Organic 6G networks: ultra-flexibility through extensive stateless functional split

Marius Corici[1] · Fabian Eichhorn[1] · Hauke Buhr[1] · Thomas Magedanz[1]

© The Author(s) 2024

Abstract

With the increase in hardware performance, the 5G mobile network architecture shifted from physical components to software-only micro-services. The very modular network functions can be deployed flexibly on commodity hardware. However, the extensive modularity of these network functions is increasing the number of managed entities, and the core network request latency. Also, it requires extensive procedures to be able to re-select the components for specific devices, a fundamental condition for a potential system scale-down. In this paper, we propose a new organic 6G network architecture that handles these challenges through a new functionality split based on the experience of IT software services. Furthermore, we provide an analysis based on main 5G procedures, showing that the newly proposed architecture is handling the re-selection of functionality significantly better, which is a cornerstone of high-speed scaling (especially scaling-out), as well as migration of functionality and users.

1 Introduction

With the adoption of software-only networks within 5G, the Generation Partnership Project (3GPP) has developed a micro-service oriented, Service Based Architecture (SBA) [1], in which previously physical network functions are implemented as software services. To be able to maintain the same functional modularity, 3GPP started the development of the architecture by implementing each functionality as a separate Network Function (NF), with its own subscriber state, connected via web service protocols (i.e., HTTP2) [2].

✉ Marius Corici
    marius-iulian.corici@fokus.fraunhofer.de
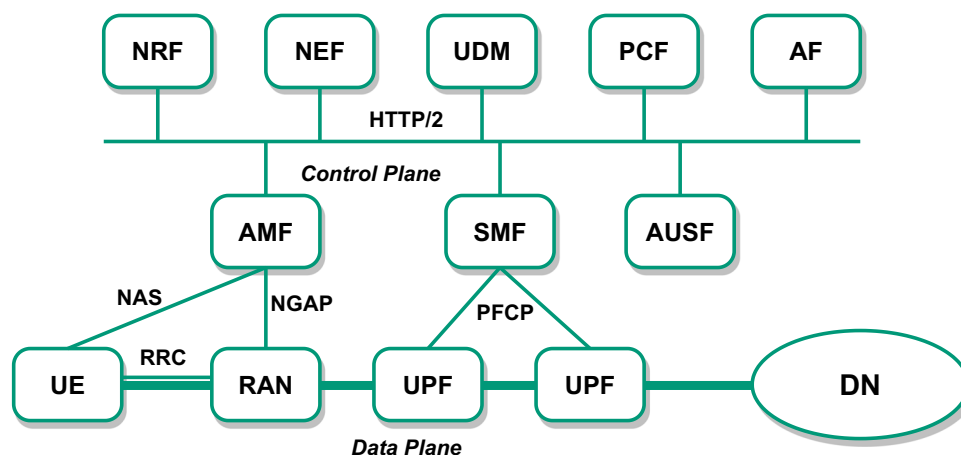
✉ Fabian Eichhorn
    fabian.eichhorn@fokus.fraunhofer.de

    Hauke Buhr
    hauke.buhr@fokus.fraunhofer.de

    Thomas Magedanz
    thomas.magedanz@fokus.fraunhofer.de

[1] Software-Based Networks (NGNI), Fraunhofer FOKUS,
    Kaiserin-Augusta-Allee 31, Berlin 10589, Berlin, Germany

Each (NF) in the 5G core is defined by its primary role and in many cases a specific aspect of the User Equipment (UE) state. The goal was presumably to maintain a form of layer separation, which was good for physical components with reduced processing capabilities. Because of this entanglement between functionality and active subscriber state, the UE is continuously bound to a set of network functions. This drastically limits the options for scaling, load balancing and subscriber migration. For any of these operations, different network functions have to be notified and the changes have to be acknowledged resulting in extensive inter-NF communication. Furthermore, because of the state binding for access control, mobility and session management between the Core Network (CN) and UE, operations changing the binding also involve an increased number of messages, including over wireless links.

Stateless NFs can alleviate these problems [3]. A simple solution to make the different NFs stateless is to externalize the state to an Unstructured Data Storage Function (UDSF). However such a solution requires that before processing a request, each NF has to fetch and finally update the UE state, which increases the overall procedure delay due to the additional messages being exchanged with the UDSF [4]. Since

Fig. 1 The 3GPP 5G SBA [1]

several NFs would store their own UE state in the UDSF, it would become a potential bottleneck, whose performance and scalability critically affect request processing throughput.

In this article, we propose a new organic 6G core network architecture aiming to eliminate the rigidity of the 5G SBA. Using a service model from the IT software services, the proposed architecture splits the functionality based on the service requested by the subscriber and not by the functionality it handles. This way a complete service request of the subscriber is executed by a single worker instead of a large set of network functions. Furthermore, the workers maintain routines for all the different procedures and are thus able to morph and to respond to any subscriber request.

Through making the worker functionality stateless, the proposed architecture is highly flexible, a characteristic which we are proving in this paper through the analysis of the relevant 5G procedures: registration, handover with CN functionality migration, Protocol Data Unit (PDU) session establishment and functionality migration for UEs which do not change their location. This last procedure enables the UE handover needed to enable a scaling without information loss. With this, we have proven that the newly proposed architecture can gracefully handle the major UE service requests while at the same time does not require special functionality for scaling or migration.

In additional papers we have provided a detailed description of the organic core network concept [5, 6], and demonstrated the infrastructure independence [7] and reduced complexity [8]. This paper comes to complement prior work, further detailing how the different procedures are implemented.

The remainder of this article is organized as follows. Section 2 assesses the 5G SBA from the perspective of flexibility. A brief overview of related work is given in Sect. 3. Section 4 introduces the organic 6G core network concept and implementation, underlining how it enables more flexibility

and efficiency. The flexibility is evaluated through a comparison of the relevant 5G procedures in Sect. 5. Finally, we conclude with a summary and outlook in Sect. 6.

This article is an extension of a paper previously published at the *2nd International Conference on 6G Networking (6GNet)*[1] held September 2023 in Paris, France [9]. The manuscript was further improved and extended. Minor mistakes were corrected and figures were cleaned up. The comparison of procedures for PDU session establishment was added to Sect. 5.

2 The 5G Service Based Architecture (SBA)

The 5G System is specified and continuously improved by the 3GPP. A simplified version is illustrated in Fig. 1 [1]. It comprises a set of Control Plane (CP) NFs at the top, implementing different functionality and the User Plane (UP) ones at the bottom. The CP includes the functionality for Access and Mobility Management Function (AMF), Session Management Function (SMF), Network Repository Function (NRF), Authentication Server Function (AUSF), Unified Data Management (UDM), Network Exposure Function (NEF) as well as any additional Application Function (AF). For NF discovery and selection, NFs use a publish-subscribe mechanism, provided by the NRF.

Whenever an NF becomes unavailable a notification is sent to all NFs which had a binding to it, triggering re-selection procedures. The re-selection is similar to the initial selection, requiring the establishment of the subscriber state in all the components. The AMF acts as the CP endpoint for Radio Access Network (RAN) and UE. It is bound to gNodeBs using the NG Application Protocol (NGAP). This NGAP connection is used for the N2 interface, but also to proxy Non-Access Stratum (NAS) protocol N1 connections to registered

---
[1] 6GNet: International Conference on 6G Networking — https://6g-conference.dnac.org/

UE. Through this, a triple binding is implemented between UE-gNB-AMF.

For authentication, the AMF communicates with the AUSF, which relies on the UDM for the necessary user information. If available, the optional UDSF can offer NFs storage of data not specified by 3GPP, e.g., for internal state persistence to improve failure and maintenance recovery. The interface towards the UP is handled by the SMF, which selects and controls the User Plane Functions (UPFs), needed for the establishment of PDU Sessions for UE. External services can be added either in a trusted form through a generic AF or in an un-trusted form gated by the NEF.

The SBA takes inspiration from web-style Representational state transfer (REST) Application Programming Interfaces (APIs), to better support the trend towards cloud-native deployments of CP NFs [10], but a key aspect of REST, namely the statelessness of services, is not implemented consistently. This inhibits scalability and flexibility. Furthermore, horizontal interfaces between the different NFs were favored resulting in a high number of interconnected micro-services. As such, procedures in the SBA often result in back-and-forth message exchanges across the different NFs. With each hop, these procedures require additional synchronization and incur an additional response delay which can be further aggravated in distributed core deployments, for example, the edge-central split of Multi-Access Edge Computing (MEC).

