Service-Aware Network Reconfiguration for 5G Networks

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Sina Khatibi, Farid Sheikh
Nomor Research GmbH, Munich, Germany

Summary

The next generation of mobile communications, also known as 5G, aims to address current and future IP-tsunami capacity problems while meeting the various service requirements. It is necessary to increase the network capacity and flexibility to meet the different Quality of Service (QoS) requirement of different services. The approach proposed by 5G NORMA project is to achieve the service flexibility by means of decomposition of mobile Network Functions (NFs) and to place them in different cloud data centres. The placement of NFs is done adaptively based on the service requirements. This whitepaper briefly present the concept of Software Define Mobile network Controller (SDM-C) in addition to a report on the proof-of-concept within the framework of the 5G NORMA project.

I. Introduction

The next generation of mobile networks, also known as 5G mobile networks, will face rapid growth of mobile traffic demand as the consequence of diverse traffic-hungry application [1]. In addition to shortage of network capacity, the drastic temporal and geographical change of traffic demand are the challenges in designing 5G mobile networks. Hence, achieving higher flexibility while reducing the CAPital and OPerational Expenditures (CAPEX and OPEX, respectively) costs [2].

5G NORMA is an EU-funded research project, which is working towards this goal of proposing a new network architecture for 5G Networks. By means of Network Function (NF) decomposition and allocating them to the edge cloud and central cloud, 5G NORMA supports the service flexibility [3]. This allocation is done adaptively based on service attributes such as the required bandwidth and latency as well the transport network capabilities. The network architecture proposed under 5G NORMA, has a number of new network elements. Two of these main elements are the Software Defined Mobile network Controller (SDM-C) and SDM-Coordinator (SDM-X). These two elements highlighted in Figure-1.

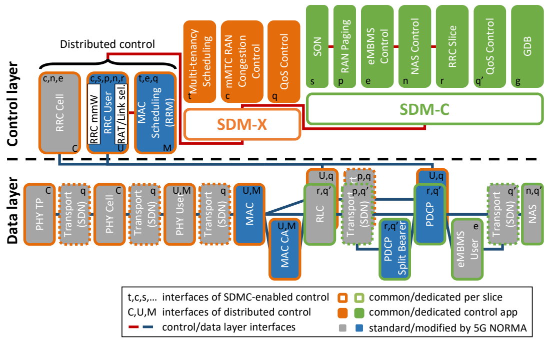

Figure 1 – 5G NORMA RAN functional architecture (extracted from [4]).

The figure also shows the important tasks and the role of these elements. The work presented in this paper will focus on SDM-C and its tasks, as the key element for resource management and network re-configuration.

This whitepaper described the details of 5G NORMA demo entitled as "Native Multi-Service Architecture" [5]. The aim of this demo is to present the proof-of-concept for a flexible, adaptive, intelligent, and service-aware (de)composition of NFs and services. The demo is composed by two parts, software (SW) and hardware (HW), developed by Nomor and Azcom respectively. Nomor contributes to the demo software developments and Azcom contributes to the demo hardware developments

II. Native Multi-Service Architecture Demo

In order to provide a proof-of-concept for a flexible, adaptive, intelligent, and service-aware (de)composition of network functions and services, a comprehensive software + hardware demo has been developed. The demo is composed by two partners: Nomor and Azcom. Nomor contributes to the software development and Azcom contributes to the hardware developments.

The key elements of this demo are shown in Figure-2; they are:

- A Software Defined Mobile Network Controller (SDM-C) and software eNodeBs (eNBs) provided by NOMOR, which defines the software demo;
- A hardware (HW) eNB provided by AZCOM, which together with the SDM-C are composing the HW demo.

SDM-C is in charge of (de)composition of NFs in order to optimise the network for high data rate demanding services (e.g., HD video streaming) as well as low-latency services (e.g., autonomous driving). SDM-C is connected with the eNBs using a bi-directional link:

- To receive the relevant Key Performance Indicators (KPIs) such as the received signal strength, the active service-type, and load in both downlink and uplink directions.
- To (re)configure the placement of the network functions in the edge-cloud (i.e., deployed at eNB with low latency and limited processing resources) and central-cloud (i.e., placed in the core network with relatively higher latency and more processing resources).

