Signalling as Data: How it Transforms Network Architecture for 6G System

Rashmi Yadav
Indian Institute of Technology Kanpur
Kanpur, India
rashmiy@iitk.ac.in

Pranav Jha
Indian Institute of Technology
Bombay, Mumbai, India
pranavjha@ee.iitb.ac.in

Abhay Karandikar
Secretary to the Government of India
Department of Science and
Technology, New Delhi, India
karandi@ee.iitb.ac.in

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1 Introduction

The upcoming Sixth Generation (6G) mobile communications system is anticipated to see a huge surge in the number of users due to new usage scenarios like 'Ubiquitous Connectivity' and 'Massive Communication' [1]. The presence of a large number of users may lead to a significantly higher signalling load (signalling storm) [2] in the 6G network and may overwhelm its Control Plane (CP). 6G system is also envisioned to support a greater diversity of use cases such as immersive communication, digital health, digital twin viz-a-viz Fifth Generation System (5GS) [1] and may require use case-specific signalling exchanges between the devices and the 6G network, not supported in the 5GS. For example, the signalling requirements of some IoT (e.g., 'RedCap') use cases may differ from those of a mobile broadband user.

Inspired by the Software Defined Networking (SDN) paradigm, the Third Generation Partnership Project (3GPP) adopted the separation of Control and User Plane functions (CUPS) as a cornerstone of its 5G network architecture[3]. User Plane (UP) in 5GS is responsible for forwarding user data and is akin to the forwarding plane in SDN-based architectures. 5G network CP controls the UP. An additional key functionality performed by the 5G CP Network Functions (NFs) is the exchange of signalling messages with mobile devices (User Equipment (UE)) and manage them[1]. For example, a single gNB-Centralized Unit-CP (gNB-CU-CP) function controls many gNB-Distributed Units (gNB-DUs) in 5GS and also exchange RRC signalling messages with UEs, connected via these gNB-DUs. With high connection density and wider bandwidths in future, a large number of UEs may connect to a single gNB-CU-CP for signalling exchange, potentially creating a bottleneck on the CP.

Considering these new challenges in the 6G era, there is a need to rethink the CP design beyond the 5G network. In this context, we think the following questions may guide us: what functionality should constitute the mobile network CP? or put another way, is the network CP the right place for 'UE signalling handling' functionality? Is it aligned with the SDN paradigm? Should the device (UE) authentication by the network be viewed as a network CP functionality as in 5G (handled by Authentication Service Function (AUSF), a core network CP NF), or should it be viewed as a service to a UE? How to flexibly support use case specific signalling in mobile networks?

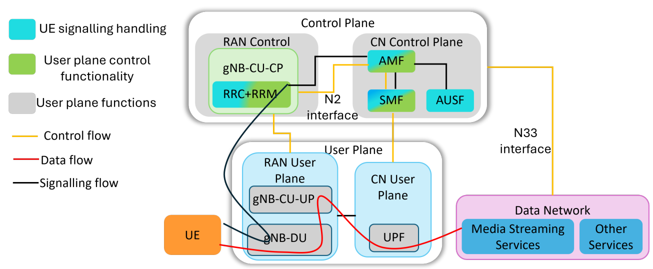

Figure 1: 5G Network Architecture (courtesy [3])

2 Proposed 6G Network Architecture

As part of our research, we focussed on the above-mentioned questions and came up with a novel architecture for 6G. In a departure from existing cellular network design, the proposal views 'UE signalling' as payload, i.e., a form of data traversing the cellular network, not different from other types of data such as 'video streaming' or 'web browsing'. This new perspective allows UE signalling handling to be moved out of network CP and treated as a service, supported by service functions accessible via the user (data) plane. For example, the authentication function (AUSF) is a service function in the proposed architecture (Figure 2) instead of being a part of network CP as in the 5GS (Figure 1) [2].

[1]To enable data transfer for a user via 5G network (e.g., download a video from the Internet), the UE of the user exchanges 'signalling messages' with the CP functions of the 5G network. These are in the form of protocol messages, e.g., Non-Access Stratum (NAS) and Radio Resource Control (RRC) protocols, which facilitate access, authentication, and data path setup for subsequent transfer of user data. Cellular networks treat signalling exchange quite differently from the user data even though they both carry information for/from the device.

[2]Figure 1 shows the 5G network architecture. 5G RAN comprises a RAN CP (gNB-CU-CP) and a RAN user plane (gNB-DU and gNB-CU-UP). The CP of the RAN, i.e., gNB-CU-CP, comprises RRC and Radio Resource Management (RRM) functionality. Similarly, the 5G core network consists of CP functions, e.g., Access and Mobility Management Function (AMF), Session Management Function (SMF), AUSF etc. and a UP function, UPF. As illustrated in Figure 1, the CP of both RAN and CN encompasses UE signalling handling and user plane control functionalities, depicted through usage of dual shades of colour in the figure.