Furthermore, in case a NF re-selection is required due to unexpected failure, normal maintenance operations, or dynamic scaling, this is only possible through executing complex SBA procedures which re-establish the subscriber state in the different components (e.g., NF Service Context Transfer Procedures [11]).

An easy alternative would be to group the NFs to optimize latency. However, this reduces the flexibility resulting in monolithic deployments with single points of failure, while at the same time still having complex subscriber migration procedures and interfaces based on Hypertext Transfer Protocol Version 2 (HTTP/2), Transmission Control Protocol (TCP)/Internet Protocol (IP) or QUIC/IP stacks, requiring de- and encoding and passing of data through network stacks. Even when running on the same host, network transmission usually cannot be avoided and may be affected by performance limitations of the host system and potentially employed virtual network solutions.

3 Related work

While many publications on 6G have focused on requirements and use cases or potential radio technologies, there seems to be a general assumption that the core network

architecture will remain in line with the 5G SBA [12]. Instead, the introduction of Artificial Intelligence (AI) and Machine Learning (ML) to improve network management has gained a lot of traction [13], but the efficacy of these top down approaches will be limited by the architectural flexibility of the managed services. However, there are a few examples of work discussing SBA improvements and evolution. Tataria et al. posit that the core network needs to be restructured to support 6G use cases and requirements [14]. Jain et al. discussed the importance of signaling latency in the CN in regard to performance and proposed protocol-level improvements [15]. They based their implementation of Free5GC.[2] By deploying all NFs on the same host and using shared memory, they were able to improve CP latency. Fully integrating NF functionality can improve even further, by skipping shims or other middleware.

Stateless NFs have been found to provide flexibility and resilience in Software Defined Networking (SDN) [16]. Kulkarni et al. discussed procedural and transactional statelessness as options for core NFs [4]. They created a transactional stateless 5G core network based on Open5GS,[3] finding that it provides robustness at the cost of additional overhead. Du et al. have shown the feasibility of a stateless 5G CN implementation for cloud-based deployments, with an intermediary NF for load balancing and proxying of the requests from the RAN, based on the Open Air Interface (OAI) core network [17]. Sthawarmath et al. present the resilience advantages of stateless core NFs and explain how an appropriately distributed and propagated UE state can improve handover latency [18]. Adhering to the 5G SBA limits the benefits these approaches can gain from stateless NFs.

Goshi et al. proposed a procedure based stateless 5G CN which they implemented as PP5GS [19] based on Free5GC. PP5GS was compared with stateful Free5GC, a modified stateless Free5GC and a set of Free5GC slices that include the NFs for a specific procedure deployed on a Kubernetes cluster with the Istio service mesh. Their evaluation of CPU utilization, request completion time and communication overhead showed the potential for improvements over the SBA by restructuring functionality based on procedures. Moreover, they exemplified that a stateless 5G CN is a viable solution that introduces a not insignificant communication overhead. Implementing services to handle specific procedures is an interesting alternative to our all-in-one-worker approach. Between these alternatives, there is a trade-off in implementation complexity, scalability and placement flexibility, which we aim to evaluate based on our proposal.

---

[2] Free5GC is an open source implementation of a 5G CN written in Golang — https://github.com/free5gc

[3] "Open5GS is a C-language Open Source implementation for 5G Core and EPC" — https://github.com/open5gs

4 The organic 6G core network architecture

To mitigate the lack of flexibility in the 5G SBA, we propose a new architecture model named Organic 6G Core Network. It represents the next step towards a truly cloud-native, stateless, software-based implementation of the CN. As illustrated in Fig. 2, the control plane of the CN is implemented as a large-scale web service, adapted to the high variety of procedures required by the UE. It is divided into three functional parts: distributed storage, worker, and front end.

Subscriber state is maintained in a distributed, dynamic storage system, enabling each of the worker components to retrieve and modify it. The storage layer keeps the subscriber and policy information synchronized across the network. We estimate the subscriber state in state-of-the-art 5G networks to be less than 1kB of data, that could easily fit into a single data packet. As such, although pieces of information may not be needed, the overhead of retrieving them in terms of communication and decoding delay is insignificant, i.e., retrieving and processing of 1kB or 200B of formatted data are fully equivalent.

A distributed pool of stateless, interchangeable workers implements the procedures of the CN, providing Authentication, Authorization and Accounting (AAA), mobility, and PDU session management among others. Each of the workers has the role of first decoding the messages received from the UE and through this determining the UE identity and procedure to be executed, fetching the UE state, executing the specific procedure steps, notifying the data path and the UE and to update the UE state. Through these steps, the workers are executing all which is requested from the CN for the specific UE request, not needing any internal horizontal communication in the CN.

The intermediary between workers and RAN is provided by the front end. Which is also stateless from the perspective of UE communication, maintaining only the binding with the RAN. It provides the endpoint for UE connections and selects and forwards requests to worker instances. As the security association of the UE is maintained in the state and associated with the UE directly, the front end is a very simple component, acting mostly as a load-balancer for the workers.

In order to ensure backwards compatibility with 5G RAN, and until new 6G protocols are defined, the reference points N1 and N2, as well as the NAS and NGAP protocols are considered without modification. Thus the proposed architecture can be demonstrated and evaluated against 5G user equipment and base stations. Similarly, following the Control- and User-Plane Separation (CUPS) of 5G, no changes to the Packet Forwarding Control Protocol (PFCP) based N4 reference point towards the UPF are envisioned at this point.

5 Comparison of procedures

To compare the 5G SBA with the proposed Organic 6G core network architecture, we shall investigate the way they

Fig. 2 The organic CN
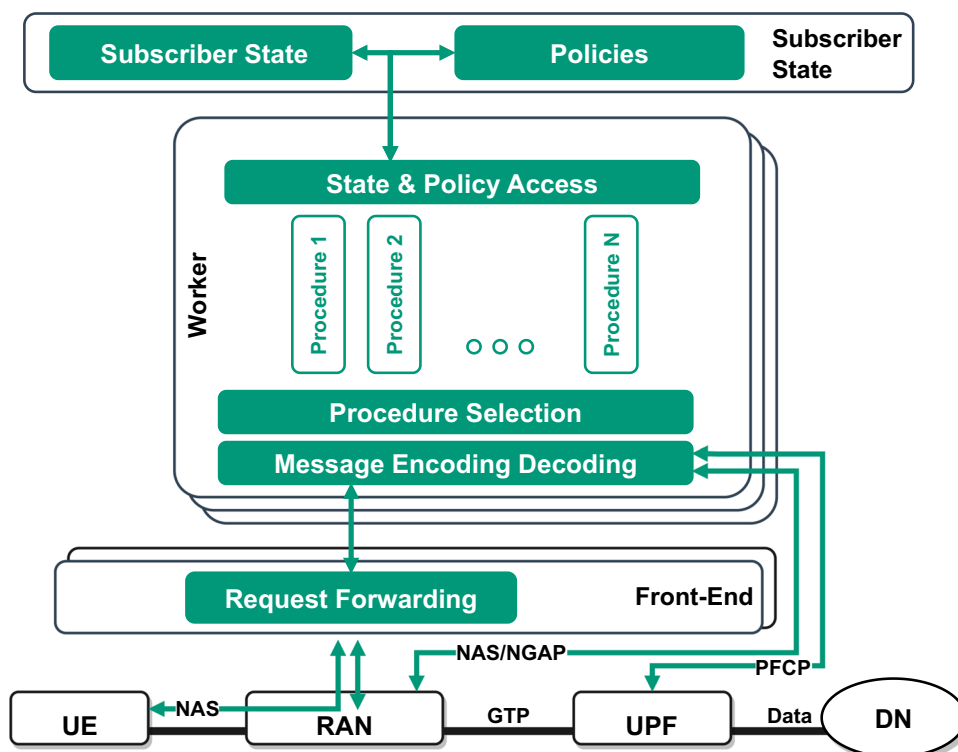
process UE-related procedures. For the sake of brevity, we focus on the most relevant procedures regarding the selection and the re-selection of core network components. This includes initial UE registration, N2 handover, PDU session establishment and the planned removal of a UE-facing component as specified by the 3GPP [11].

5.1 5G SBA registration procedure

The 5G SBA procedure includes the following steps, as illustrated in Fig. 3. The UE triggers the procedure by sending the

initial registration request to the RAN component (1) which selects the appropriate AMF and forwards the message to it (2). The RAN effectively proxies requests between UEs and AMFs: the N1 interface between UE and AMF using the NAS protocol is wrapped in NGAP.

