server (HSS). The eNBs (eNode B) are connected to the MME and SGW by means of the S1-AP and S1-U interfaces. The MME acts as the manager of the network connectivity. It is

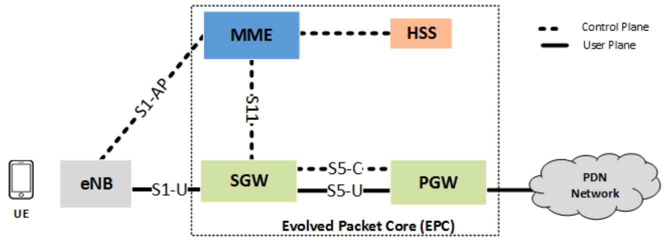

Fig. 2. 3GPP LTE/EPC architecture

responsible for UE authentication and authorization, UE session setup, and intra-3GPP mobility management. The SGW and PGW are responsible for data forwarding, IP mobility and QoS control in the data plane [9].

*2) **Cellular Internet of Things (CIoT)**:* Machine Type Communication (MTC) and IoT is a novel paradigm with a rapidly growing interest in the industry (i.e. operators, vendors, verticals) and standardization bodies. In the near future, billions of MTC and IoT devices are expected to be connected to one another and with the network. Forecast show that approximately 26 billion IoT devices will be connected together by 2020 [10]. Traffic produced by IoT devices is very different from smartphones traffic and several hundred thousands of them might exist per square kilometer.

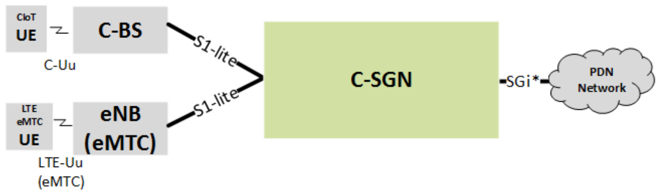

Fig. 3. Lightweight Core Network (CN) architecture for CIoT [11]

In this regards, a study item was started in 3GPP SA2 to study and evaluate the architecture enhancement needed to support IoT devices (e.g. ultra-low complexity and low data-rate IoT devices) [11]. In this study item, the operators are working on enhancing the current EPC architecture and at the same time on designing a complete new architecture for later phases. Enhancing the current architecture includes changing some of the existing functions in the entities [12]. For instance, the mobility function in the MME is not required for some of the IoT devices (e.g. sensor, smart meter), since these devices are fixed geographically to a location during their operational lifetime. Thus, the network entities are build with set of necessary functionalities. Different enhancement proposals can be found in the current study item [11].

Another possibility is to design a complete new architecture. Fig. 3 shows the proposed Lightweight Core Network (CN) architecture for CIoT devices [11]. This lightweight CN is composed of a single CIoT Serving Gateway Node (C-SGN) which supports reduced but necessary functionalities of existing EPC entities (i.e. MME, SGW and PGW). This C-SGN gateway is connected to the LTE eNB and also a new CIoT base station by means of the S1-lite interface, which also supports reduced and necessary functionalities of S1-AP and S1-U interfaces. Unlikely with current EPC, in Lightweight CN the control and user planes are combined, and both control messages and user data are sent on the S1-lite interface.

3) Control and User Plane Separated Architecture (CUPS): Currently, EPC entities are deployed in a hierarchical manner, and forcing all user traffic to pass through these centralized functional entities. Centralizing all user plane functionalities in the S/PGWs makes the network remarkably inefficient, complex and inflexible. In addition, it may also increases the network delay and network bottlenecks. Thus, a study item was started in 3GPP SA2 on the C/U-plane separation architecture [13], the core network entities (i.e. SGW, PGW) are decoupled into control plane and user plane entities. For example, a SGW will be decoupled into SGW-Control plane (SGW-C) and SGW-User plane (SGW-U) entities as shown in Fig. 4. Besides the ability to independently scale the different entities when they are decoupled, such a separation also allows to flexibly place U-plane functions close to the RAN (i.e. near eNBs), and hence improve the user's experience, for example for low latency services.