Based on feedback reports provided by eNBs, the SDM-C sends reconfiguration commands to the eNB schedulers. This message exchange is done by means of a dedicated communication protocol (described in the following sections) via the southbound interface (SBI).

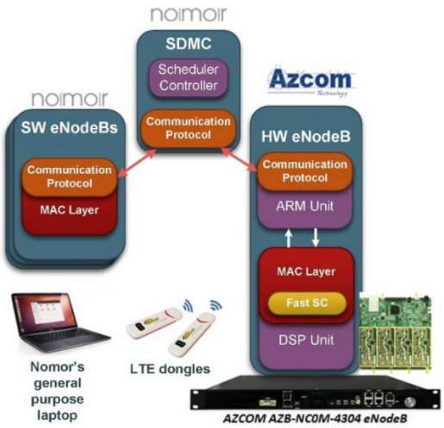

Figure 2 – Key elements of demo (based on [5]).

The scheduler of the hardware eNB is referred to as the Fast-SC (Fast Scheduler) and is adopted to support the commands from the SDM-C. In addition, the HW eNB can support two different service types for the LTE dongles, which are:

- A Low Latency (LL) service,
- A Mobile Broadband (BB) service.

Using 5G NORMA's flexible network architecture, the eNodeB(s) can be moved either to the edge-cloud or the central-cloud configuration. In edge-cloud, the core network functionality is brought close to the edge-user, hence providing smaller E2E delay, at the cost of higher processing requirements and also lack of central coordination. In case of central-cloud, the core functionality is placed at a central location, thereby providing better centralized radio resource management, at the cost of higher E2E delay. SDM-C performs reconfiguration of network functionality between edge-cloud and central-cloud, based on the quality of service (QoS) Class Indicator (QCI) and the service type, in addition to the status of the buffers. The reconfiguration leads to improvement of QoS, which can be addressed in terms of latency and throughput.

A. Network Reconfiguration

The importance of SDM-C and network reconfiguration shall be explained with the help of a sample scenario, as shown in Figure-3. There are two eNBs in this scenario and three User Equipments (UEs). The UEs are differentiated based on the respective service running on them. Two UEs are demanding video streaming while the third one is an autonomously driving car. The autonomously driving car may be connected to either one of the two eNBs. The eNBs are also connected to SDM-C, and communicate feedback and commands with each other.

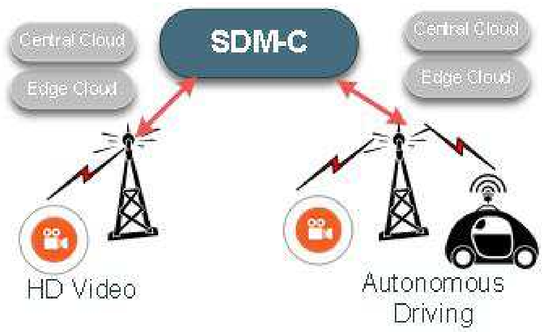

Figure 3 - Scenario layout(based on [5]).

The car can freely move in and out of the coverage area of these two small-cells. When the car UE moves into the coverage area of these two small-cells, SDM-C will recognise that there is a delay-critical service and network reconfiguration should take place to cater for this change. The network will reconfigure itself as edge-cloud, as shown in Figure-4. As a result, the connected users observe an improvement in End-to-End (E2E) latency. This will have the effect that the autonomous cars will be able to drive in a more responsive manner and hence an improvement in its user experience.

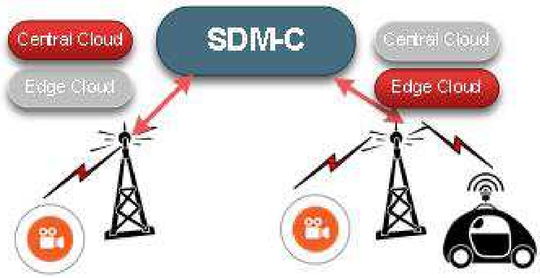

Figure 4 - Network reconfiguration into edge-cloud (based on [5]).