In case of an initial registration, authentication procedure has to be performed as well [20]. To perform authentication, the AMF contacts the AUSF (3), which in turn sends a request to the UDM (4–5). This chain is then reversed as a challenge needs to be propagated to the UE (6–7). The UE's response to the challenge is sent to the selected AMF (8) which forwards
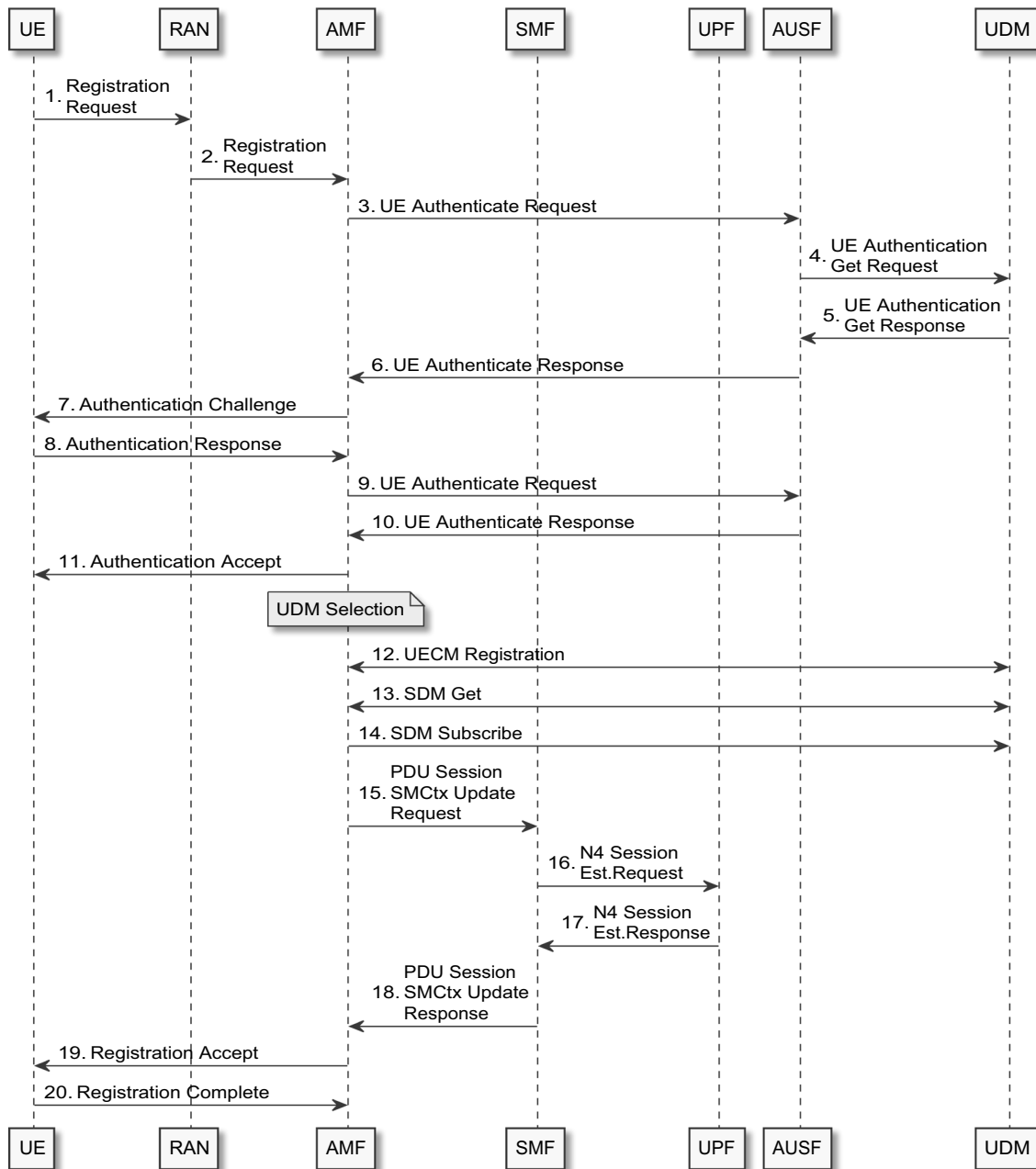

Fig. 3 5G SBA registration [1]

it to the AUSF for confirmation (9). After the authentication accept is sent (10–11), the AMF first updates the information of the UE in the UDM (12–14) and then triggers a PDU Session Update by selecting and sending a request to the SMF (15, 18) which at its turn establishes the data path through selected UPFs (16–17), assuming the UE requested a PDU session initially. The registration is accepted and the UE confirms this with the Registration Complete response (19–20).

The SBA registration procedure involves at least four CP NFs, the AMF, SMF, AUSF and UDM, but other functions might be involved in more complex scenarios. Because the generally network-based communication between different NFs, being implemented as micro-services, introduces processing overhead and communication delays, the overall latency is increased. One can imagine, that the different steps

of the procedure handled in the CP could be processed without transmission, which would improve energy efficiency and security, by shrinking the attack surface. Furthermore the bindings between the UE and the AMF, respectively the SMF are established and maintained for the duration of the UE communication.

5.2 Organic 6G network registration procedure

The organic 6G registration procedure (Fig. 4) is similar to the 5G one, but it employs less NFs and internal communication. When a front end receives a registration request, it immediately forwards it to a worker, without knowing which procedure it is (1–3). The worker decodes the messages and requests the user state (4–5), processes the request, and then

Fig. 4 Organic 6G CN registration
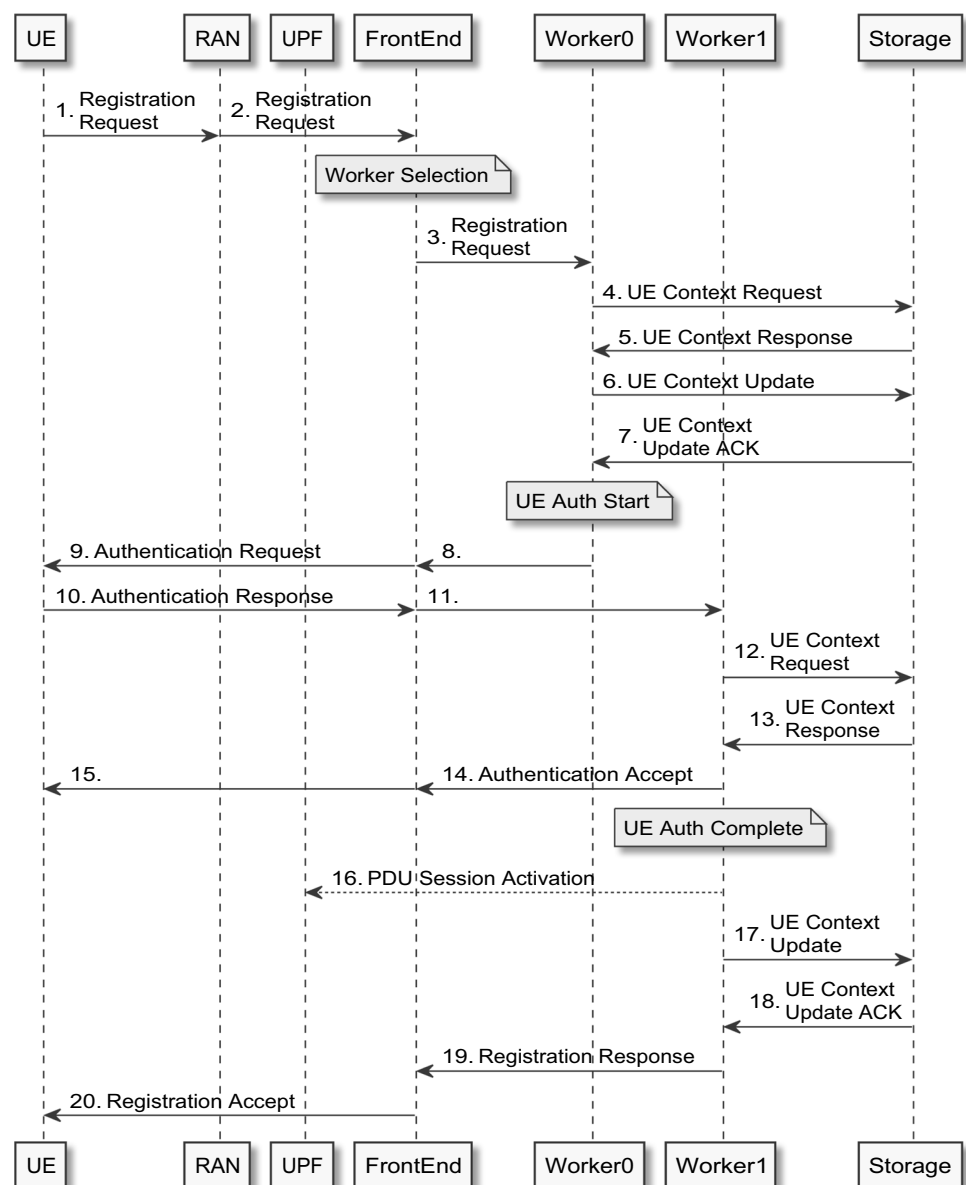
updates the stored state (6–7). Then it starts the UE authentication handshake (8) which is forwarded as an authentication request to the UE (9). The Authentication Response (10–11) sent by the UE may reach another worker, due to load balancing, which in turn fetches the UE state (12–13) and processes and completes the attachment (14–15). Finally, data path is established (16), context is updated in the storage (17–18) and the UE is notified (19–20).