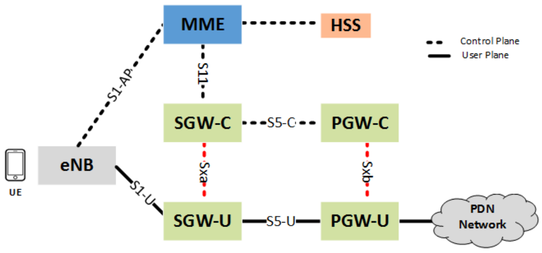

Fig. 4. 3GPP EPC based CUPS architecture [13]

The new interfaces Sxa and Sxb are introduced between the control and user plane entities. The protocols used on these interfaces are not yet standardized, possible protocols can be GTP-C (GPRS Tunneling Protocol) or SDN based protocols like OpenFlow. GTP-C here has the advantage that it does not require (much additional) standardization effort, and it is already supported by other EPC entities (e.g. S11 and S5-C interfaces).

4) Next Generation (NextGen) Core Network: New services will require, for example, massive connectivity, extreme broadband, ultra-low latency, ultra-high reliability [14]. These requirements impose great challenges on the existing core network. Among these challenges is how to make evolve the existing core network, built on custom equipment and based on static network behavior and computationally heavy protocols ultimately leading to high CAPEX and increasing network operational cost.

The NextGen architecture (i.e. 5G) shall support a new RAN (i.e. 5G base station), LTE eNB and also non-3GPP access base stations (e.g. WiFi) [15]. In addition, the NextGen architecture should be as cloud-friendly as possible, such that its elements can be efficiently implemented in a cloud computing environment.

Compared to current EPC, proposals for a NextGen architecture show fewer entities such as control plane gateway (CP-GW) and User plane gateways (UP-GW), see Fig. 5. The CP-GW contains the Mobility Management (MM) Session Management (SM) functions and these functions can be enhanced functionalities of MME, SGW-C and PGW-C. Similarly, UP-GW is composed of necessary functionalities of SGW-U and PGW-U. These CP-GW and UP-GW entities run as software

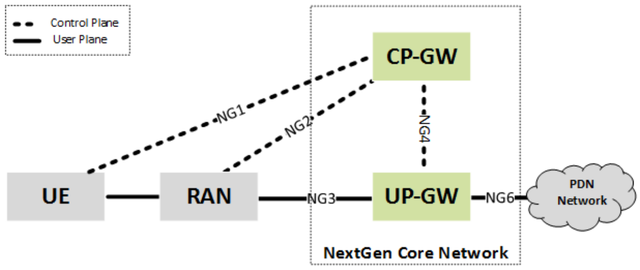

Fig. 5. NextGen (5G) core network architecture proposal [15]

components on operators' telco-cloud systems rather than using dedicated hardware components. The implementation of the indicated interfaces NG1, NG2, NG3, NG4 and N5 is a large area for discussion. However, it is clear that already from a cost perspective, keeping the interfaces towards the RAN as similar as possible to todays interfaces (or even the same) is the most logical choice.

III. Network Slicing

Traditionally, telco networks mainly target mobile phone like devices (e.g. smartphones, tablets, etc.). But, in the future, the mobile network needs to serve a wide variety of devices (e.g. MTC devices, vehicular devices, etc.) with different requirements. Thus, the idea of providing multiple isolated network slices for a variety of services on a common infrastructure is emerging in the telco industry.

A slice is composed of a collection of logical customized network functions that supports the communication service requirements of particular use cases or business models [14]. In detail, the operator's physical network is sliced into multiple virtual and end-to-end (E2E) networks and each slice is logically isolated. Each slice has a dedicated treatment in terms of performance (e.g. latency, throughput, etc.) or functionality (e.g. resiliency, security, etc.).

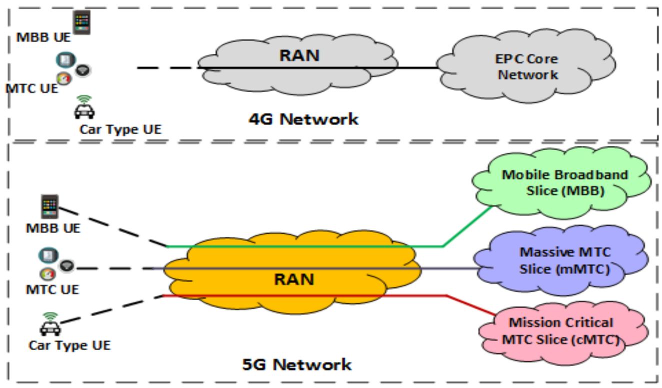

Fig. 6. 4G and 5G core network mapping based on the UE type. Slicing is an End-to-End solution.

