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Organic 6G Continuum Architecture: A uniform control plane across devices, radio, and core

Marius Corici[1,2], Fabian Eichhorn[1], Thomas Magedanz[1,2]
[1]*Fraunhofer FOKUS Institute*, [2]*Technische Universität Berlin*
Berlin, Germany
{marius-iulian.corici, fabian.eichhorn, thomas.magedanz}@fokus.fraunhofer.de

***Abstract*—6G visionaries propose uniform control plane operations across connected devices, radio, and core networks. We introduce an advanced, organic 6G continuum concept and architecture, extending the core network's control plane to encompass near-real-time radio control and user equipment via a novel web-based services functionality split. This design, when compared with the 5G Service Based Architecture, showcases a reduction in complexity and an increase in flexibility.**

***Index Terms*—6G, 6G continuum, core networks, organic 6G core, wireless mobile networks, organic 6G networks**

I. Introduction

BUILDING on the advancements of 5G mobile telecommunication networks, sixth generation (6G) networks are foreseen to further enhance capabilities, by adding new functionality at both the core network and near-real-time control levels, enabling new services and knowledge-based network optimization [1] [2] [3]. These new functionalities go beyond communication and will deeply integrate AI into the network [3]. They aim to utilize network information and indications or commands transmitted among Network Functions (NFs), requiring the rework of internal communication interfaces.

When facing the same functional-diversity-challenge, the 3GPP employed the Service Based Architecture (SBA) [4] in the 5G core network. The SBA specifies each NF as a distinct micro-service, complete with a unique front-end, request processing and user state data. In parallel, OpenRAN proposes splitting the radio control plane functions into real-time (RT), near-real-time (near-RT) and non-real-time (non-RT), with dedicated interfaces interconnecting them [5]. Thus, there are two separate control planes with their own interfaces and functionalities. A potential overlap in functionality cannot be ruled out. This can result in two independent control loops with potentially conflicting goals operating in the same network. Some form of coordination or interfacing between these could prevent dissonant behavior and improve system efficiency.

The natural progression would be, to extend the SBA and its micro-services architecture to the Radio Access Network (RAN) [6] and possibly to the User Equipment (UE) [7]. Although appealing, due to its uniformity, integrating this without service differentiation among NFs leads to scalability issues and potential system instability, because of the vast disparity of RAN and UE components compared to the core components (many orders of magnitude more).

While advocating for a continuum between UE, RAN, and the core, we propose a refined understanding of the architecture. This is based on current network functionality, but still preserves the flexibility to add new functions in a scalable and complexity-aware manner.

After assessing the current network constraints, which mostly stem from the lack of context-awareness in the actual NFs, we introduce the Organic 6G continuum architecture, which categorizes services based on real-time requirements, maintained state information and communication intensity. This differentiated structure utilizes varied communication routes and intensities, and has different scalability levels, appropriately dimensioned for the specific goal. In comparison to the 5G system composed of OpenRAN and SBA core network, our proposed architecture, even when partially implemented, clearly displays reduced complexity and enhanced flexibility.

This article is structured as follows. Section II discusses the continuum concept and requirements. Section III presents the Organic 6G Continuum proposal, followed by a discussion of its implementation feasibility in Section IV. Next, Section V compares the organic continuum with the expected SBA-ORAN-based equivalent. Section VI Section VI concludes the text.

II. Continuum Concept And Requirements

The continuum concept, as depicted in Figure 1, is straightforward: all the control plane functionality of the core network, RAN and UE are connected in a single logical network, enabling the direct exchange of messages between any of the NFs. In contrast to the existing dedicated-protocols approach, one would anticipate a larger message overhead, since the same encoding is applied across various types of messages. However, this is considered a minor disadvantage, as wireless

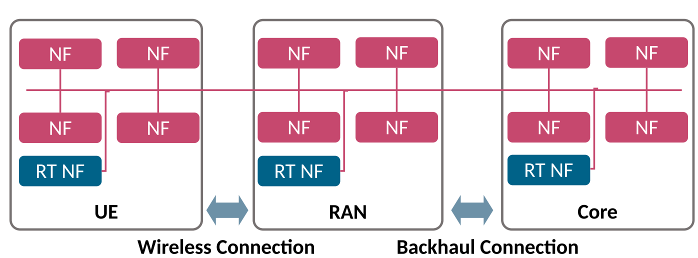

Fig. 1. Continuum Concept

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and backhaul links have significantly large enough capacity to compensate this packet overhead.

