# Control Communication as Data: A New Perspective on 6G Network Architecture

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***Abstract*—The upcoming Sixth Generation (6G) mobile communications system envisions supporting a variety of usage scenarios and services with differing characteristics, e.g., immersive communication, hyper-reliable and low-latency communication, massive & ubiquitous connectivity, sensing, artificial intelligence services etc. To accommodate such diverse services, the network architecture of the 6G System (6GS) needs to be scalable, modular, and flexible. In this paper, we identify some architectural limitations of the Third Generation Partnership Project (3GPP) defined Fifth Generation System (5GS), especially that of its control plane (CP). Further, to address these limitations, we propose a novel network architecture for the 6GS. The key innovation introduced by our proposal is to treat the control communication between a user device and the network (also referred to as signalling messages, exchanged between the device and the network CP functions preceding the user data transfer) also as data (or payload). Consequently, we propose moving the "signalling handling functionality" out of the network CP functions, where it is located currently, and handling it through a service plane within the cellular mobile network; this service plane is also introduced as part of our proposal. Such a service plane within cellular mobile networks has hitherto not been a fixture of these networks, though one outside the mobile networks has been supported for long. The proposal results in a service-driven architecture for future mobile networks like 6G. We explicate that the proposed architecture brings increased modularity, scalability, and flexibility to the mobile network, especially its CP, which now offloads some of its functionality to the proposed service plane. We also compare its performance with the 5G network architecture using a process algebra-based simulation tool.**

***Index Terms*—6G network architecture, Software-defined network, CUPS architecture.**

## I. Introduction

The notable rise in the diversity of use cases has paved the way for the continued evolution of mobile networks. The upcoming Sixth Generation (6G) mobile communication system is envisioned to support new use cases such as holographic-type communications, tactile internet, intelligent operation networks, digital twin, and Industrial Internet of Things (IIoTs) with cloudification [1]. It is also foreseen that there will be a large number of connected users in the 6G era enabled by usage scenarios like 'Ubiquitous Connectivity' and 'Massive Communication' [2]. The 6G System (6GS) is also expected to witness many new operator services, e.g., related to sensing, Artificial Intelligence (AI), positioning [3], in addition to legacy operator services, i.e., connectivity, short message service (SMS), mobility etc.. A scalable, flexible and modular network architecture is an essential ingredient for tackling such diverse services and the anticipated massive connectivity in the 6G networks. These architectural characteristics would be particularly important for the network control plane (CP), which would bear the brunt of the enormous signalling load (signalling storm [4]) generated especially by the newer services and the huge number of users [5]. The high signalling load is expected to pose congestion risks and scalability challenges for the mobile network CP [4] [5].

Third Generation Partnership Project (3GPP) adopted technologies such as Network Function Virtualization (NFV), Control and User Plane Separation (CUPS), and network slicing for the Fifth Generation System (5GS), which resulted in improved scalability and flexibility of 5GS over the previous generation mobile communications systems. However, there is scope for further improvement in mobile network architecture, especially in its CP through the application of Software Defined Networking (SDN) framework as defined in [6]. It should be noted that the CUPS architecture of the 5GS likely borrows its inspiration from the SDN framework, though as we argue in this paper, the 5GS architecture does not fully adhere to the standard SDN definition [6]. The literature survey shows that the current research on the application of SDN framework to mobile networks mainly focuses on the centralized or distributed architecture of the CP for reduced control overheads or scalability purposes. However, there is limited discussion/rethink on certain other aspects, such as what functionality should constitute the mobile network CP within an SDN-based architecture. Is the network CP the right place for 'end user signalling handling' functionality ? Should 'Non-Access Stratum (NAS) signalling messages' be handled by Core Network (CN) CP functions such as Access and Mobility Management Function (AMF) or should this functionality be moved out of AMF? Should the user authentication function (Authentication Server Function (AUSF) in 5GS) be part of the CN CP? These questions assume even more importance in the upcoming 6G era, when increased end-user signalling load due to a surge in the number of user devices may overburden the network CP.