On the other hand, when autonomous driving service is not active in the system, for example when the car user leaves the coverage area of eNBs, the SDM-C will recognise this change and will reconfigure into central-cloud as shown in Figure-5.

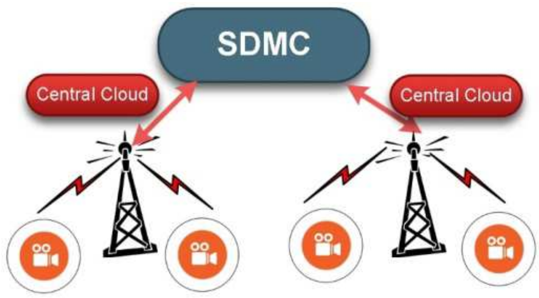

Figure 5 - Network reconfiguration as central-cloud (based on [5]).

This helps in centralised coordination and hence an improvement in throughput. Consequently, the video streaming users will experience better throughput and they can receive videos faster and with higher quality.

Some modifications have been introduced to the main scenario due to the hardware limitation. Due to limited space in the presentation booth, deploying of two eNBs is not practical in terms of space and demo organization. Moreover, the two cells would completely overlap leading to a number of co-channel interference problems. Based on these limitations, the hardware demo has been limited to only one eNB and SDMC communication.

The overall design with respect to communication between eNB and SDM-C remained the same; however, for the case of edge-cloud, there will be only one eNB and the two UEs with two different services. The improvement in terms of latency in edge-cloud shall be computed at SDM-C and communicated to the eNB. For the case of central-cloud, the coordination between two HW eNBs cannot be shown by only one eNB. Hence, the demonstration of the coordination among the eNBs is focused on only the software eNBs, using Nomor's network simulator, as explained in the following sections. In the case of HW eNB and demonstration of the gains from central-cloud, the idea is to simulate the effect of interference coordination with another simulated eNB at the SDM-C. Based on this, SDM-C computes and sends an appropriate gain in end-user performance to the HW eNB for applying the effect of simulated interference mitigation via central-cloud. The net-effect should be an improvement in throughput for the video streaming UE.

Results from hardware demo showed that SDM-C can be integrated with real-world commercial hardware eNBs for LTE. This work also demonstrated that the novel communication protocol designed for SDM-C – eNB communication can be utilized for communication with real-world HW eNBs. The positive effects of network re-configuration for improving the UE's performance were also demonstrated.

B. Service-Aware Scheduling

Service-aware scheduling is an important feature of 5G networks that can be placed inside the SDM-C unit. The demo also highlights the use of this feature in improving system performance. The HW eNB supports user-selective scheduling based on the metric and in the demo setup, the decision logic at SDM-C controller can control and modify this UE-specific scheduling for specific users based on the feedback parameters. The decision logic developed inside SDM-C shall take into account the type of service running at the user, its pending load, the RSRP and the Modulation and Coding Scheme (MCS), etc. Based on these inputs, the slow-scheduler at SDM-C will then decide how to set the UE-dependent priority metric for each user. The decision shall also take into account the current network configuration. For example, if the network is configured to be central-cloud, the service-aware scheduling should ideally give higher preference to a user running a particular service. In the case of central-cloud, throughput demanding services can be served in a better manner, and hence such services should be prioritized. On the other hand, if the network configuration is set to edge-cloud, users with latency-critical service should be given higher priority because in edge-cloud, services that are more latency-critical can be served in a better manner.

As a result of such service- and network-aware scheduling, it can be demonstrated that for different network configurations, i.e. central- and edge-cloud, different services show different set of performances. Hence, emphasizing the importance of flexible network architecture for supporting a multitude of services in the future 5G wireless networks.

C. Software Demo with Simulator

A software demo has been developed, which targets at showing the achieved gains and KPIs at a larger scale, to demonstrate the effects which cannot be observed with the hardware demo with only one eNB. This software demo comprises a network simulator and an SDM-C. The network simulator used is a system-level LTE simulator, developed by Nomor Research GmbH. This is a multi-cell, multi-user LTE emulator with real-time simulation capabilities. The SDM-C application is developed, as a standalone software application, which can run on multiple platforms and communicates with eNodeB(s) of the network simulator for resource management and (re)configuration of eNodeBs into different network configurations.