Fig. 6 shows a potential mapping of network slices based on the UE type alone. In 4G, the network does not differentiate the UEs and treats all UEs in the same manner ("one-size-fits-all"). On the contrary, in the proposed 5G network, the UEs are treated separately based on the UE characteristics (i.e. UE Usage type). Each UE type is connected to the specific network slice which is specially designed for this UE type. For example, Machine type communication (MTC) UE type is connected to the MTC slice and Mobile Broadband (MBB) UE type is connected to MBB slice.

A. Network slice design principles

Network slices (NS) are designed based on the specific requirements of each use case. However, providing a different slice for each use case might not be the best solution, since the network's operational complexity is expected to grow with the number of network slices. Thus, we propose that the number of slices in the network should be the minimal set covering all use case requirements.

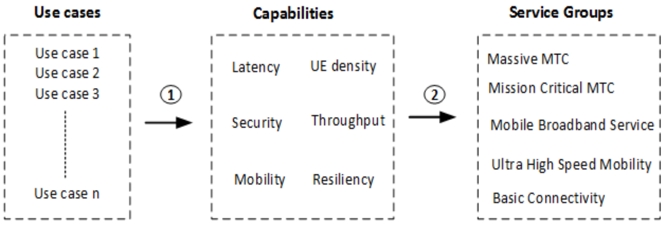

Fig. 7. Use case grouping to identify service groups.

In this regard, we propose to design the NS based on the requirements of service groups, rather than on the requirements of each individual use case. As the requirements of different use cases overlap, they can be naturally grouped into a service group. Fig. 7 shows a use case grouping based on overlapping capabilities. Grouping the use cases into service groups is done in two steps: (i) the 5G use cases ([14] and [16]) are mapped to the key network capabilities. The key network capabilities are those that satisfy the use case requirements to achieve a desired level of user experience, such as latency, density, security, throughput, mobility and resiliency. For example, these capabilities are mapped to a degree of compliance from 0 to 3 representing each a range of the associated KPIs (e.g. degree from 0 to 3 where 3 is most stringent range and 0 is lowest). (ii) The use cases which focus on similar capability requirements (i.e. similar range of KPIs) are grouped in a service group. Hence, each service group provides those grouped use case requirements. For example, the Massive MTC ($mMTC$) service group most stringent capabilities are UE density and security, and other requirements can be relaxed. Thus, this $mMTC$ network slice is designed with highest density with ultra-high security capabilities.

IV. Slice Selection Function

Although the 5G core network architecture is still under discussion, it can be expected that it will consist of a set of different architectures that also encompass EPC. Different services are currently identified through the UE type, so at first the UE types are mapped to the corresponding slices. For example, EPC, CIoT, CUPS and NextGen architectures are mapped to different network slices (e.g. NS1 for EPC, NS2 for CUPS and NS3 for CIoT, etc.) and run on top of operators' telco-cloud systems. The UE's are divided into the UE Usage type based on the UE characteristic i.e. there is only one "UE Usage Type" per UE subscription [9].

Fig. 8 shows the future mobile core network accommodating different slices (i.e. NS1, NS2 and NS3). Each slice is composed of different network functions (NF) that can be control plane (CP) functions or user plane (UP) functions, or combined control and user plane functions (CCUPS). For instance, NS1 is composed of different sets of CPs and UPs

