Open6GHub

Organic 6G Software-Based Networks

Adaptability, Flexibility, Simplicity, Reliability and Openness at the System Level

Position Paper

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Contents

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Executive Summary: Leveraging Software Flexibility in the RAN-Core Continuum to Build more useful Networks

The complexity of 5G networks has significantly increased over 4G networks due to the transition from physical functions to cloud-based microservices. Despite the 5G core network's radical shift to a Service-Based Architecture (SBA), 5G Core did not fully exploit the offered flexibility of such an architecture; it merely settled for implementing each network functionality as a separate micro-service but did not gain significant benefits out of this approach. Consequently, when new services are integrated, due to the high inter-network functions dependencies number, the core's complexity grows, making it very costly to develop, deploy or manage. In practice, this often resulted in highly suboptimal deployments. SBA is not the problem, but how it is implemented. Did we needlessly define too many micro services?

To improve the utility of networks, the telco industry could adopt software practices from the IT sector, enabling extensive network flexibility. Greater flexibility offers multiple benefits: continuous adaptability to evolving demands, improved performance, enhanced dependability, tailored service offerings, and improved energy efficiency. By using fluid or infrastructure-free deployments on any available computing resources, networks can operate on any infrastructure while incorporating third-party functions within a transparent continuum. This creates a "network of networks" [1] across various administrative domains, providing agnostic access and trusted connectivity wherever it's needed.

Open6GHub seeks to capitalize on this software flexibility opportunity with its Organic 6G Network Architecture. This architecture natively integrates flexibility across infrastructure, network, and management [2]. It extends the 5G structure with a specific modular design that supports seamless operations, integrated RAN-core subscriber management, state handling and automation based on IT industry best practices. Its cutting-edge approach allows networks to adjust themselves quickly to changing needs, making the same network more useful for the operators.

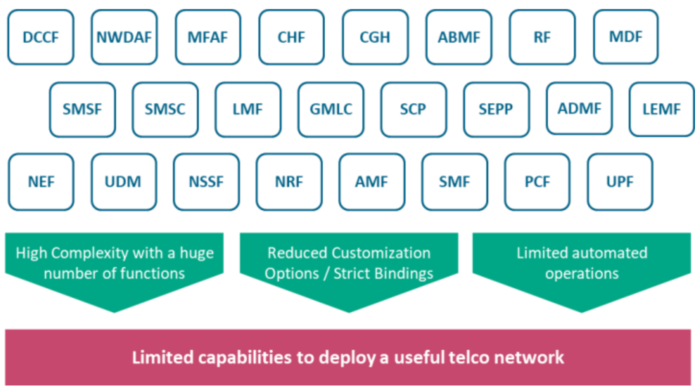

Figure 1: 5G Architecture Limitation: including all functionality in the same way, based on the outdated physical network function design

6G Architecture Opportunities

Moving from 5G to 6G, in our opinion, one of the most important developments will be turning it into a truly software-oriented, well modularized system, offering flexible composition and versatile functionalities adaptable to diverse requirements, still maintaining interoperability with 5G components, within a united, harmoniously cooperating system.

IT Software Best-Practices Modular System Composition

A modular 6G system aims to improve and converge the RAN and the core though implementing the device control functionality only once. The primary objectives include reducing architectural complexity without sacrificing functionality, enhancing network utility through greater customization. The almost 100 different types of Network Functions (NFs) of 5G are interconnected to the extent that they create a monolithic structure that operates statically once deployed. A genuinely modular 6G network, with reduced dependencies among NFs, enables flexible services and easier network management. This flexibility empowers the future system to rapidly introduce new network services, better fit solution to a network's current situation, and distribute the network services across connected devices while maintaining interoperability.

In contrast to past telecom generations, whose adoption required disruptive changes, a modular 6G system favors a gradual evolution from the highly flexible 5G architecture. A truly software-based solution supports incremental upgrades without large-scale infrastructure changes, enabling a gradual transition towards a more performant and reliable network able to granularly adapt to network service requirements.