Here, we present a survey of the existing research related to SDN-based enhancements in the mobile network. The work in [7] proposes a centralised CP for multi-Radio Access Technology (multi-RAT) Radio Access Network (RAN) to enhance the simplicity and flexibility of the network. Relocation of the CP functionality of RAN to the CN to reduce the signalling cost between RAN and core has been discussed in [8]. Authors in [9] proposed a decentralized CP architecture for the 5GS with independent control functions for different control events for flexible and scalable networks. An SDN architecture where a middle cell and a middle cell controller are introduced between the macro cell and the small cell to reduce the control overhead of the macro cell and to address the scalability problems is proposed in [10]. In [11], authors proposed a new 5GS core architecture based on the SDN concept. They introduced a centralised SDN controller for easier and more flexible management of the user plane. In [12], a hierarchical CP is designed to lighten the load of the controller. It focuses on the vertical scalability of the CP. In [13], a scalability metric for the SDN CP is proposed. Besides, a comparison between different SDN architectures is analysed via mathematical methods. In [5], authors propose to process a subset of signalling messages within the user plane (data plane). In addition, there is a vast amount of literature on SDN-based network architectures, albeit unrelated to mobile networks [14], [15]. Hyperflow - a distributed event-based CP is proposed in [14]. It is a logically centralised but physically distributed controller, which provides scalability. It localizes the decision-making to individual controllers while minimising the CP response time to data plane requests. To summarize, current research in the context of the application of SDN framework to mobile networks mainly focuses on the centralized or distributed architecture of the CP. To the best of our knowledge, they do not address the questions discussed above.

To address these questions and bring in further enhancements to the cellular mobile network architecture, especially to its CP, we propose to completely separate 'user device (User Equipment (UE)) control communication' handling from the network CP functions. In a significant departure from the existing mobile networks, the proposed architecture views 'control communication exchanged between a UE and the network' (also referred to as 'UE signalling') as data traversing through the cellular mobile network, not different from other types of data, such as 'video streaming' or 'web browsing'. As part of our proposal, we introduce a service plane within the mobile network, responsible for handling the signalling exchange with UEs and supporting legacy and new operator services, e.g., connectivity, authentication, mobility, sensing, and AI services [3]. We think that 'UE signalling as data' is better aligned with the SDN paradigm elucidated in [6]. We analyse and evaluate the proposed architecture using Performance Evaluation Process Algebra (PEPA) [16], a formal language used to model distributed systems. We find a significant reduction in the number of control messages exchanged in the proposed architecture for data session and user connectivity service along with an improvement in network scalability. This proposal is an extension of our other works [17] and [18].

The rest of the paper is organised as follows: Section II covers some limitations of the 3GPP 5GS architecture. Section III provides an overview of the proposed architecture, highlights its advantages and how it addresses the architectural limitations of 5GS mentioned in Section II. Section IV covers the performance evaluation using PEPA. Section V provides the conclusion and information on future work.

## II. Introduction to 5GS control plane and its limitations

This section presents the 5G network architecture as defined by 3GPP, especially its CP and some of its limitations. Please note that we exclusively present the network functions pertinent to the proposed work in this paper. Figure 1 shows the 5G network architecture, comprising two planes, the control plane and the user plane. *It should be noted that there is no service plane within the 5G network*. 5G RAN comprises a RAN CP (gNB-CU-CP) and a RAN user plane (gNB-DU and gNB-CU-UP) [19]. The CP of the RAN, i.e., gNB-CU-CP (RAN-CU-CP) comprises RRC and RRM functions [20] which hosts the following functionalities: exchange of RRC messages with UEs, RRC connection management, UE measurement reporting and control, NAS message transfer, security function, radio resource management (RRM), e.g., establishment, configuration, maintenance and release of Signalling Radio Bearers (SRBs) and Data Radio Bearers (DRBs), QoS management, connected mode mobility handling.

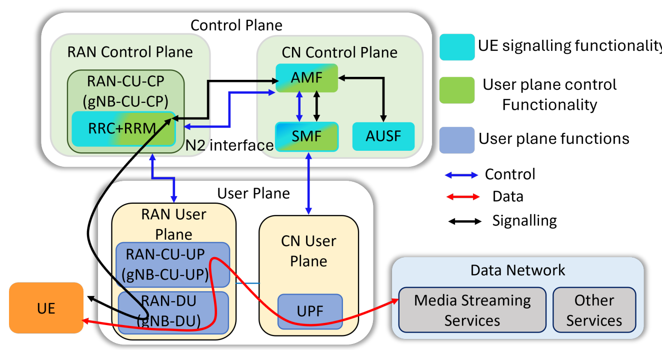


Fig. 1. 3GPP 5GS Architecture [21].