The biggest challenge with this proposition lies in the substantial number of messages exchanged. Specifically, if the UE or RAN functionality gains direct access to all NFs, this means millions of messages are transmitted concurrently. This message storm escalates especially because the change of UE state in one NF triggers numerous new messages aiming to change the state on other NFs, a significant complexity increase factor in the current networks.

Within the context of the Open RAN definition and considering current SBA messages, the continuum manages near-RT messages. These messages are synchronous to the request but have a larger delay ranging from tens of milliseconds to seconds. Historically, RT functions in UE, RAN and core communicated through dedicated protocols such as NGAP, NAS or PFCP. Yet, given that the continuum's functionality is near-RT, there's no objection to extending its near-RT interface.

Notably, the near-RT Intelligent RAN Controller (near-RT RIC) functions at a comparably acceptable delay level, allowing for its immediate integration into an SBA-inspired architecture. Although its applications are designed primarily for a single central unit, their remote interfaces could potentially serve broader regions, including multiple RAN instances—similar to the CN. By optimizing protocols, it's plausible to achieve a more integrated approach to RAN and fusing the near-RT RAN functionality with the core network. This includes the device control in the RAN and in the core as well as the RAN topology control including power control or beam steering policies.

The network utilizes two types of databases: one for long-duration data, which stores subscription profiles, subscriber-related policies, accounting, and archival data; and a near-RT database that captures the immediate device state dynamically. The long-duration databases can be linked to the continuum, allowing them to share information with other NFs. However, for interactions between databases, it's more effective to rely on background data traffic and direct database synchronization, given their optimized operations. The near-RT databases, currently spread across different NFs, make each function stateful. Centralizing this data and making the NFs stateless, would bring extensive flexibility and reduce system complexity.

CN functionality comprises multiple services. If separated from the device state, these services can be further broken down, enhancing system flexibility but also increasing message exchanges. A more effective approach would involve a strategic redefinition of functionality, aiming to significantly decrease communication between CN functions.

III. ORGANIC 6G CONTINUUM

Our proposed "Organic 6G Continuum" integrates the expected control plane functionalities of the UE, RAN, and CN into one coherent architecture, as depicted in Figure 2. In this section, we delve into this architecture, highlighting the decisions which informed its design.

We propose classifying the functionality which interacts over the near-real-time continuum based on their temporal scope: real-time functions that respond in milliseconds or less to ensure the seamless service continuity, and near-RT functions that include both stateless and stateful functions, as well as dynamic and static databases.

The real-time functionality encompasses data plane functions in the UE, the RAN, and the User Plane Function (UPF) within the CN. It also includes the real-time RAN control present in the UE, Remote Radio Heads (RRHs), and Central Unit Control Plane (CU-CP). While these components won't differ much from their current non-continuum counterparts, the crucial change is the introduction of a uniform interface. This change enables direct communication between all functions within the continuum.

To minimize the volume of sessions, potential interfaces, and to efficiently aggregate data from a vast number of RAN and CN real-time functions, we propose the reduced Service