In the case of the Organic 6G, the only binding of the UE is maintained in the subscriber base. Although the state has to be fetched and modified twice, the number of the steps is still drastically reduced compared to the 5G SBA.

5.3 5G SBA handover procedure

For simplicity, we only consider the two-phase N2-based handover with a single SMF, while underlining the AMF and UPF re-selection. The preparation phase (Fig. 5) begins with the source RAN (S-RAN) indicating the need for a handover to the already selected source AMF (S-AMF) (1).

The S-AMF then selects a suitable target AMF (T-AMF) (2). Based on T-AMF selected by the S-RAN and sends a *Create UE Context Request* to it (3) to trigger the establishment of any required PDU session at the respective target UPF (T-UPF) (4–5). Now the T-AMF has to wait for all involved SMFs to respond to the SM Context update (6). Next, the RAN (TRAN) receives and acknowledges the *Handover Request* from the T-AMF (7). This acknowledgement includes information such as PDU session IDs that have to be forwarded to the SMF (8–9, 14), for the downlink tunnel establishment and potential forwarding in the T-UPF and source UPF (S-UPF) (10–13). The preparation ends with the T-AMF responding to the S-AMF, providing the T-AMF with information on the success of the UE context relocation and information necessary for the execution phase (15).

After the preparation phase, the S-AMF sends the *Handover Command*, containing information required for the execution phase (Fig. 6), to the S-RAN, which forwards it in part to the UE (1–2). The S-RAN requests the upload RAN status transfer from the S-AMF which informs the T-AMF

Fig. 5 5G N2-handover preparation phase [1]
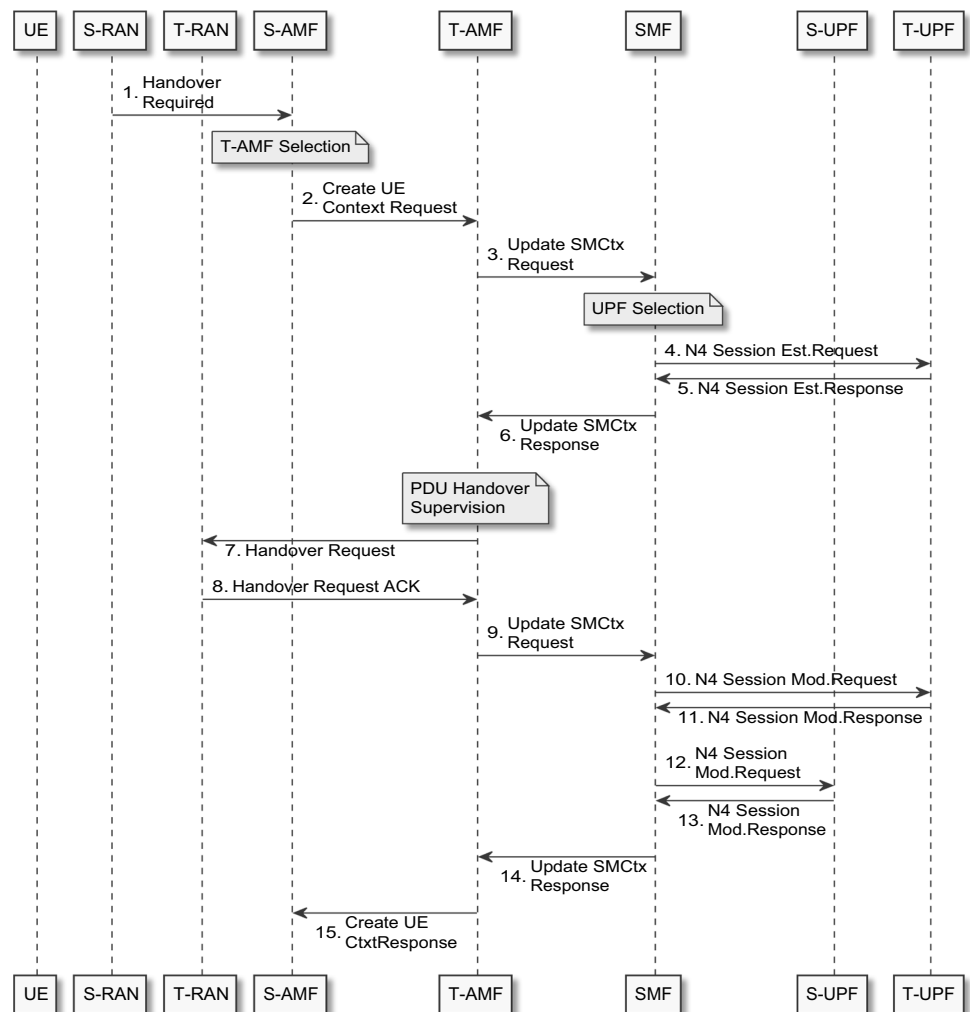
Fig. 6 5G N2-handover execution phase [1]
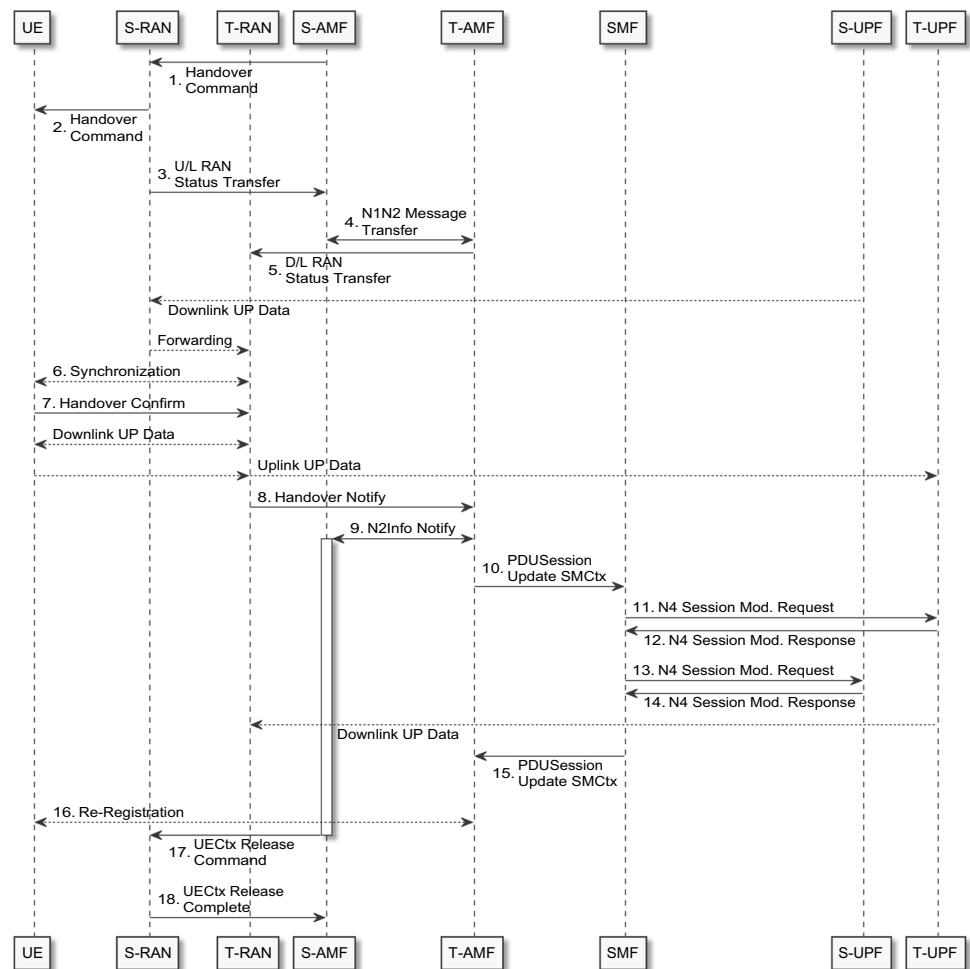
(3–4) and the T-AMF then triggers the downlink RAN status transfer at the T-RAN (5). From this point onward, the UP downlink data from the S-UPF is forwarded by the S-RAN directly or indirectly to the T-RAN. The UE synchronizes with the T-RAN (8) and then sends the *Handover Confirm* message (9). Now the UP data in the down and up link is transmitted between UE and T-RAN. The uplink UP data is also sent to the T-UPF, however, the downlink data is still being forwarded from the S-RAN. To also change the downlink data path, the T-RAN notifies the T-AMF of the handover progress (13). The T-AMF informs the SMF in an *Update SM Context* request, to complete the handover (14,19). Any active PDU Sessions will now be redirected in the downlink, upon receipt of the respective *N4 Session Modification* requests from the SMF to source and target UPFS (15–16), thus completing the UP data re-routing (17). Optionally, the UE registers with the T-AMF in a handover-aware, shortened procedure (19) and the UE Context is released by the source AMF and RAN (20–21).