To integrate third-party applications, a new open and flexible framework is needed, drastically reducing the dependencies on the already deployed system. For this, new interfaces are essential to provide effective security and integrity.

Flexible/Fluid Operation

To enable a more flexible network, 6G should adopt a management approach that allows network services to move freely across the network using the newly found flexibility inherent to software [3]. This creates a dynamic environment that can adapt to the changing needs. This approach has technical challenges, including the need for robust tools to manage the shifting services and ensure that NFs responsible for infrastructure and connectivity do not lead to system failures when restructured.

Despite these challenges, 6G's fluid approach aims to improve efficiency and resource allocation by decoupling services from specific infrastructure nodes. However, considerations like performance, delay, and special control path requirements must be accounted for in network orchestration. The goal is to maintain flexibility without compromising on critical factors such as reliability and performance.

User State Management

Like previous generations, most 5G NFs are stateful with information stored in implementation-specific repositories either within the NFs or in a centralized database. Thus, user state management is the main limiting factor for flexibility and scalability. To address 6G's high distribution and dynamicity requirements [2], the network services implementing the procedural logic have to become truly stateless, enabled by a distributed user state service which offers the state information to the stateless services locally, while transparently and optimally migrating it in the background to where it is needed.

However, this approach brings additional complexity and network overhead. The ideal solution might require dynamic state management that adapts to evolving requirements, ensuring proper service handling during dynamic deployments or service scaling. Balancing these factors is essential as 6G systems advance.

RAN-Core Convergence

One of the key functionalities of the mobile network is user management. In 5G user management happens in both RAN and core control planes. The RAN controls local handovers and ensures continuous connectivity. The core network provides mobility management and user policies. This requires user profiles and tracking of the current user state. For this purpose, the user management needs to communicate with the User Equipment (UE) in near-real-time which is only possible inside or very close to the RAN control plane.

In the 6G control plane, a close collaboration between RAN and core network is required, because, following recent research trends, both possess features of subscriber management in near real time. The 6G user management of RAN and core networks needs to converge to handle the increase in flexibility and improve efficiency. Therefore, the 6G architecture needs to relax the separation between RAN and core on the control plane layer so network services can communicate effectively and take single decisions related to device control in near real time. Avoiding intermediaries and overhead from additional protocol translations as much as possible, the focus should be on a unified control plane interface [4].

Migration to 6G through Software Upgrades Only

The transition from 4G to 5G demanded significant investments from operators. And while the introduction of campus networks opened the possibility to develop products for operators small and large alike, the diversified requirements of operators and the low flexibility of 5G networks made this almost impossible. Thus, as of today, products are developed either for macro-operators or for small custom private networks, further increasing the development cost.

An important aspect of the introduction of 6G would be to enable dynamic scaling of networks in terms of resource consumption or supported number of users, such that the synergies in development between small- and large-scale 6G networks can be utilized. That includes the efficient control of the RAN and the potential to incorporate network infrastructure of 3rd parties. The latter is especially important for the deployment of campus networks, but mobile network operators can also benefit from sharing network infrastructure among each other. However, for this sharing to be applicable, suitable mechanisms to ensure trust and evaluate the correctness of network operation need to be developed. Concepts like Zero Trust might be, in part, a suitable solution for the trust-related issues, but the monitoring of network performance is still an open concern. Thus, a balance needs to be found between the right of an operator to keep his network layout private, and the right of the 3rd party to monitor the correct provisioning of networking services.

Also related to specific operator models is the extent of capabilities and configuration of a system to commission, which is not a question of size but of services-types. Not all deployment scenarios require the same features. 5G however is defined to entail a certain ensemble of services. As of today, these are always included and paid for by every operator. An adaptable solution that can offer reduced capabilities, tailored to an application's demands regarding features and services, can facilitate both re-usability and cost efficiency.

Organic 6G Networks Concept

To fit the network to the changing user requirements, we propose a new Organic 6G network with extensive flexibility across the infrastructure, 6G system, and network management layers, as shown in Figure 2.