Similarly, the 5G CN consists of CP functions, e.g., AMF, Session Management Function (SMF), AUSF, and a user plane function (UPF) [21]. The AMF hosts the following functionality: termination of RAN CP interface (N2), termination of NAS (N1), NAS ciphering and integrity protection, registration management, idle mode mobility management, providing transport for Session Management (SM) messages between UE/gNB and SMF etc. The SMF includes session management, UE IP address allocation & management, DHCPv4 and DHCPv6 functions, selection and control of UPF, configuration of traffic steering at UPF, termination of SM parts of NAS messages, etc. The AUSF supports the authentication of UEs.

The 5GS supports the CUPS architecture with its CP broadly responsible for two categories of functionalities: user plane control (or network resource control, e.g., setting up data paths for UEs via user plane) and UE signalling handling (e.g., NAS/RRC (Radio Resource Control) message exchange with UEs). There is a **tight coupling between user plane control and UE signalling & operator service handling in the 5GS CP** and certain CN and RAN CP functions perform both (illustrated through the usage of dual shades of colour in the Figure 1). This may lead to CP scalability issues in the 6G era due to the expected high signalling load generated by massive connectivity [5]. This tight coupling may also limit the independent evolution of signalling and user plane control functionality. Furthermore, an altogether clean separation of functionalities between these two planes is missing bringing **inconsistency to the CUPS implementation**. For example, a glaring anomaly is the transfer of the Short Message Service (SMS), a form of user data, to the UEs via CP functions like AMF and gNB-CU-CP. SMSs are delivered using NAS signalling messages unlike other user data that are delivered via user plane functions.

The 3GPP 5G network CP architecture impacts the interface design between the control and user planes. For instance, F1 Application Protocol (F1AP) is the protocol used on the interface between the RAN control plane (gNB-CU-CP) and user plane (gNB-Distributed Unit (gNB-DU) or RAN-DU). It is primarily used to configure gNB-DU but also carries RRC (UE signalling) messages for UEs as the gNB-CU-CP also handles UE signalling. Integrating both these types of functionalities in a single protocol results in a relatively **complex protocol** between gNB-CU-CP and gNB-DU.

The two categories of services (application-based services (e.g., media streaming service) and operator services (such as initial access, registration, connectivity, SMS, mobility) are enabled differently in the 5GS. As external Application Functions/Servers (AF/AS) are outside the boundary of the 5GS and independent and decoupled from the 5G CN and RAN functions, they access the CP functions of the 5G CN over a standardized interface (via reference points: N5/N33) to enable service delivery through the user plane [21]. However, the delivery of operator services is tightly integrated within the CP of the 5GS RAN and CN; there is a limited possibility for a user to influence it via interfaces like N33, e.g., one can't have a user-specific authentication scheme. There are no applications (or service plane) to enable operator services within the 5G network; these services are enabled by the network CP functions.

## III. Proposed Architecture for 6G System (6GS)

This section presents the proposed architecture.As illustrated in Figure 1 and discussed previously, it is evident that the CP of both RAN (gNB-CU-CP) and CN (AMF, SMF and AUSF etc.) in 5GS broadly encompasses UE signalling handling (including support for operator services) and user plane control functionalities. This characteristic has been depicted through the usage of dual shades of colour in Figure 1. As part of our proposal, we separate the handling of UE signalling & operator services (e.g., connectivity, SMS, mobility, sensing, AI services, positioning) from the network CP. Additionally, we also treat UE signalling as a service (data). The "signalling & operator service handling functionality" is moved out of the network CP (in the proposed architecture) to a separate service plane within the cellular mobile network, as shown in Figure 2; this service plane is introduced as part of our proposal. As a result, the network CP becomes quite thin (as shown in Figure 2) and is left with only the user plane control functionality similar to an SDN controller defined in [6]. The proposal results in an evolved service-driven architecture for mobile networks where almost all information exchange (including the control communication) between a user (device/UE) and the network is treated as service (payload or data), driving the network behaviour in a nice loop-like structure. While various generations of cellular mobile networks have been supporting external service functions, e.g., media servers, content delivery networks, IP Multimedia Subsystem, a service plane within the network (i.e., within RAN/CN) hosting service functions has hitherto not been considered. The introduction of the internal service plane in mobile networks and the treatment of signalling (control communication between UE and the network) as payload are the novel features of our proposal.