In this handover procedure, most of the steps were dedicated to the preparation of the target data path as well as to establishing the downlink data traffic redirect during the handover. However, several steps were needed to synchronize the information between source and target AMF, to ensure that the subscriber state is consistently handed over.

5.4 Organic 6G handover procedure

We propose that the Organic 6G core will also split the handover into preparation and execution phases. When a handover is required, the worker does not need to be handed over, as it is stateless and does not own the UE association. Similarly, the front end does not need to execute a handover as it does only have an association with the RAN. The procedure is similar to the SBA reference one, staying compatible with the 5G UP, with a reduction of state synchronization messages.

The preparation phase (Fig. 7) starts with the RAN sending the handover required message to the S-FE (1). The FE selects a Worker and forwards the request to it (2). The worker fetches the UE context (3–4), selects a new data path and executes its redirection (5–6). It also updates the user context

Fig. 7 Organic 6G N2-handover preparation phase
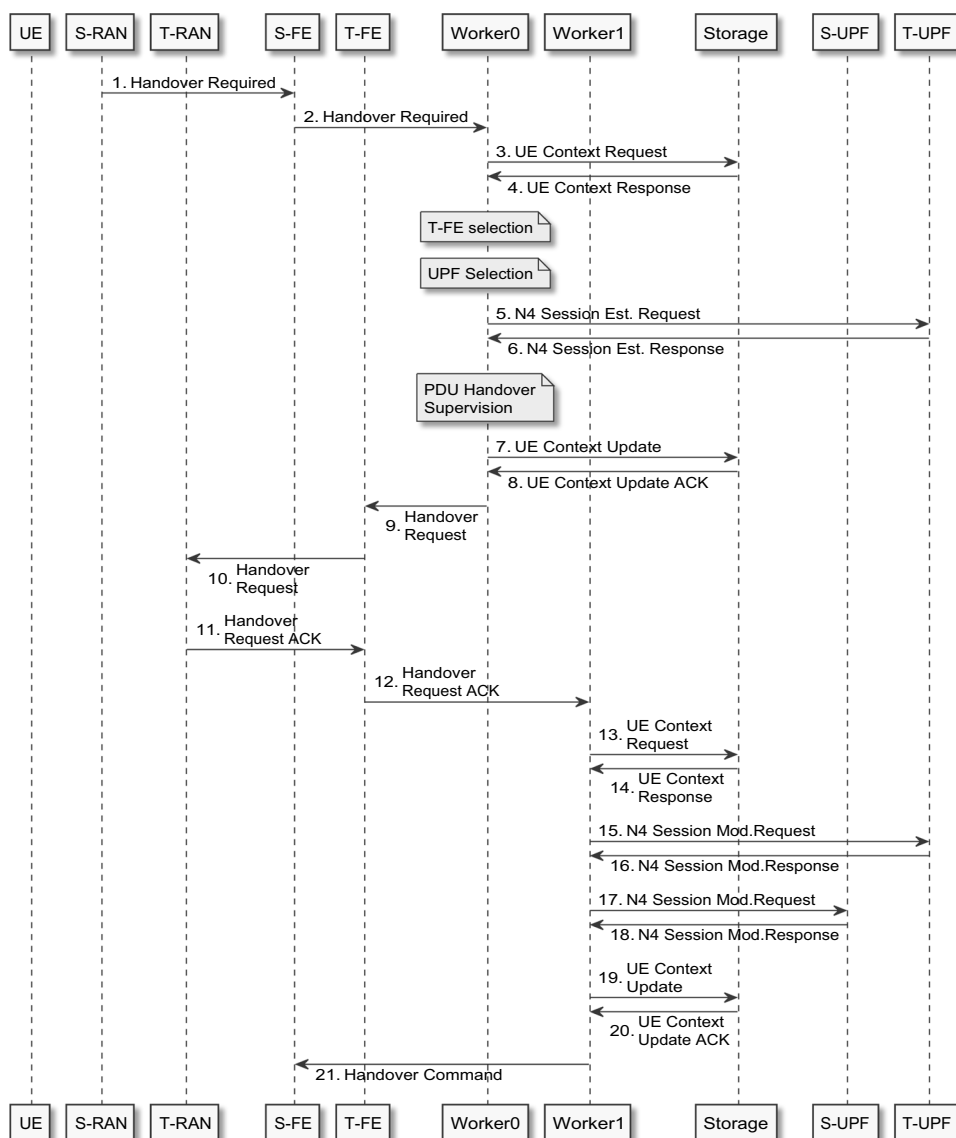
(7–8) and sends the handover request to the tRAN (9–10). For the redirection of PDU session paths, a new worker selected by the target front end (T-FE) is selected (11–12). The worker taking the role of the SMF selects a new UPF and requests session establishment via the N4 interface (13–20).

The execution phase follows immediately (Fig. 8), following the same steps as the 5G handover due to the messages exchanged with the UE and the RAN. The major difference between the procedures is that there is no need to do N1N2 Message Transfer and N2 Info notify. Instead, a single worker is selected (4–5) which handles the adaptation of the data path (6–12) and the cleaning of the UE contest from S-RAN (8–15). We can surmise that the organic 6G handover procedure is faster given the removal of potential inter-AMF communication for state synchronization and the direct selection of the SMF-like worker during the execution phase.

5.5 5G Planned AMF removal procedure

To enable system scale-down in the SBA, it is critical to execute the planned AMF removal procedure (Fig. 9) through which the different elements in the network are informed that a specific AMF will be removed. The need and duration of this procedure impose significant delay on the scale-down. As such we will analyze this procedure from the perspective of dynamicity expected from 6G systems.