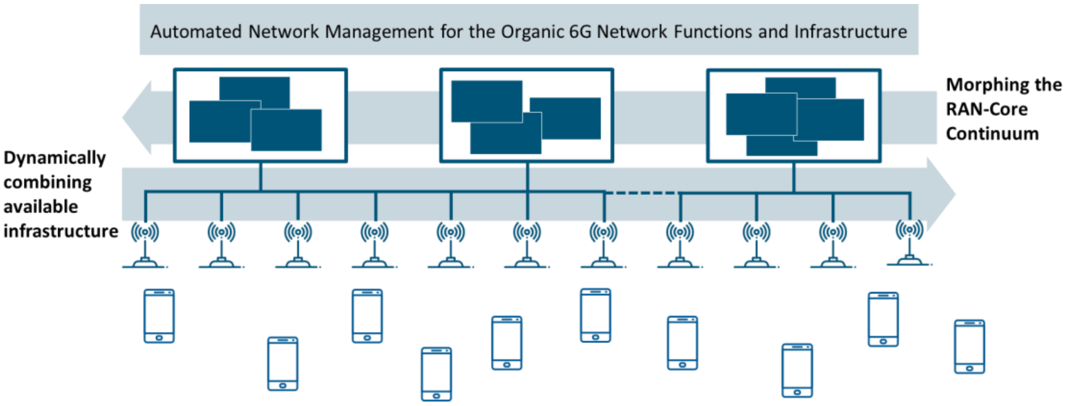

Figure 2: Organic 6G Networks: Automatically Combining and Morphing to meet the Service Requirements [2]

This design adapts in near-real-time to current demands and available infrastructure by merging operator-owned and third-party resources into an infrastructure plane, on which various 6G functionality can be deployed. The infrastructure plane supports nomadic and mobile networks and third-party compute resources connected through reliable or unreliable links, providing a transparent infrastructure layer.

Above this infrastructure layer, the RAN and Core Functionality continuum offers a new approach that continuously morphs itself, adjusting to momentary needs and available infrastructure, by changing where and how many subscribers are served at the different locations. This continuum includes near-real-time functionality in the RAN, device control, and a dynamically allocated data plane on a similar level with 5G networks.

To achieve this flexibility, an automated network management system oversees both the infrastructure and the 6G functionality, ensuring that all morphing operations can be transparent to the network operator. This automated management enables seamless adjustments to meet evolving requirements while maintaining maximum network utility in terms of performance, quality of the offered service, reliability, security, and energy efficiency.

The 6G RAN-Core Continuum

To address the dynamic requirements of the RAN and core network control, we propose implementing a layered services structure that separates processing and device state management while minimizing inter-service message exchanges through distinct processing layers. This Organic 6G Continuum is shown in Figure 3.

Front-End Service (FES) instances serve as interfaces connecting with the end-to-end real-time data path functionality, including User Equipment (UE) and Real-Time RAN. These FESs also interface with User Plane Functions (UPFs) and applications similar to the 5G Network Exposure Function (NEF), maintaining topological awareness and facilitating event notifications for registered network elements. Within the service framework, the FES is designed to discern the request type to correctly route it based on UE's identity and network location.

Worker services encapsulate higher-level functionalities related to subscriber and core network operations. This includes near-real-time RAN functions like traffic engineering and subscriber management, and core network functions like Authentication, Authorization, Connectivity, Session, and Mobility Management. These services are tailored to adapt communications based on near-real-time user status and context, without requiring horizontal communication between themselves. For each request, these services fetch device states and possibly subscription and policy details, ideally from a consolidated database similar to 5G's User Data Management.