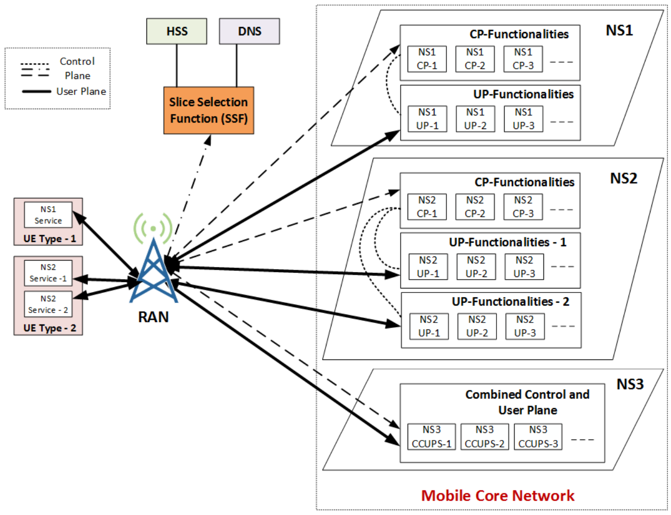

Fig. 8. Different 5G architecture running in the operator's core network.

which serves a specific UE type. The control plane functions in the NS1 can be MME, SGW-C and PGW-C and user plane functions can be SGW-U and PGW-U.

A. Slice Selection based on Décor solution

3GPP Décor introduced in Rel-13 specifies how one or more dedicated core networks within a Public Land Mobile Network (PLMN) can be selected for specific types of subscribers (i.e. UE usage type) [9]. This selection operation can be done by selecting a dedicated control plane (MME) and then the appropriate user planes (SGW and PGW) according to the UE usage type. This technology can be used as a tool to apply different network functions for different service scenarios. The eNB is able to communicate with the dedicated CN (e.g. slice) based on UE usage type provided by the UE or else by the HSS (more details in [9]).

The network slice and the corresponding functions are designed to provide specific services for the UE usage type. For instance, voice and video services for MBB UE types, and ultra-low latency with high mobility service for the Car UE types, etc. However, UE characteristics are dynamic and unpredictable. For example, a Car UE might demand video services for back seated users that want to watch a movie while traveling. At the same time, the other services related to the Car UE type should be active. Décor solution is limited to select a single slice based on UE usage type, but not multiple slices based on service requirements. Thus, we here propose a new "Service-based Slice selection function".

B. Service based Slice Selection Function (S-SSF) for NextGen

We propose in the paper to select multiple slices based on service type for a UE additionally to the UE usage type. The Slice Selection Function (SSF) is a separate entity in the network which is connected to the eNB, HSS and DNS (Domain Name System) as shown in Fig. 9. SSF can be placed as individual function or place in any default CP function like in default MME in Décor. The SSF directs the eNB to route the UE traffic to a specific slice based on UE usage type and service type parameters. Services such as voice, video, ultra-low latency are mapped to the service type parameter which is unique for an application in the network. This service type will be operator specific and configured in the UE dynamically (e.g. through the SIM card). Fig. 9 shows the mobile core network with two different network slices. NS1 is belonging to the Car UE type and NS2 is belonging to the MBB UE type. We have considered EPC network functions for simplicity in each slice (i.e. NS1 and NS2), but there can correspond to other architectures than EPC.

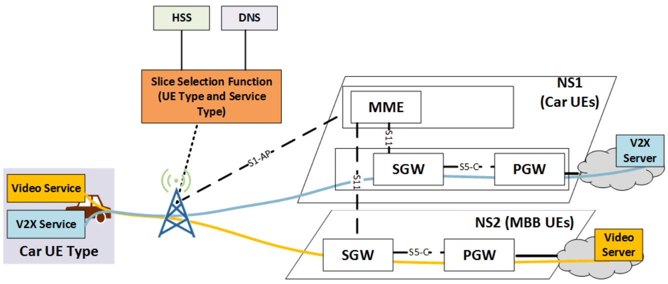

Fig. 9. Service type based Slice selection function for to select multiple slices for a UE type.

In Fig. 9, NS1 functions such as MME can be considered as the CP and the SGW and PGW can be considered as UP. The MME in NS1 is connected the network functions in the NS2 (i.e. MBB SGW and PGW) based on the request from the SSF. The main and default slice for the Car UE type is NS1 (Car type NS). When the Car UE type requests a MBB service which is served by NS2, the MME in NS1 will establishes a secondary bearer (temporary bearer) for a UE in NS2 based on the command from the SSF. Thus, a Car UE type can obtain the V2X service and MBB service simultaneously by connecting to two different network slices as shown in Fig. 9.