Before the AMF can be removed it needs to transfer all UE contexts to another AMF or store them in the UDSF (1–2) and deregister from the NRF (3–4). Then, either the NRF or the AMF itself should notify any CPNF that subscribed to availability updates (6–7). The AMF also notifies any connected RAN nodes of its unavailability, so they can direct new UE requests to other AMFs, as needed. For each connected UE

Fig. 8 Organic 6G N2-handover execution phase
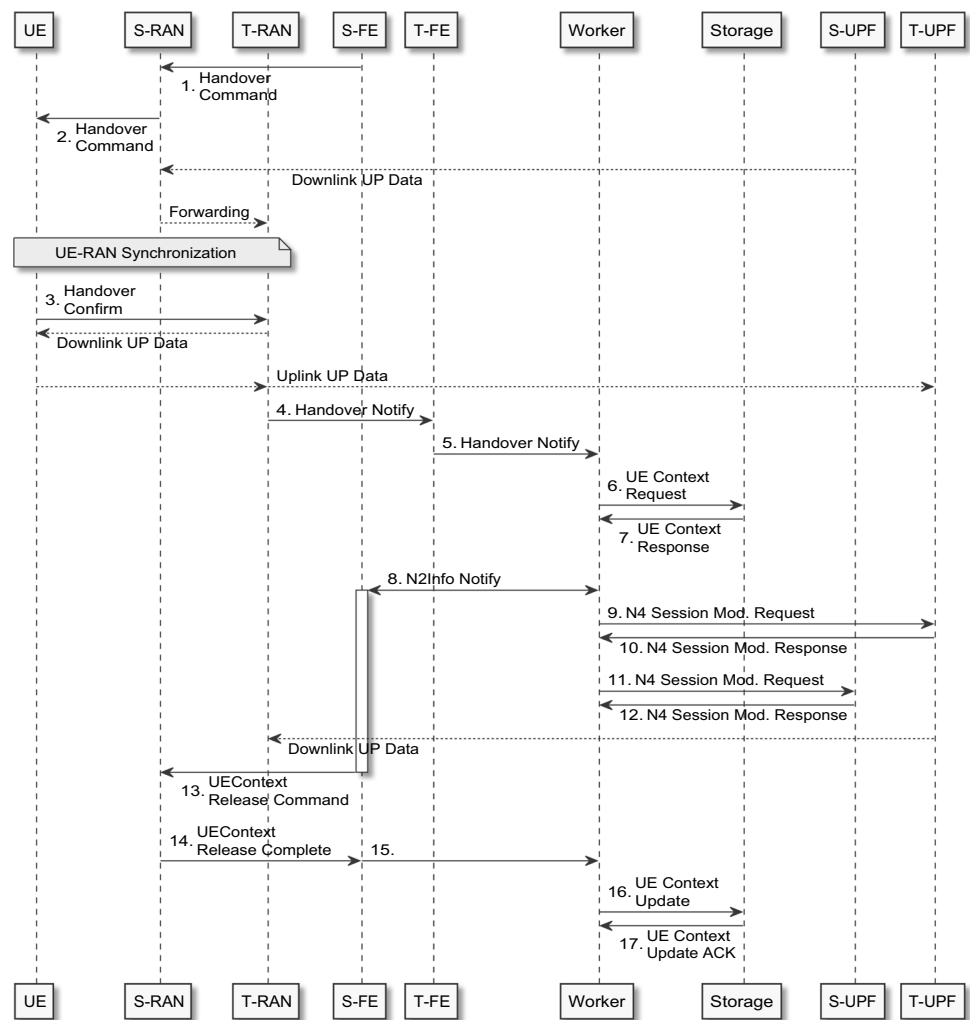
the respective RAN node can release the NGAP UE (TNLA) binding (9) at which stage the AMF holds no information and can shut down.

## 5.6 Organic 6G front end removal procedure

It is foreseen, that 6G networks will embrace more dynamic service deployments. Continuous integration, testing, delivery and deployment practices point towards more frequent updates and replacements. Furthermore, the scale-down procedures can happen more often, to decrease energy consumption. Therefore, such removal procedures should be considered.

As the workers are fully stateless, there is no need to make any special considerations on their removal. They can be removed from the front end selection and immediately stopped when no requests are coming. Please note, that their removal may not even be necessary as they do not maintain any state, thus being dormant processes with no CPU consumption in the time they do not have anything to process.

Considering the organic 6G CN, the closest equivalent to the AMF removal procedure discussed before, is the removal of a front end (Fig. 10). The front end does not hold UE context information outside of any particular procedure, so assuming the removal is not started before all other procedures are completed, it does not need to persist the UE context. As such, no notifications to any other component in the core network is needed. Instead it notifies the RAN nodes of the upcoming unavailability (1–2) and waits to complete the running procedures (3). The RAN nodes consecutively forward requests to different front ends, based on their internal load balancing algorithm.

Since the removal of a NF in the SBA necessitates informing all related NFs, it is inherently more complicated and less flexible than the removal of front ends from the organic CN. Therefore, the Organic 6G CN can scale up and down quickly and without any limitation. Practically the only information to be exchanged is with the RAN to consider these variations, which could be removed by the evolution of the RAN to 6G.

**Fig. 9** 5G SBA planned AMF removal sequence with UDSF
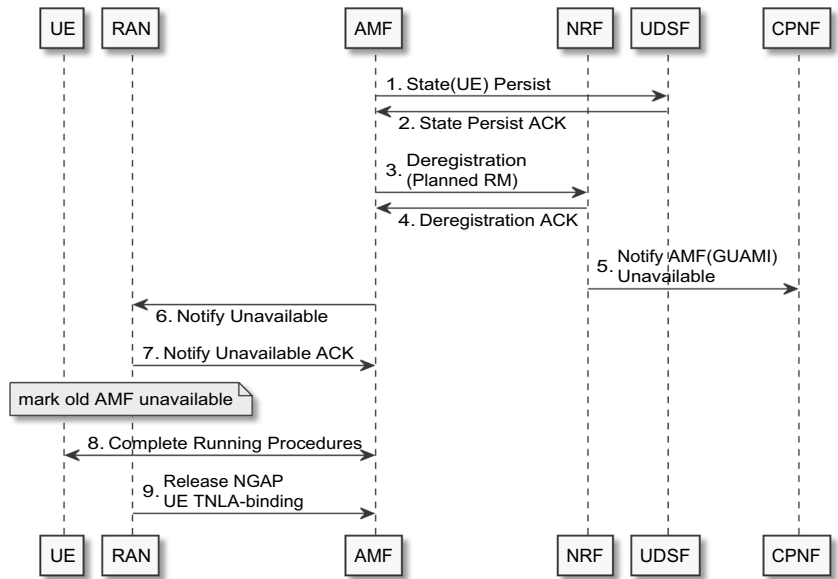
5.7 5G PDU session establishment

When a UE needs to transmit packet data, it may request the establishment of a PDU session, outside of the registration procedure as well. It can be assumed that the AMF already has the subscriber information from the registration procedure. We discuss the "UE-requested PDU Session Establishment for non-roaming and roaming with local breakout" scenario [11]. The sequence of messages is detailed in Fig. 11.

For a PDU session to be established, a tunnel needs to be created from the gNodeB via an appropriate selection of UPFs to the Data Network (DN) or public Internet. The UPFs are controlled by the SMFs. But the only interface between UE and CN is via the AMF it is registered with. So when the AMF receives a NAS message containing a request for the establishment of a PDU session (1–2), it first has to select the appropriate SMF. It will then send a *Create (SM) Context* request to the SMF (3) which retrieves the subscription

information from the UDM (4–5), if needed. After receiving the subscription information, the SMF responds to the AMF. Next, if dynamic Policy and Charging Control (PCC) is required, the SMF selects a Policy Control Function (PCF) to create an *SM Policy Association* (7–9). It sends the *SM Policy Control Create* request to the PCF, which then makes a policy decision after first querying the Unified Data Repository (UDR) for related information. After the association is created and the SMF receives the PCC rules, it continues by selecting one or more UPFs To create the user plane tunnel as requested, the SMF sends *N4 Session Establishment Requests* to the UPFS (12–13). Now the SMF informs the AMF about the acceptance of the UE request and provides additional information in the *N1N2 Message Transfer*, which the AMF acknowledges (14–15). The AMF in turn informs the RAN, which then sends the *Session Establishment Accept* to the UE (16–19) and starts sending the first packets of user data to the UPF. To complete the tunnel establishment, the AMF has to request an update to the *SM Context* to the SMF, triggering an *N4 Session Modification Request* containing additional tunnel information to be sent to the UPF (20–22). Afterwards, the UPF can start sending downlink data to the UE. If it hasn't done so previously, the SMF registers the new session with the UDM (23–24). The SMF responds to the AMF and instructs the UPF about the UE's IPv6 address configuration, which forwards this information to the UE itself (25–27). Finally, another *SM Policy* update request is sent to the PCF.