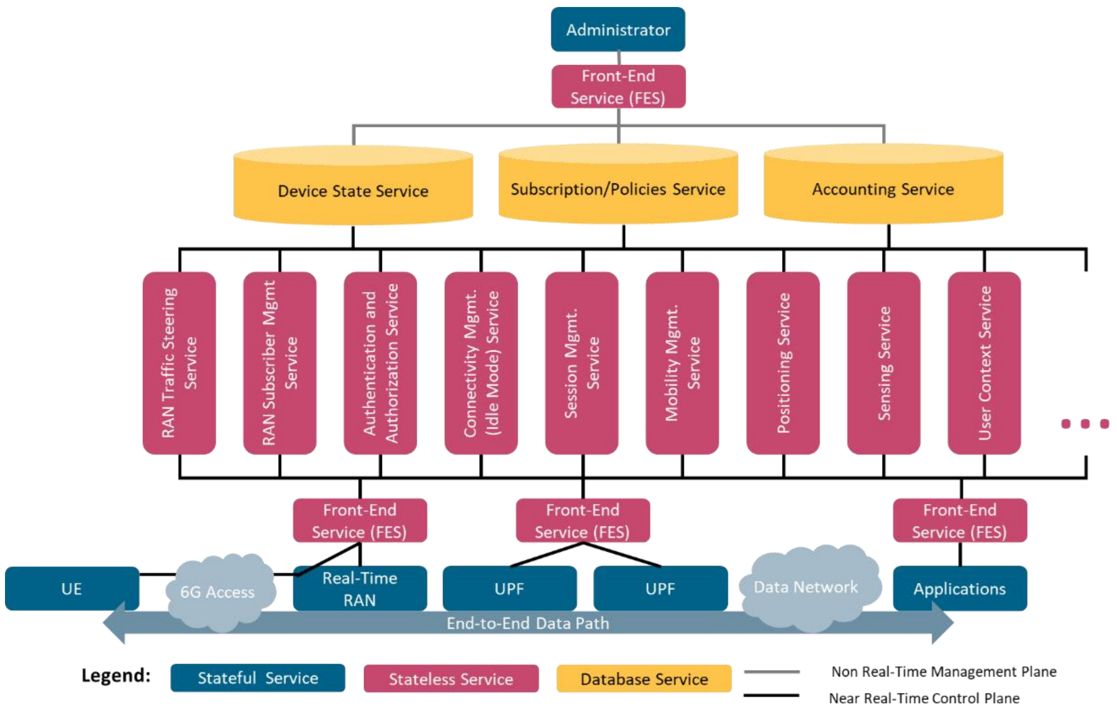

Figure 3: Organic 6G RAN-Core Continuum

An accounting service is introduced for monitoring service usage, supporting optimization, accountability, and compliance. To enhance system management, a dedicated FES enables administrators to access and update subscriber-related information efficiently, aiming for a unified standard interface to simplify operations across various solutions.

The FES is not tracking UE state, solely focusing on directing requests based on their type and UE identity, which allows for scalability and flexible placement within the network. This structure supports the integration of new services simply by updating the FESs to recognize new request types and updating databases with necessary profiles and policies, thus avoiding the cascading interdependencies typical to 5G networks.

This vertical separation of services also enables differentiated services like network slicing within the same system, allocating specific worker services to device classes while maintaining privacy and customization. Upgrading services becomes seamless with load balancing through the FES, allowing parallel operation of different service versions for a smooth transition between system upgrades.

The same separation mechanism facilitates easy upgrades of the worker services. Utilizing the load balancing mechanism in the FES, virtually two versions of the workers can run in parallel addressing different classes of UEs and enabling a smooth migration. Extending this, the FES can act as a proxy between a 5G system, a beyond 5G system with some optimizations and a 6G system while the state of the multiple systems can be grouped within a single database.

Infrastructure Plane

The 6G infrastructure plane can be viewed as a large and dynamic resource pool, on which 6G functionalities get deployed according to current network demands. It consists of physical as well as virtualized infrastructure components potentially even spanning domains of multiple (third-party) providers. It may even include non-terrestrial and nomadic parts (i.e., drone meshes, satellites) further increasing network dynamics.

One of the key challenges of such a large and dynamic resource pool is that all infrastructure elements (irrespective of being hardware or software) still need to be controlled or managed. Access from controllers or management entities requires connectivity between them and their controlled/managed resources. The distributed and dynamic nature of the RAN-Core-Continuum further exacerbates this challenge with the dynamics not only appearing in the infrastructure, but also the control plane.