SDM-C and network simulator communicate with each other using the novel communication protocol designed for encapsulating and communicating messages. The communication protocol takes care of parsing and serializing messages in the correct format. The communication protocol also checks for message integrity and identifies the source and target of different messages. A generic message structure for all kinds of messages exchanged between SDM-C and eNB(s) shall be used, as highlighted in Figure-6.

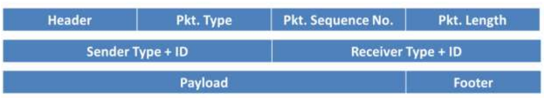

Figure 6 - Generic messages structure

The different messages exchanged between SDM-C and eNBs can be broadly classified into two main types, i.e. feedback and command messages. Feedback messages are sent from eNB to SDM-C and contain feedback about the transmission parameters of the eNB and about the UEs connected to the particular eNB. The command messages, on the other hand, contain commands or (re)configuration requests from SDM-C to eNB. This incorporates commands like network reconfiguration or a change in priority of the connected UEs for scheduling.

Once the SDM-C has performed network (re)configuration, it has an estimate of the gain in terms of throughput and latency. This gain or improvement is estimated by SDM-C and is transmitted to eNBs in a separate command message. Finally, the important task of the SDM-C in the system is to control scheduling at a slower scale and based on active service at each user. The eNB scheduler can be controlled by using another command message with per-user priority.

The communication protocol has been designed in such a way that it is easily extensible to be used for connecting SDM-C with multiple eNodeBs at the same time. The protocol has been tested successfully for communication with multiple eNodeBs. The same communication protocol has been implemented in SDM-C, the HW eNodeB and also in Nomor's software network simulator, for communicating with simulated eNodeB(s), which will be explained as follows.

The overall layout of the developed software demo is shown in Figure-7. In this scenario, seven small-cells have been placed in the form of a hexagonal layout. A number of UEs move around the scenario according to a random mobility model. There are two groups of UEs in the simulation. The first group is the video-streaming users, which are users that download and/or stream video files. For such users, achieving high throughput is of prime importance. For this group, the UEs and their KPI plots are highlighted with orange colour in the following figures. The second group of users, i.e. the machine-type-communication (MTC) users, are highlighted in blue. These users have a mission-critical service which requires lower latency. Example of such users are mobile factory robots, which send smaller packets, i.e. low throughput requirement; but require quick response time, i.e. have strict latency demands.

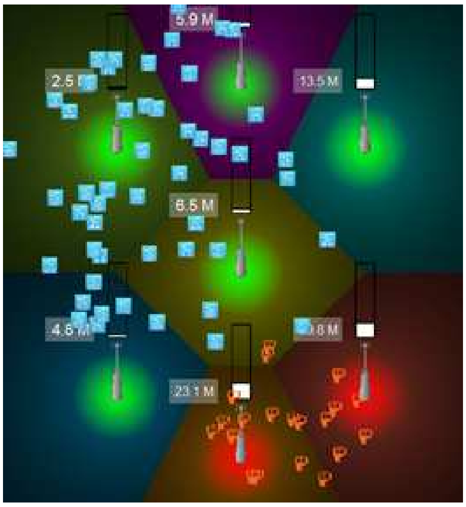

Figure 7 – Service layout for software demo.

For the software demo, three main modes of operation of SDM-C are investigated. The main envisioned task for SDM-C is that it can move specific eNodeBs into central- or edge-cloud configuration. The SDM-C performs this task intelligently, based on the network parameters. This mode of operation is called "Intelligent Service-Aware Configuration". Besides this automatic intelligent network configuration, SDM-C also supports two other modes, i.e. "All-Edge" or "All-Central" configurations; where all eNodeBs are switched into edge-cloud or central-cloud, respectively.