For this procedure we included some optional steps, to better illustrate, how many requests need to be sent between different NFs. We expect these steps to occur regularly enough to remain relevant.
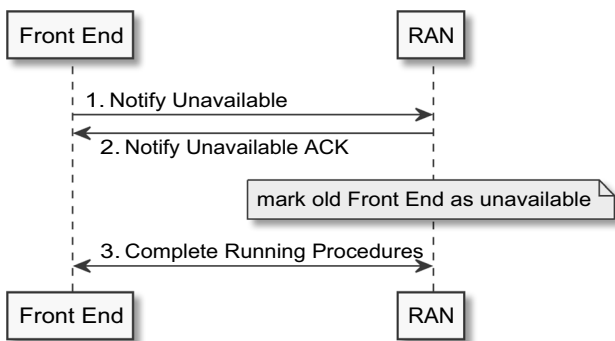
Fig. 10 Organic 6G planned front end removal sequence

Fig. 11 5G PDU session establishment
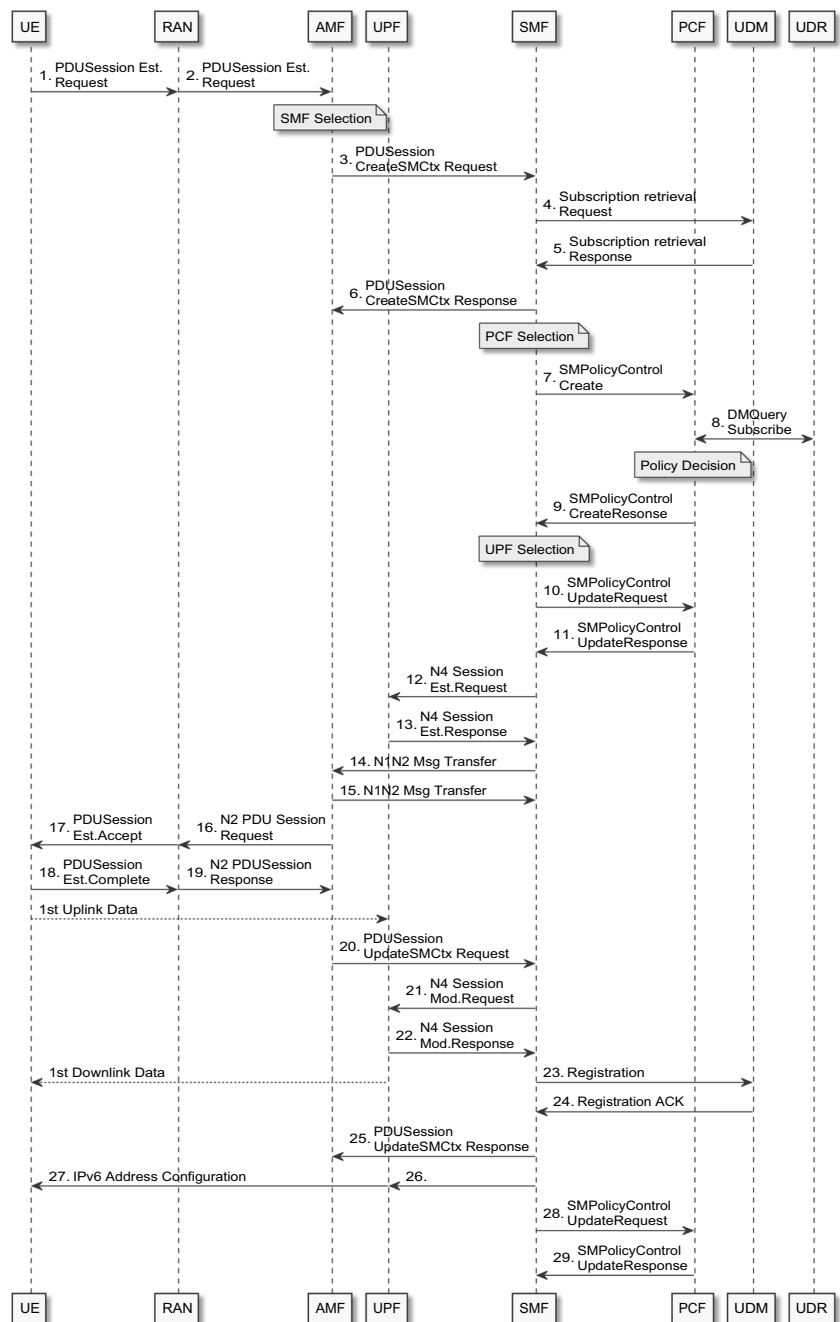
## 5.8 Organic 6G PDU session establishment

Our proposal for an organic 6G PDU session establishment procedure is shown in Fig. 12. While the UE to RAN communication remains basically the same (1–2, 11–14, 21), the CN internal communication is different. Upon receipt of the *PDU Session Establishment Request* (3), several steps can be completed by a single worker (between 5 and 10), given all the necessary information was retrieved in the first UE context request (4–5). This should allow for faster processing and response times. In the second half of the procedure,

the front end can select a different worker and the previous one does not keep the track of the state, so the next worker handling the UE response has to fetch the UE context again.

5.9 Discussion

To understand the difference between 5G and the organic 6G, we try to quantify the differences between procedures. The key metric is the request processing latency of the CN. Overall request latency depends on the RAN technology and environment, the front and back haul connectivity, but also

Fig. 12 Organic 6G PDU
session establishment
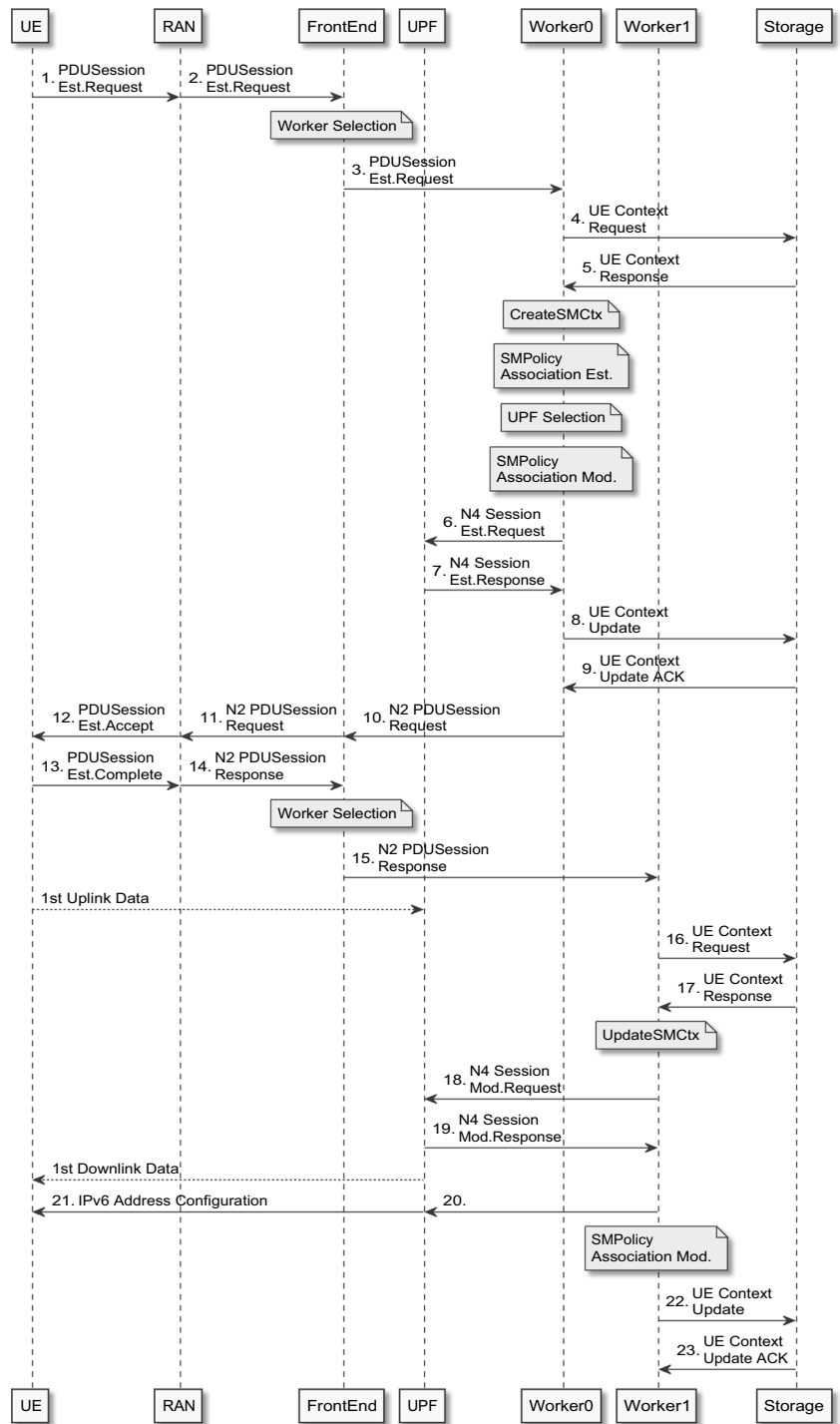
the time spent processing the request. Regarding the latter, the core network architecture and deployment are important contributing factors. Especially when the core network is deployed as a distributed set of micro-services, transmissions between NFs will increase the latency. Therefore, we consider the number of messages between NFs. Table 1 presents a quantitative evaluation of the presented procedures. The organic 6G procedures are similar if not better with regard to

the number of involved NFs and messages exchanged, in the cases of registration, NF removal and PDU session establishment. Notice that the actual 5G registration procedure was simplified for the sake brevity and comparability. In the case of the handover procedure, the organic 6G version uses more NFs and message transmissions. This is due to the additional handover between front ends and the state fetching and storing. PDU session establishment illustrates how multiple

Table 1 Comparison of SBA and organic procedures with regard to the number of NFs and messages

Procedure	NFs	Messages
5G registration	6	20
Organic registration	5	20
5G handover	7	31
Organic handover	8	38
5G AMF removal	5	8
Organic FE removal	2	2
SBA PDU session establishment	7	29
Organic PDU session establishment	5	23

request-response interactions between NFs required in the 5G core, can be avoided by the organic core.