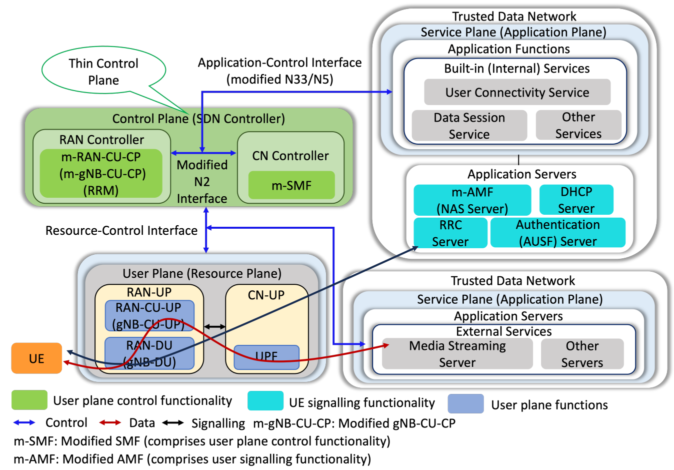


Fig. 2. Proposed architecture for 6G System.

UE signalling exchange in the proposed architecture happens between the UE and the application server like functions (handling UE signalling) deployed in the proposed internal service plane. These application servers handling UE signalling messages are also called signalling service functions (SSFs) or signalling servers in this paper. It is to be noted that these SSFs can be implemented as NFs in NFV-like virtualized environment. The communication path between a UE and the signalling servers is depicted using a solid black line in the figure. However, there can be other data paths as well, such as UE-(gNB-DU)-(gNB-CU-UP)-UPF-signalling server. We have not shown other data paths in the figure for the sake of simplicity. These communication paths can be referred to as a signalling path. It is no different from regular data paths that carry user data through the user plane, except for the flexibility to bypass certain user plane functions as shown in Figure 2. This split in CP functionalities prompts a re-framing of the 3GPP 5GS architecture, leading to the redefinition of certain network functions, as detailed in the following section.

The RRC + RRM functionality, previously integrated into gNB-CU-CP (CP of 5GS RAN), has now been split into an RRC server, a User Connectivity Service Function (UCSF) and a RAN controller (CP function). The following functionality is assigned to the RRC server, e.g., exchange of RRC messages with UEs, RRC connection management, security function, UE measurement reporting and control, NAS message transfer. Connected mode mobility management is moved to UCSF, another function in the service plane. In contrast, user plane control functions such as establishment, configuration, maintenance and release of Signalling Radio Bearers (SRBs) and Data Radio Bearers (DRBs), QoS management, RRM etc., remain as part of the RAN controller or m-gNB-CU-CP (modified gNB-CU-CP) as shown in Figure 2. Besides, the RRC server and UCSF are now a part of the service plane in data network, possibly alongside other service functions such as the media streaming server, as shown in Figure 2.

Similarly, the CP of the CN undergoes re-framing. The proposal involves the relocation of UE signalling handling functionalities of AMF/SMF, such as NAS signalling exchange (N1), NAS signalling security, idle mode mobility management, registration and connection management, etc. to a signalling service function, which is named as m-AMF (or NAS server) and placed in the service plane along with the RRC server. Besides, functionalities such as UE IP address allocation and management (DHCPv4, DHCPv6 functions) also is moved out of SMF and made a part of a DHCP server in the service plane. Packet Data Unit (PDU) session management is moved to a Data Session Service Function (DSSF) in the service plane. It is to be noted that data session establishment for a user in 3GPP 5G terminology is known as PDU session establishment. Conversely, the remaining user plane control functionalities, including the termination of the RAN CP interface (N2), user plane function selection and control, configuration of traffic steering at UPF, etc., are retained in a modified CN controller (CP of the core network), denoted as m-SMF. The AUSF has also been moved out of the CP to the service plane as user authentication is treated as a service in the proposed architecture.

Functions like UCSF or DSSF are slightly different from the RRC Server or AUSF as they help orchestrate the operator services like user connectivity or data session establishment for UEs, which require data path (re)configuration over the user plane. Like other external AF-based services (e.g. media streaming), they utilize an N33/N5-like interface with the CP to achieve the same. While functions like the RRC server or AUSF directly interact with UEs via signalling paths without any interaction with the CP. Please note that there may be separate controllers in the CN and RAN, as shown in Figure 2. Further, the proposed architecture's user or resource plane may remain the same as the 3GPP 5GS with only minor changes. The proposed architecture offers many advantages discussed next.