III. Simulations Results

The results are presented and discussed based on SDM-C's modes of operation. In the "All-Edge" configuration, i.e. when all the eNodeBs are placed on the edge-cloud, the core network functionality is brought close to the eNodeBs. This, in turn, means that the E2E delay for the users can be reduced considerably, since the packets do not have to be routed back and forth to a central core network, therefore, saving considerable amounts of extra delay. This effect is highlighted in Figure-8 and Figure-9. Here it can be seen that the throughput of both user groups is relatively low, because the eNodeBs in edge-cloud configuration cannot efficiently coordinate among each other to improve throughput. However, the E2E latency is lower in this setting, because of the edge-cloud configuration. Therefore, this configuration better satisfies the service-requirements for the MTC users.

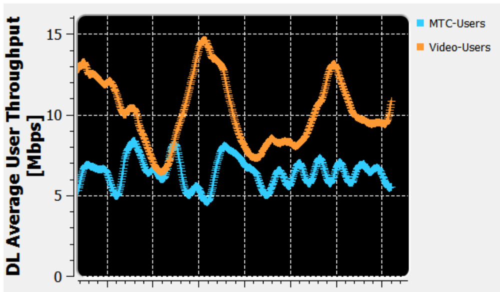

Figure-8: Throughput for "All-Edge" configuration

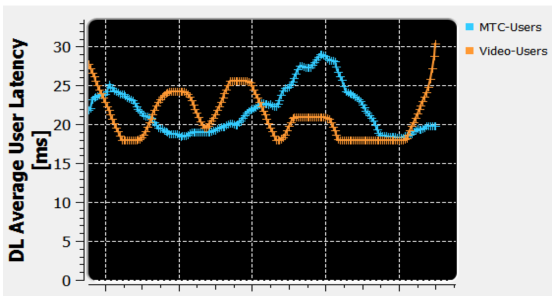

Figure-9: Latency for "All-Edge" configuration

For the case when all eNodeBs are shifted to the central-cloud configuration, it enables the eNodeBs to efficiently coordinate among each other to reduce interference and hence improve throughput. As a result of this, it can be seen from Figure-10 that the throughput is improved for both group of users. The coordination mechanism deployed to achieve the throughput gain, is Beamforming with Interference Fluctuation Mitigation. However, on the other hand, the latency becomes worse. This high latency, as visible from the plots in Figure-11, is not suitable for MTC users, since for such users the latency must be lower to guarantee proper functionality.

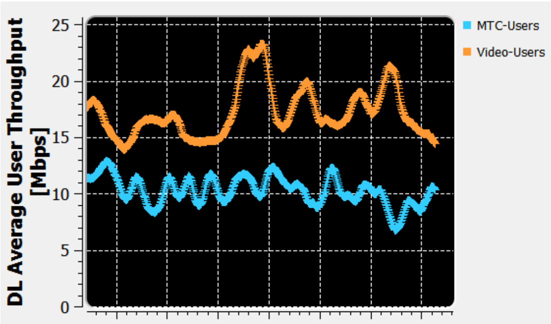

Figure-10: Throughput for "All-Central" configuration

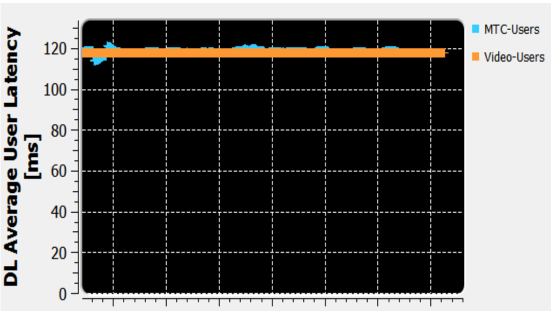

Figure-11: Latency for "All-Central" Configuration

This case shows that if all eNodeBs are moved to central-cloud, the service-requirements for MTC users cannot be satisfied. Therefore, an intelligent configuration based on service-aware decision logic shall be considered that can benefit both types of services.

The proposed intelligent service-aware SDM-C logic is highlighted in the scenario layout of Figure-7. In this scheme, SDM-C can intelligently place individual eNodeBs into central- or edge-cloud. SDM-C is capable of using different system parameters to place the eNodeBs into central- or edge-cloud, e.g. it can use the load on eNodeBs or the type of dominant service running. In the current demo, SDM-C makes use of the dominant service-type to make decision on which eNodeBs to be placed in the central-cloud and which eNodeBs can be moved to the edge-cloud.