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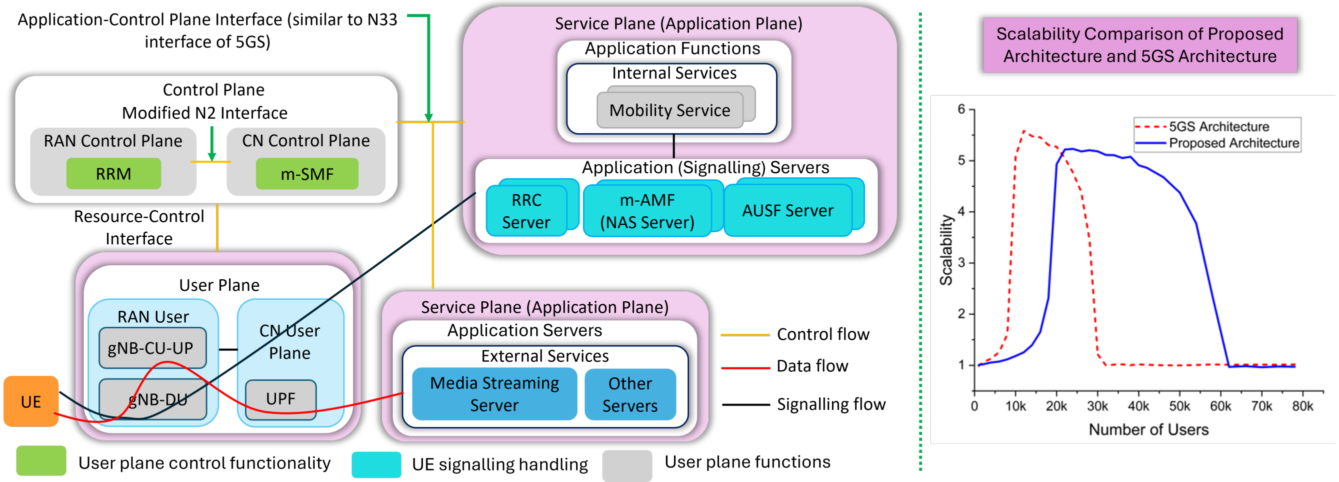

Figure 2: Proposed 6G Network Architecture and its Performance (Scalability) viz-a-viz 5G

Our proposal results in an evolved service-driven architecture for mobile networks where almost all communication between a user (along with its device) and the network (including signalling exchange) is treated as service or data. With the proposed separation, the CP becomes quite thin and is left with only the user plane control functionality similar to the SDN CP, as shown in Figure 2. The UE signalling handling functionality is moved out of the CP, to the application (or service) plane in data networks, for instance, RRC message handling of gNB-CU-CP, NAS message handling part of 5G AMF (m-AMF), SMF, and AUSF have been moved from the CP to service plane as application servers also referred as 'signalling servers'. Consequently, UE signalling exchange now occurs between UE and these signalling servers deployed in the data network (as services). The proposed architecture does not restrict the number of signalling servers, which can be added on demand, to handle the UE signalling load. In contrast, dynamic addition of CP NFs may be difficult in 5GS, e.g., it may not be easy to add a gNB-CU-CP dynamically for an already deployed set of gNB-DUs. This makes the CP of proposed architecture more scalable, e.g., with the same no of gNB-CU-CPs in RAN, as compared to the 5GS.

The proposal should prove particularly advantageous for handling large signalling loads and supporting use-case-specific signalling in the 6G network. Network CP in the proposed architecture is completely independent of signalling messages. For example, in contrast to the 5G network, the UE authentication messages do not terminate in the network CP here but on an AUSF server in the service plane (in data network), as shown in Figure 2. Similarly, the short message service (SMS) delivery also does not use CP as opposed to the 5G network. Hence, the CP in the proposed architecture is unlikely to become a bottleneck under even high signalling load. Use-case-specific signalling may easily be supported here via deploying separate use-case-specific signalling servers. The proposal also simplifies the communication protocols between the CP and UP as they no longer carry UE signalling messages and not deliver services like SMS. The proposed architecture would likely outperform a few other proposals [2], [4]. While these other approaches try to handle the issue of "signalling storm" through clever placement of CP NFs or by offloading a few signalling messages to the data plane, our novel approach of treating 'signalling as data' has the potential to resolve this issue more completely. We have analysed the performance of the proposed architecture and part of it is shown in Figure 2. The detailed analysis is available in [5]. The evaluation considers the parameters, such as the capability to handle signalling load, network scalability, etc. These results confirm the hypothesis that this architecture is better suited to handle high signalling loads viz-a-viz the 5G network. We plan to evaluate its performance in the actual testbed as well to confirm its promised advantages. By treating 'signalling as data' and moving the signalling handling functionality out of the CP, the proposed architecture overhauls the network architecture for future mobile networks such as 6G. If this new paradigm is adopted, it will have a big impact on 6G standardisation under bodies like 3GPP. It will also benefit the stakeholders, e.g., the network operators and equipment manufacturers considerably. Cellular mobile networks originated in telephony networks, but it has gradually incorporated the Internet and data network design principles in their architecture. We think this proposal takes cellular networks further in that direction. Future work entails exploring the architecture's impact on service models, network security etc.

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