To address this, we envision a zero-touch control plane fabric (CPF) that acts as “glue” between the dynamic resource pool and the distributed control plane of the RAN-Core-Continuum. The CPF (see Figure 4) provides robust and zero-touch control plane connectivity that ensures controllability of resources in the resource pool. Existing solutions like Kubernetes could provide some flexibility for core services already, but they are neither covering all networked resources nor do they provide zero-touch connectivity. Especially, they assume to have some working connectivity for their own management already in place. Furthermore, the CPF also supplies additional services aiding management and control, such

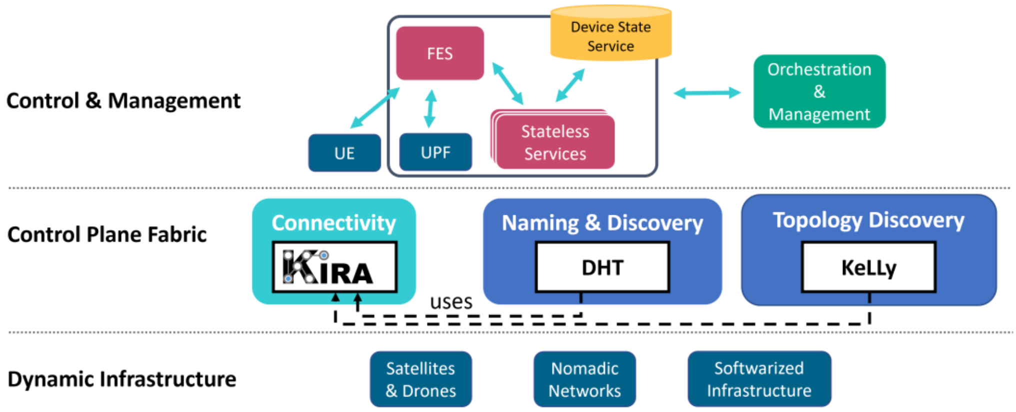

Figure 4: Control Plane Fabric

as service discovery, or a topology discovery mechanism that provides topological information for service placement decisions.

We identify three main requirements for the CPF and its connectivity service in particular:

- Scalability – the number of entities in the control plane can be very high, especially if one considers the number of RAN and core components and UEs. Since all 6G core components must be able to communicate with their corresponding resources, control plane connectivity must be provided between all 6G components.
- Zero-Touch – control plane connectivity and other CPF services need to be provided without any manual configuration or administration and should be self-adapting to changing conditions such as link or node additions and failures. A zero-touch solution has no dependencies and cannot be broken by misconfiguration or circular dependencies.
- Resilience – the CPF services must be maintained even if links, nodes or services fail. Especially, connectivity needs to be restored as long as a viable path still exists. All other control and management functions cannot be carried out if there is no control plane connectivity.

As motivated above, the CPF ensures that organic management can control decentralized core network deployment, e.g., to configure network devices, instantiate core network services in edge data centers. KIRA [5] with its scalable zero-touch ID-based routing protocol is a good fit for providing suitable 6G control plane connectivity. It can also provide service discovery functionalities using an integrated distributed hash table (DHT). Furthermore, KeLLy [6] is a scalable zero-touch topology discovery mechanism based on KIRA.

Management and Automation

Adjusting to real-time network conditions and optimize connectivity, near-real-time network management becomes essential. This orchestration ensures that services respond appropriately to specific situations by maintaining comprehensive awareness of the network topology. This includes understanding service deployments, resource consumption, and availability across various locations, similar to an NFV orchestrator, and anticipating service usage to better manage peak loads.