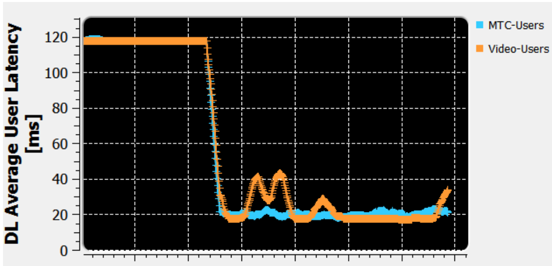

Figure-12: Latency KPI for "All-Central" (left) vs "All-Edge" (right) configuration

For the case of the scenario presented in Figure-7, the distribution of UEs in the simulation is such that the lower right corner of the simulated area is occupied mostly by video streaming UEs, which are connected to the two eNodeBs in the lower right segment of the simulated area. These two eNodeBs have a higher number of video streaming UEs. The remaining eNodeBs in the simulation have a larger number of MTC users connected to them.

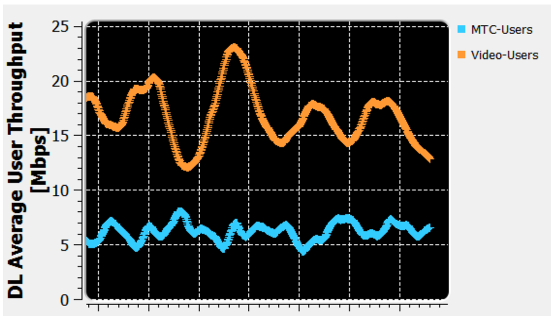

Figure-13: Throughput for Intelligent Service-aware configuration

SDM-C can detect the concentration of different service-requirements in different cells based on the feedback messages it receives from the connected eNodeBs. In the simulated scenario, SDM-C detects that the two cells at the bottom right can best serve the requirements of their users if they were placed in the central-cloud. Therefore, it places these eNodeBs in central-cloud, highlighted with red in the figure. On the other hand, the remaining cells in the scenario have users with low-latency requirement and are moved to edge-cloud, highlighted as green cells.

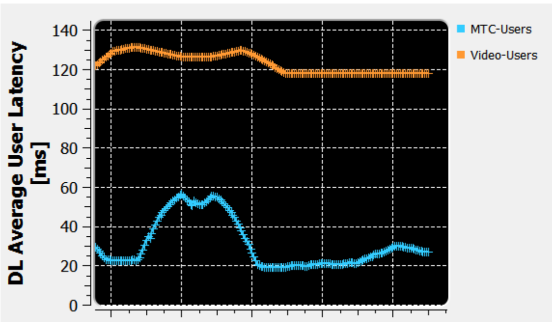

Figure-14: Latency for Intelligent Service-aware configuration

As a result of such intelligent placement of eNodeBs into central and edge-cloud configuration, the video streaming UEs can achieve the desired higher throughput due to better coordination among eNodeBs. This throughput improvement can be seen in the throughput plot in Figure-13. On the other hand, the E2E latency of MTC users can be reduced at the same time. This can be seen from the latency curve for MTC users in Figure-14. Therefore, the introduction of an intelligent SDM-C improves the overall system performance and can better serve a mix of different services in the network.

Conclusions

The development of a 5G Network architecture is still in its research phase. One of the most promising features for the upcoming 5G networks will be network virtualisation resulting in an increased network flexibility. Based on the proof-of-concept and results presented in this paper, it can be concluded that the introduction of new network elements as SDM-C to the core network dramatically improves the performance of different services and helps to provide automatic reconfiguration of network architecture. For the future of telecommunications, with a diverse service-types, it is therefore essential to re-design the network architecture and include important new software-based network elements like the Software Defined Mobile Network Controller, SDM-C. In future 5G network the concept will be extended from a cell specific configuration to user and data flow specific configurations as well as to allocate resources to control and user plane separately.

Acknowledgment

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