### *A. Advantages of the proposed architecture*

This section highlights a few advantages of the proposed 6G architecture. Segregation of UE signalling handling & operator service handling functionality from the network CP **simplifies the CP, making it thinner** viz-a-viz the 5GS CP and enhancing its simplicity, scalability and modularity. This segregation of functionality reduces the load on the CP. For instance, in an authentication service, the UE exchanges authentication messages directly with the AUSF server, bypassing the CP (gNB-CU-CP). This contrasts with the 5GS, where authentication messages are relayed through the CP (gNB-CU-CP and AMF). Relaying user authentication messages via gNB-CU-CP is just an overhead for gNB-CU-CP as it does not play any role in user authentication. Nevertheless, it has to encode and decode these messages in 5GS.

The reorganisation also **aligns well with the SDN paradigm** as the CP is required to perform only user plane control functionality. The proposed architecture allows operator services to be treated the same way as external application-based services, leading to **consistent handling of services** bringing further simplicity to the design.

Further, this proposal results in the simplification of the control flow. For instance, the number of session management-related messages is reduced due to the setup of a direct path between UE and the service functions handling UE signalling (e.g. RRC server), leading to **simplified information (call) flows**. Also, the number of hops between the RAN controller and the CN controller in the proposed architecture is less than the corresponding entities in 5GS, i.e., between gNB-CU-CP and SMF, respectively. It may result in performance improvement in terms of CP latency. Transposition of UE signalling handling functionality to functions in service plane **simplifies the protocols** between the CP and the user plane, such as Next Generation Application Protocol (NGAP) and F1AP, as these protocols are no longer required to carry UE signalling messages.

The proposed architecture has a clear-cut demarcation between the user service handling and the CP functionality unlike the 5GS. For example, the CP of the proposed architecture need not participate in the transfer of user data such as SMS, as is the case with 5GS. These are handled by the service functions (NAS/RRC servers) and the user plane functions. This reduces the complexity of the CP further, e.g., a network function like Short Message Service Function (SMSF), used for SMS delivery in 5GS, may not be required here at all.

The 5GS uses the same type of signalling messages for all use cases. However, it is possible to have different signalling requirements for different use cases, e.g., the Internet of Things (IoT) and human users. The proposed architecture may be able to support this requirement with ease by enabling the deployment of **use case specific signalling servers (e.g. more than one RRC or NAS servers) to handle use case**

**specific signalling**. In a nutshell, the separation of signalling handling from the CP enables the independent evolution of the signalling and CP. Our proposal can also support **flexible function deployment and chaining for signalling handling** as various signalling handling functions, such as the RRC server, NAS server, and Authentication server, can flexibly be placed and chained together to serve UEs. Some of these functions can also be instantiated as individual modules of a single service function depending on the requirement.

The proposed architecture may also offer advantages in terms of network access security. Since UE signalling handling is segregated from the CP (of RAN and CN) and is terminated on a separate signalling server, it leads to the possibility of localizing the attack originating from a UE within the signalling servers without compromising the network CP, where the logical control and management of RAN and CN are located. This aspect will be explored further in our future work. Please note that there is no impact on the UE both with respect to signalling exchange as well as data transfer in the proposed architecture viz-a-viz the 5GS. The signalling protocol between the UE and the network may also remain the same as the 5GS if needed. The impact is only on the network architecture and the message flow between different functions on the network side.

## IV. RESULTS

In this section, we present how the proposed architecture scale viz-a-viz the existing 5GS architecture. The scalability has been evaluated with respect to two basic services offered by the mobile network i.e., data (PDU) session establishment service and user connectivity service. Scalability *(S)*, according to [22], can be defined as the ratio between the productivity of a system at two configurations (configuration here implies the number of NFs used) having different scales, say $m_1$ and $m_2$, which corresponds to the different numbers of NFs used in the network, for instance we have considered $m_1$ = *(1,1,1)* and $m_2$ = *(3,3,1)*. The mathematical expression for scalability is given as [22]:

$$S(m_1, m_2) = \frac{C(m_2)}{C(m_1)}. \quad (1)$$

Where, *C(m)* is the productivity of a system at the scale *m*.