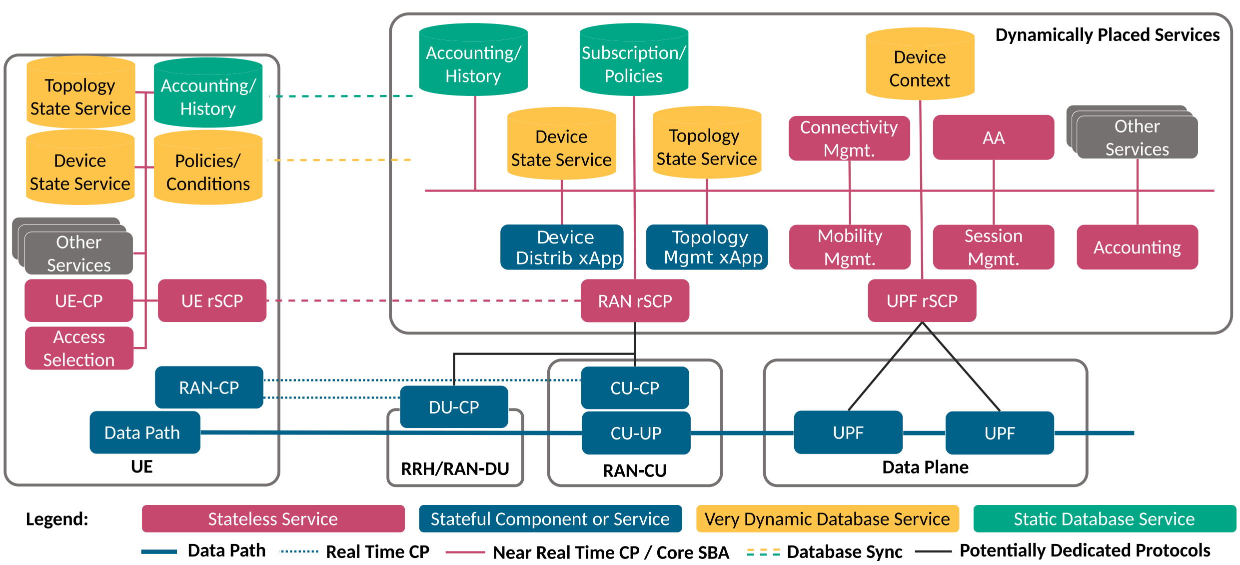

Fig. 2. Organic 6G Continuum

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Communication Proxy (rSCP). This intermediary component serves as a regulator, mediating the communication between external and internal elements. The rSCP mainly acts as a forwarder, capable of pinpointing the location of functions and streamlining the communications. When interacting with the continuum, it performs as a slim front-end, ensuring load balancing, which is based on the request type and the requester's identity.

Instead of directly connecting real-time functions to the continuum, channeling messages through a unified interface for all real-time components, simplifies things. This approach eliminates the need for additional network discovery adjustments that could potentially impact various continuum functions, when data path changes occur. This streamlined method also bolsters the system's flexibility, as modifications to real-time functions don't propagate to all other continuum network components, facilitating easier deployment, upgrade, or migration.

Besides the CN, the organic continuum is equipped to manage the near-RT functions of the RAN, commonly referred to as xApps. These are broadly divided into two main directions: Device Distribution (DD) and Topology Management (TM). The DD operations are concerned with the device positioning and molding their connectivity into the RAN ecosystem. On the other hand, TM focuses on adaptive network planning. Given that these services necessitate a comprehensive grasp of the RAN landscape — and considering the vastness of this information — it would be inefficient to separate them into stateless entities. Hence, they should internally retain the specific information they need.

We recommend unifying these two services into single entities that can assimilate recommendations from various optimization goals, including performance, service quality, reliability, and energy efficiency. This strategy eliminates redundant interconnections among multiple decision points. By integrating diverse objectives, a centralized scheduler can maximize utility, seamlessly blending different targets and issuing consolidated directives to real-time UE and RAN functions.

To enhance flexibility and reduce complexity, we propose a reimagined CN functional split [8]. This new approach segregates the CN functionality into device state storage and a suite of stateless services. Each stateless service focuses on a primary connectivity function, such as Authentication and Authorization (AA), Mobility Connectivity Management, Session Management, and Accounting, drastically reducing the need for intra-CN communication. For these services to operate effectively, they retrieve the state at the onset of processes and update it upon completion. These actions represent their sole interactions concerning the state, significantly reduced compared to the current state fetching and updating which happens at each NF for each message received. Furthermore, a device context service is introduced. This service facilitates informed decision-making in dynamic network contexts, especially when there are fluctuations in radio resources or service usage, paving the way for complete connectivity customization. Beyond this, we can foresee the incorporation of other connectivity services like positioning, sensing, and UE behavior analytics.

This model is designed for agility. Stateless services can be swiftly added or removed anywhere within the network, ensuring seamless scalability and migration. Additionally, the model facilitates the optimization of device state and context distribution throughout the network. This is achieved through specialized database data-sharing mechanisms and potentially direct synchronization with the UEs. Instead of relying solely on specific continuum interface messages, there is an opportunity to employ bulk data exchanges.

To seamlessly integrate the functionalities within the UE and the network under the continuum, we suggest employing the existing RAN rSCP in the network and introducing a UE rSCP within the UE itself. These act as singular connection points between the UE and the network, streamlining discovery processes and request distribution. By masking underlying complexities, they pave the way for enhanced scalability and adaptability within the system.

Utilizing the same RAN rSCP is not perceived as an issue since the rSCP is designed to distinguish requests based on identity and type and has the same roles of load balancing and distribution. Consequently, there's no need for a separate functional type.