While the 5G procedures are quite efficient, they would become more complex, once NFs are implemented statelessly and a UDSF is introduced. But these interactions are not part of the standard and up to the implementer. One of the main goals of the organic 6G core is externalizing the state to improve reliability and flexibility. The numbers suggest, that this could be achieved without incurring significant latency.

Through efficient caching in the workers and clever load balancing by the front end, enforcing a UE-to-worker affinity, delays due to state retrieval can be reduced. The introduction of new functionality in the 3GPP system often involves additional NFs with dedicated interfaces being introduced. This increases overall system complexity. In our proposal on the other hand, the new functionality would be provided by the existing NFs.

6 Conclusion and further work

The 6G flexibility requirements put very high pressure on the 5G SBA to change [14]. This may not be possible while maintaining the same type of micro-service based functional split. Instead we propose a new Organic 6G CN which realizes the CP as a single web service with differentiated requests. The Organic 6G CN is enabling highly simplified subscriber handovers as well as a native scaling mechanism, proven in this article through the analysis of the main related procedures, due to its completely stateless nature. To maintain a proper comparison, the Organic 6G CN procedures were considering a 5G RAN. The in-depth analysis of the procedures shows that the Organic 6G core has the potential to perform significantly better during UE triggered procedures, while at the same time perform extremely fast in case of CN scaling procedures. This represents also the way in which the procedures here described will be implemented in the near future and will be practically compared with the 5G ones. To maintain

the proper comparison level, we will use the existing, highly modular code of the Fraunhofer FOKUS Open5GCore 5G SBA [21] and regroup the functionality to fit the organic 6G core.

Declarations

Conflict of interest The authors declare no competing interests.

References

1. The 3rd generation partnership project (3GPP)(2022) System architecture for the 5G system (5GS). TS 23.501 v17.7.0, 3GPP. 3GPP
2. The 3rd Generation Partnership Project (3GPP) (2023) Technical realization of service based architecture. TS 29.500 v17.10.0, 3GPP. 3GPP
3. Szalay M, Nagy M, Géhberger D, Kiss Z, Mátray P, Németh F, Pongrácz G, Rétvári G, Toka L (2019) Industrial-scale stateless network functions. In: 2019 IEEE 12th International conference on cloud computing (CLOUD), pp 383-390. https://doi.org/10.1109/CLOUD.2019.00068
4. Kulkarni U, Sheoran A, Fahmy S (2022) The cost of stateless network functions in 5g. In: Proceedings of the symposium on architectures for networking and communications systems. ANCS '21, pp 73–79. Association for Computing Machinery, New York, USA. https://doi.org/10.1145/3493425.3502749

5. Corici M, Troudt E, Chakraborty P, Magedanz T (2021) An ultra-flexible software architecture concept for 6G core networks. In: 2021 IEEE 4th 5G world forum (5GWF), pp 400–405. https://doi.org/10.1109/5GWF52925.2021.00077

6. Corici M, Troudt E, Magedanz T (2022) An organic 6G core network architecture. In: 2022 25th Conference on innovation in clouds, internet and networks (ICIN), pp 1–7. https://doi.org/10.1109/ICIN53892.2022.9758088

7. Corici M, Eichhorn F, Troudt E, Magedanz T (2022) Organic 6G networks: graceful handling of infrastructure flexibility. In: 2022 IEEE globecom workshops (GC Wkshps): 2nd Workshop on Architectural Evolution Toward 6G Networks - 6GArch (GC 2022 Workshop - 6GArch), Rio de Janeiro, Brazil

8. Corici M, Troudt E, Magedanz T, Schotten H (2022) Organic 6G networks: decomplexification of software-based core networks. In: 2022 Joint European conference on networks and communications & 6G summit (EuCNC/6G Summit), pp 541–546. https://doi.org/10.1109/EuCNC/6GSummit54941.2022.9815730

9. Corici M, Eichhorn F, Buhr H, Magedanz T (2023) Organic 6G Networks: ultra-Flexibility through extensive stateless functional split. In: 2023 2nd International conference on 6G networking (6GNet), pp 1–8. https://doi.org/10.1109/6GNet58894.2023.10317754

10. Erl T, Carlyle B, Pautasso C, Balasubramanian R (2012) SOA with REST: principles, patterns & constraints for building enterprise solutions with REST, 1st edn. Prentice Hall Press, USA

11. The 3rd Generation Partnership Project (3GPP) (2023) Procedures for the 5G system (5GS). TS 23.502 v17.7.0, 3GPP. 3GPP

12. Wikström G, Peisa J, Rugeland P, Johansson N, Parkvall S, Girnyk M, Mildh G, Da Silva IL (2020) Challenges and technologies for 6g. In: 2020 2nd 6G Wireless Summit (6G SUMMIT), pp 1–5. https://doi.org/10.1109/6GSUMMIT49458.2020.9083880

13. Hong E-K, Lee I, Shim B, Ko Y-C, Kim S-H, Pack S, Lee K, Kim S, Kim J-H, Shin Y, Kim Y, Jung H (2022) 6g r&d vision: requirements and candidate technologies. J Commn Net 24(2):232–245. https://doi.org/10.23919/JCN.2022.000015

14. Tataria H, Shafi M, Molisch AF, Dohler M, Sjöland H, Tufvesson F (2021) 6g wireless systems: vision, requirements, challenges, insights, and opportunities. Proc IEEE 109(7):1166–1199. https://doi.org/10.1109/JPROC.2021.3061701

15. Jain V, Chu H-T, Qi S, Lee C-A, Chang H-C, Hsieh C-Y, Ramakrishnan KK, Chen J-C (2022) L25gc: a low latency 5g core network based on high-performance nfv platforms. In: Proceedings of the ACM SIGCOMM 2022 conference. SIGCOMM'22, pp 143-157. Association for Computing Machinery, New York, USA. https://doi.org/10.1145/3544216.3544267

16. Kablan M, Alsudais A, Keller E, Le F (2017) Stateless network functions: breaking the tight coupling of state and processing. In: Proceedings of the 14th USENIX conference on networked systems design and implementation. NSDI'17, pp 97–112. USENIX Association, USA

17. Du K, Wang L, Wen X, Liu Y, Niu H, Huang S (2022) ML-SLD: a message-level stateless design for cloud-native 5G core network. Digital Communications and Networks. https://doi.org/10.1016/j.dcan.2022.04.026

18. Sthawarmath S, Renault E, Lejkin T (2022) Designing stateless control-plane for nextgeneration telecom networks. In: 2022 IEEE International mediterranean conference on communications and networking (Medit-Com), pp 154–159. https://doi.org/10.1109/MeditCom55741.2022.9928749

19. Goshi E, Stahl R, Harkous H, He M, Pries R, Kellerer W (2023) PP5GS-an efficient procedure-based and stateless architecture for next-generation core networks. IEEE Trans Netw Serv Manag 20(3):3318–3333. https://doi.org/10.1109/TNSM.2022.3230206

20. The 3rd Generation Partnership Project (3GPP) (2023) Security architecture and procedures for 5G system. TS 33.501 v17.8.0, 3GPP. 3GPP

21. Fraunhofer FOKUS Institute: Open5GCore - 5G Core Network for Research, Testbeds and Trials. http://www.open5Gcore.org. Accessed 15 Feb 2023