The detailed explanation for the C(m) and basic and scaled configuration is available in [18].

*1) Data (PDU) Session Establishment Service:* Scalability for the 5GS and the proposed architecture is shown in Figure 3. We consider basic configuration and scaled configuration for estimating the scalability metric. The saturation point for 5GS for data session establishment, as shown in Figure 3, is around 10,000 users, i.e., it can serve a maximum number of 10,000 users in case of the basic configuration, while the data session establishment rate saturates at around 20,000 users for the proposed architecture, providing a much better performance than the 5GS.

Similarly, in the scaled configuration, the 5GS saturates at around 34,000 users whereas the proposed architecture saturates at 62,000 users again providing a much better performance as compared to the 5GS. It should be noted that the network starts dropping the incoming requests from users as the saturation point is reached. This means that with a given number of processors/NFs, the proposed architecture can achieve a higher data session establishment rate viz-a-viz the 5GS. The curve, as shown in Figure 3, emphasises that the proposed architecture has the capacity to support a larger number of users, reaching a saturation point much later than the 5GS. The proposed architecture achieves higher scalability compared to the 5GS over a much wider range of incoming data sessions.

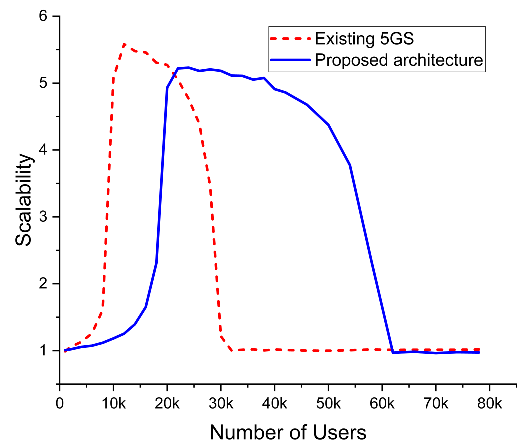


Fig. 3. Scalability in case of data session establishment for the proposed and the 5GS architecture.

*2) User Connectivity Service:* This section presents the comparative analysis of the 5GS and the proposed architecture for the user connectivity service. Figure 4 shows the scalability results in the case of the user connectivity service for 5GS and the proposed architectures. It can be observed that 5GS reaches its saturation point much earlier than the proposed architecture. Additionally, as the figure shows, the proposed architecture achieves higher scalability vis-à-vis 5GS over a wider range of incoming user numbers.

## V. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a novel mobile network architecture to separate the handling of UE signalling and operator services from the user plane control (resource control) functionality, enhancing the modularity, scalability, and flexibility of the network CP. The transposition of UE signalling handling and operator services functionality from the CP to a service plane, introduced as part of the proposed architecture, is a paradigm shift. It leads to simplified protocols and opens up new ways to implement use case specific signalling in mobile networks. The proposed architecture also has improved implementation of CUPS viz-a-viz 5GS. We have considered data session establishment and user connectivity services as

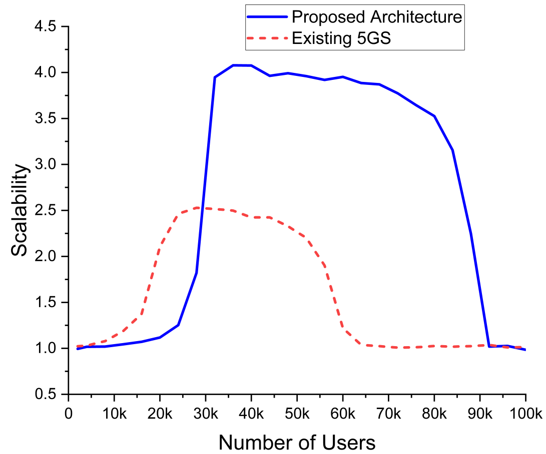


Fig. 4. Scalability in case of user connectivity for the proposed and the 5GS architecture.

examples to analyse the performance of the proposed architecture using the PEPA-based simulation method. Based on the performance results and other benefits, it can be concluded that the proposed architecture is a promising option for future networks to handle vast and diverse traffic demands, massive connectivity, and new operator services. In future, we plan to analyse this architecture viz-a-viz its impact on reducing the security threats to the 6G system.

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