The UE rSCP serves as a bridge, connecting internal control plane functionalities, and facilitating access selection, which acts as the UE counterpart to the Device Distribution xApp. It also interacts with various databases that either store UE-specific information or policies relayed from the network. Leveraging the continuum interface, the network can directly tap into these services. This allows fetching unique context data available only at the UE, initiating the acquisition of such data, and transmitting directives and signals to the UE via a shared interface. Consequently, the network can harness the vast array of UEs as data reservoirs, much like current web services, thereby gaining profound insights into the prevailing radio context. Furthermore, the network can relay both conditions and policies that dictate UE behavior, rather than just commands. This empowers UEs with a substantial degree of autonomy, enabling them to adaptively interact with their surroundings.

The UE rSCP also lays the groundwork for UEs to communicate directly amongst themselves, facilitating the exchange of insights and knowledge about their immediate environment. This paves the way for collective connectivity blueprints, enhancing the real-time communication capabilities, like sidelink, with supplementary policies and conditions, crucial for informed decision-making.

In addition to the aforementioned exchanges, the UE and the network can share accounting data, network usage statistics, and insights on subscription profile behavior asynchronously to the communication. At present, this exchange occurs over a separate Over-The-Air (OTA) upgrade interface [9], which, while closely aligned with 5G SBA protocols, remains distinct from other connectivity aspects, especially due to the large amount of data that could be transmitted over this interface. Integrating this into the continuum would be beneficial, especially to learn when OTAs can be executed efficiently as background data, not to disturb the communication.

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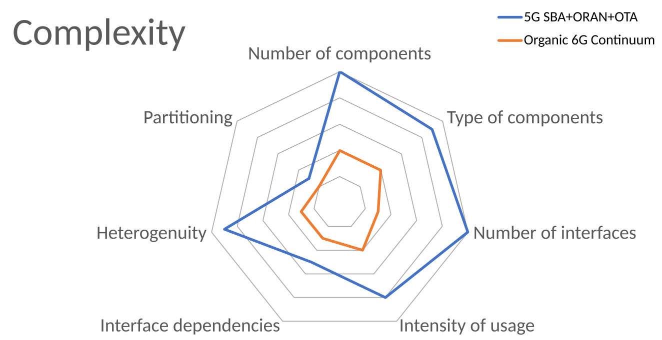

Fig. 3. Empirical Complexity Comparison

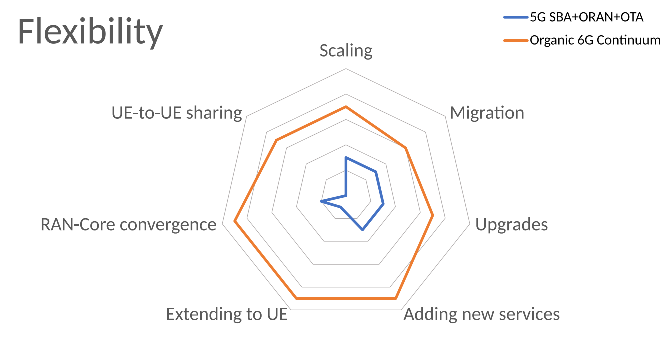

Fig. 4. Empirical Flexibility Comparison

IV. Organic 6G Continuum Implementation Feasibility

In this section, we briefly overview notable advancements across various facets of the Organic 6G Continuum's practical implementation, assessing the feasibility of our proposed model.

Recently, there's been a surge in tools and open-source components tailored to the 5G SBA, targeting different approaches. This surge, largely propelled by campus network deployments and network slicing, gave rise to cloud-native environments designed for core networks. This encompasses new protocols like in Magma [10] and standardized deployments encompassing all interfaces. In the context of the 6G core network, there has been a clustering of functions with separation of device state and division by UE-triggered procedures. This has been implemented and showcased in platforms like the Fraunhofer Open5GCore [11] and Free5GC [12] [13]. The potential of rSCP in integrating network functions, whether co-located or distributed, was also evaluated. Additionally, the complete deployment of an SBA structure for UEs was undertaken, though in the context of an over-the-top roaming proposal. Commercial phones have also implemented similar strategies for Over-the-Air upgrades and for disseminating network policies for access network discovery and selection, albeit utilizing older webservices models [9].

The integration of RAN and SBA, while still in its early stages, is viewed as a pivotal standardization goal by leading manufacturers [14]. The anticipated shift from current protocols to SBI indicates that interfaces to the near-RT RIC functionality might also transition to SBI, given their shared encoding mechanisms [5].

The concept of mixing RAN and core subscriber-centric functionalities within a unified Service Based Interface (SBI) -based continuum has also been validated, particularly when core network data is leveraged in the RAN context [15].