*1) **Network Slice Attach Procedure**:* In what follows, we present two session establishment procedures for a UE to obtain services from two different slices simultaneously.

a) NS1 Attach Procedure (V2X Service): Initial attach procedure in EPC enables the UE registration to the network during the UE initial power on [9]. The UE sends the Attach Request message that includes its identity to the eNB. After receiving the Attach Request message, the eNB forwards the message to the MME. But, in our proposal, the eNB extracts the UE usage type and service type (e.g. Car UE type and NS1 service type), and forwards this information to the SSF (flow#2 in Fig. 10). The SSF then sends the DNS Query Request to the DNS and obtains the list of available NFs (i.e. MMEs, SGWs and PGWs) for the combination of UE type and Service type in the DNS response message. For instance, if the UE is not provided the service type parameter, then SSF uses the default service parameter (it can be extracted from the HSS). After successfully obtaining NF list, the SSF selects the MME, NS1-SGW and NS1-PGW based on the operator's policy (e.g. present load of the gateways, UE location, etc.) and sends the Selection Response message to the eNB with selected MME, NS1-SGW and NS1-PGW information. Then, the eNB forwards the Attach Request message to the selected MME with a selected NS1-SGW and NS1-PGW information, and the MME establishes the bearer with NS1-SGW and NS1-PGW for a V2X service as shown in Fig. 10 (from flow#8 to flow#16).

In our proposal, there is no more selection function (i.e. S/PGW selection) in the MME and all network function selection takes place in the SSF. The SSF can however be placed within the MME for certain implementations. In addition, it is also possible that the SSF only selects the MME and then the MME selects the SGW and PGW (i.e. similar to EPC procedure). For this, the MME requires a new selection mechanism to select the SGW and PGW based on the service type parameter. In this paper, we consider that a SSF selects all network functions in the slices (e.g. MME, SGW and PGW).

b) NS2 Attach Procedure (MBB service): According to the previously described procedure, the Car UE type is already attached to the network and using the V2X services from NS1. Now, the same Car UE type wants to use another service on a different slice. For example, a UE requests a video service which is served by the MBB slice (i.e. NS2). In this case, the UE sends the Resource Modification message to the eNB, this message includes a new service type parameter (i.e. NS2 service type). The eNB sends the Selection Request message with NS2 service type to the SSF. The SSF extracts the available network functions in the NS2 from the DNS server and sends the selected NS2 function information (i.e. MME, NS2-SGW and NS2-PGW) to the eNB. The eNB then sends the Resource Modification message to the old MME (i.e. the UE is attached to this MME for NS1 service) with the new NS2-SGW and NS2-PGW information. The old MME will establish the secondary bearer in the NS2 as shown in Fig. 10 (from flow#24 to flow#32).

Another possibility is that the SSF can select a new MME in the NS2 (flow#21 in Fig. 10). In this case, the new MME will establishes a bearer in NS2-SGW and NS2-PGW. But, the UE will have a connection with two control plane functions (i.e. NS1-MME and NS2-MME), which might create conflicts and increases the complexity (i.e. tracking updates, ECM connectivity, etc.). Thus, we propose a solution in which a UE is connected to a single control plane entity and multiple user plane entities in different slices. Current 3GPP specification does not allow a UE to connect to multiple SGWs simultaneously. We believe that in the 3GPP NextGen architecture, this possibility is likely to be adopted and our proposal will pave the path for accessing these multiple user plane entities simultaneously.

C. Selection Function Comparison

Table I gives a general overview of which parameters are used by different technologies to select the network functions. 3GPP EPC uses location parameters which are (i) UE location (e.g. TAI list, ECGI) and (ii) service/application location (APN type) for selecting the network entities (e.g. SGW and PGW). In addition to these location parameters, the selection function also takes into consideration each entity traffic load [9]. For example, the MME selects the SGW based on a network topology, gateway load (from DNS), APN type, but it does not use the UE Usage Type and Service type parameters. On the other hand, the Décor selection function uses a UE Usage Type parameter to select a dedicated MME and this selected Décor MME uses the location parameters to selects other entities (i.e. SGW and PGW), which is similar to the EPC selection mechanism.