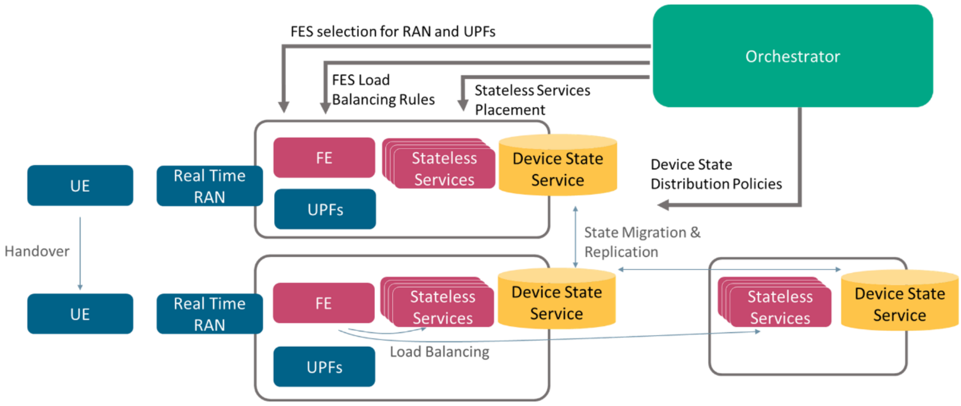

Figure 5: Orchestrating the Continuum

Orchestration must account for UE mobility, communication peaks, and potential congestions, implementing strategies to manage these challenges. Key functionalities overseen by the orchestrator include administrative RAN and UPF selection to distribute load across multiple, parallelly available resources. Ideally, each location would have an FES with sufficient computing power to handle local processing demands or to defer to remote capacities whenever necessary.

The orchestrator also sets and dispatches load balancing rules, which, while straightforward to apply in the FES, based on UE identity and request type, require complex decisions about service allocation per UE class and whether to use local or remote services.

An essential part of orchestration involves managing stateless services and the placement of database front ends to ensure efficient data handling. The orchestrator also handles device state distribution, favoring local data storage to reduce latency but requiring frequent data migrations and replications due to device mobility and potentially unreliable backhaul. Centralizing device state information can simplify the system architecture by allowing worker services to also centralize, reducing the reliance on more costly edge resources without improving processing delays. This streamlined orchestration enhances overall network performance and responsiveness.

Practical Implementations of the Open6GHub Concepts	
	Open6GCore: Organic 6G Reference Control Plane Implementation With the Open6GCore, Fraunhofer FOKUS created the world's first 6G core network prototype addressing R&D requirements. It implements an organic core network, while maintaining compatibility with 5G RAN and user plane interfaces.
	KIRA: Organic 6G Control Plane Fabric Reference Implementation KIRA is the KIT's scalable, zero-touch control plane fabric implementation. It provides resilient IPv6 connectivity without any configuration between all connected KIRA nodes in very large networks with 100.000s of nodes. It handles link and node failures and supports efficient topology discovery as well as simple name registration and lookup services.

Summary and Conclusions

From the initial demonstrator implementations, it became evident that transitioning towards a system capable of morphing flexibly in near-real-time to adapt to changing conditions is the way to achieve a more effective network. The experience gained from addressing the challenges in standard 5G systems has shown that architectural flexibility could resolve many issues, leading the Open6GHub project team to foresee the significant role that organic networks will play in 6G.

It is expected that early adopters of near-real-time infrastructure and functionality morphing for 6G will gain a competitive advantage in the long term. Leveraging the practical demonstrators and toolkits developed by Open6GHub, various technology stakeholders can leverage this momentum to enhance and maximize the utility of networks through near-real-time adaptability.

Open6GHub has already demonstrated the benefits of integrating the RAN-core continuum within the 5G ecosystem. Building on this groundwork, there are numerous ongoing R&D and standardization efforts aimed at further improving near-real-time flexibility, which are set to bring additional advantages and more openness to 6G networks.

Benefits of the Open6GHub RAN-Core Continuum

- **Enabling a more adaptable network**
  - Morphing of networks – organic spawning, merging and adapting
  - Support for mixed static and nomadic scenarios
  - Extreme resilience through near-real-time adaptation to the environment
- **Reduced complexity**
  - Merging of RAN and core device control functions
  - Defining layers of services
  - Many stateless functions
- **A more continuous evolution of the network system**
  - Graceful integration with 5G networks
  - Easy integration of new services
  - Support for easy functionality upgrades
- **Improved business models**
  - Near real-time adaptation of the network to make it more useful
  - Automatic morphing to the service needs

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