Data synchronization between databases and UEs is primarily facilitated by device manufacturers for logging and debugging purposes [16]. However, such contexts might also be transmitted within a network-aware environment.

In essence, the diverse elements of our proposed Organic 6G Continuum have seen prototypical implementations across research settings, thus validating their practicality. What remains is the articulation of a comprehensive, cohesive architecture as proposed herein.

V. Comparison with 5G Service Based Architecture

In this section, we compare the proposed Organic 6G continuum with the extension of a straightforward 5G SBA architecture to both the device and RAN, highlighting the decreased complexity and increased flexibility.

The incorporation of rSCP functionality for communication with the UE, RAN, and data plane notably reduces the number of sessions, allowing for the establishment of singular control sessions across the network. This is highly important when communicating with the large number of UEs and RANs.

Without losing any existing functionality, our re-structuring of services towards goal-oriented objectives markedly diminishes the number of elements and the horizontal communication within the network. This results in fewer intra-network sessions, reduced encoding and decoding processes, minimized internal dependencies, heterogeneity, and subsequently, a decreased end-to-end procedure latency.

A distinct advantage is the clear separation of device state information, which eradicates horizontal, inter-service communication for state synchronization. This was previously responsible for over 50% of the 5G's horizontal core network communication and increased request processing delays.

The use of stateless services combined with an rSCP as a load balancer offers exceptional deployment flexibility. It ensures rapid scalability and eases the transition to new service versions, even enabling running properly dimensioned versions of the same services in parallel. This can be considered an elegant way of defining network slices customized for different classes of devices.

Moreover, introducing new services to the device and the network becomes more straightforward. Such additions no longer necessitate the update of horizontal interfaces. Instead, they might only demand an upgrade of the device state and a policy, dictating how to process any new requests at the rSCP level. This solution solves the complex entanglement issues evident in the 5G SBA.

Additionally, by integrating the Open RAN near-RT functionality, RAN management, UE connectivity, and UE OTA operations via a singular interface, we achieve a substantial synergy among systems that were previously distinct. This integration paves the way for the development of new services and optimizations within the network. Most notably, it empowers the network to leverage UEs as valuable information sources, a capability that was so far absent but is crucial for delivering highly personalized network experiences. Furthermore, setting up direct interfaces between the UEs, as well as between the UEs and RAN near-RT control, lays the groundwork for enhanced collaborative shaping of the immediate RAN environment and UE communication. This forms the foundation for advanced customization at the local level and promotes a more UE-centric approach to connectivity. This shift alleviates the network's burden of intensive RAN resource scheduling tasks and handover decisions.

To summarize, we provide an empirical expert comparison of the organic continuum and the 5G ecosystem in Figures 3 and 4. It visualizes the improved features of the organic continuum, showcasing a decreased complexity mainly due to the uniform interfaces and regrouping of functionality and an increased flexibility due to the uniform mechanisms.

VI. Conclusion

In this letter we have presented a high-level architecture for a 6G network control-plane continuum, enabling the flexible and simple handling of current communication services, as well as the means to easily integrate new network services, providing a holistic network perspective.

To further develop this proposal towards maturity, we will use it as a blueprint for the further specification and standardization of the different functional elements, as well as for practical prototyping and validation. Especially important is the integration within a single prototype of the different, currently still isolated developments, as presented in Section IV, as well as the testbed validation of the metrics empirically assessed in Section V.

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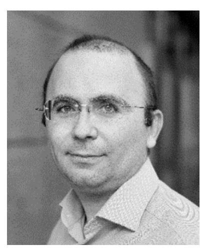

Marius Corici (Dr. Eng.) is the Deputy Director of the Software-based Networks division of Fraunhofer FOKUS and tutor at Technische Universität Berlin leading the research and development teams for Open5GCore, NEMI and Organic 6G Core software toolkits, designing and specifying new architectures and features for beyond 5G and 6G networks.

Fabian Eichhorn (Dipl. Eng.) is a senior researcher at the Software-based Networks division of Fraunhofer FOKUS. Since 2015 he has been contributing to various research projects. Currently, he is working for the German Open6GHub project and contributes to architecture, design and implementation of the Organic 6G Core.

Thomas Magedanz (Prof. Dr. Eng.) is professor at the Technische Universität Berlin, Germany, leading the chair for next generation networks since 2004. In addition, since 2003 he has been Director of the Business Unit Software-based Networks (NGNI) at the Fraunhofer Institute for Open Communication Systems FOKUS in Berlin developing new concepts, architectures, practical software implementations and testbed for telecommunication networks.