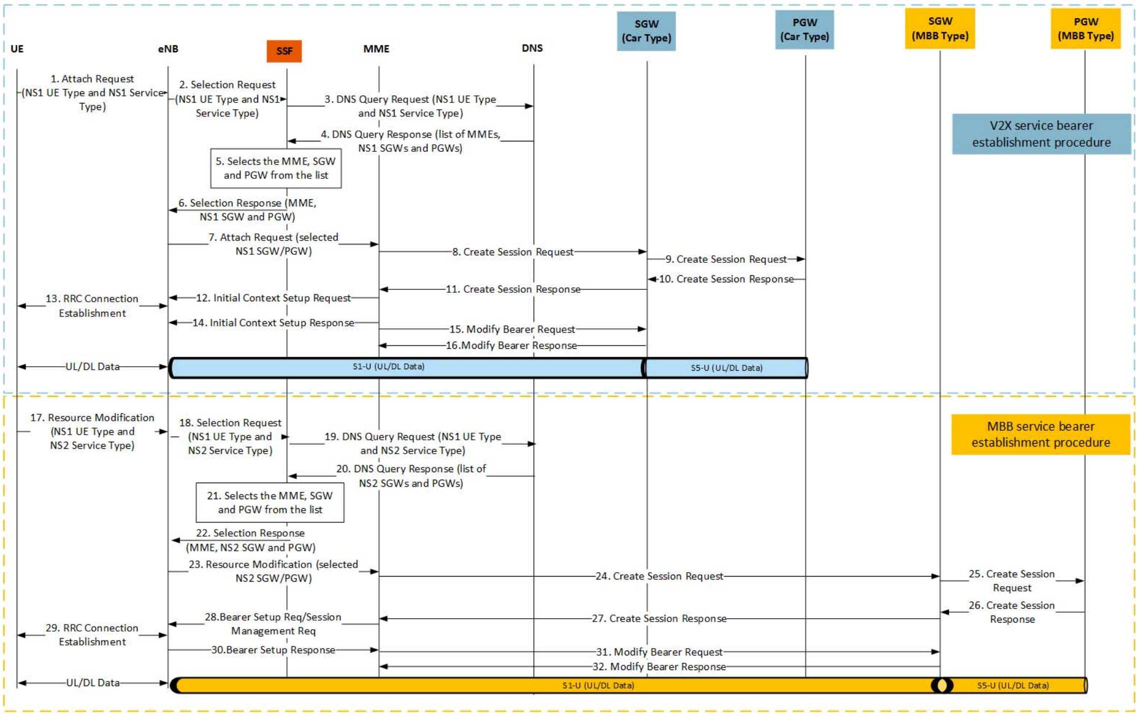

Fig. 10. Signaling flow for a UE to connect two different network slices.

TABLE I. SELECTION FUNCTION PARAMETERS ARE USED IN DIFFERENT TECHNOLOGIES.

Technology	Location	UE Usage Type	Service Type
3GPP LTE/EPC	x	-	-
Décor	x	x	-
S-SSF	x	x	x

The S-SSF for NextGen architecture as being discussed currently uses a Service Type parameter in addition to the UE Usage Type parameter for selection of any entity in the network. A new selection function (i.e. SSF) introduced in the NextGen architecture based on this proposal selects the network functions based on the location, UE Usage type and Service Type parameters.

V. CONCLUSIONS

We have presented in this paper the mobile network evolution and related standardization status on EPC architecture towards 5G. In the 5G era, network slicing becomes a key concept allowing for the coexistence of different architectures and resource allocations on a common infrastructure. We introduce the network slicing terminology and slice design principles based on service group capability requirements, and discuss the importance of slice selection function in the 5G core network. We propose a new slice selection mechanism to select the appropriate network slice based on UE usage type and service type to address the case of multipurpose UE devices. The proposed mechanism allows the UE to connect to multiple slices for different services. Future work includes validating the proposed solution in a proof of concept.

We believe that the mechanism proposed in this paper will pave the way to a seamless experience for the user, offering at the same time session continuity through different usage contexts of multiple services, while maximizing the network efficiency for the operator.

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