6G Architecture Design: Evolution or Disruption?

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Abstract. *In this paper, we aim the shed light on an intriguing question in a essential concept concerning the future 6G network architecture: can it be based on an evolution of the 5G network, or should it follow a disruptive path? Based on the analysis of 6G expected applications, requirements, and enablers, we found that there will not be an exclusively evolutionary or disruptive approach to this architecture, but network solutions that should complement each other to cover all the needs required by the 6G service.*

1. Introduction

Recently, 5G started to gain momentum in the telecommunication industry, significantly impacting the sector. However, there is always an inherent questioning about the next generation, especially in academia.

In this paper, based on several papers published so far, and on experiences of designing and deploying a 5G network, we aim to answer an intriguing question: could 6G architecture be based on an evolution of 5G-Advanced, or should it take a disruptive approach? This will be discussed in the following sections, based on the 6G use cases, requirements, and enablers identified by the academic community so far.

2. DEFINITIONS

This paper considers an evolutionary or disruptive approaches to designing a new generation technology architecture. By evolutionary approach, we mean that most of the previous architecture is leveraged. In general, the framework of the previous architecture is maintained, improving or adding elements, interfaces, protocols, and functionalities. On the other hand, a disruptive approach discards any framework from the previous generation, starting the design of the solution from scratch and the context of the new architecture is totally innovative. A noticeable advantage of the evolutionary model is the reuse of a large part of the investment made by the mobile network operators. On the other hand, the disruptive model gives freedom for research and new implementations, as it does not require compatibility with legacy technologies.

3. RELATED WORK

Strinati & Barbarossa [Calvanese Strinati and Barbarossa 2021] proposes and evaluates a disruptive architecture that refreshes the communication and transmission concept, leading it towards objectives-based, semantic aspects and in the impact that bits have on the interpretation of the message. The prediction of quantum security in the architectural framework classifies it as disruptive [Wu et al. 2021], as it need to be rethought entirely and include intelligent-native in all framework layers.

An example of evolutionary architecture proposal that highlights the role of AI as fundamental for the management of 6G connectivity is presented by Yang et al. [Yang et al. 2020]. Similarly, Han et al. [Han et al. 2020] also reiterate the primary role of AI in realizing a network with pervasive intelligence in a evolutionary approach.

Many other articles, not shown here due to lack of space, show that there is a clear dichotomy between evolutionary and disruptive perceptions in state of the art, leading us to shed light on these differences to support emerging initiatives and discussions.

4. BACKGROUND

The evolution of mobile networks comes in response to a demand for new services or more advanced applications with more important requirements.

3GPP Release 15 introduced 5G in non-standalone mode (NSA), while Release 16 gave us the next-generation core (NGC) or 5G core (5GC), establishing a disruptive evolution in all network core structures so that the EPC network elements are neither leveraged nor evolved to NGC. Release 17 is expected to add both enhancements and new features. Noticeable enhancements are positioning features improvement, with higher accuracy in specific use cases, latency reduction for URLLC applications, introduction of reduced-capability user equipment, or RedCap UE, that will address both mMTC and URLLC requirements, support for non-terrestrial networks (NTN) access (LEO, MEO and GEO satellites) and use of higher frequencies, from 52.6 up to 71 GHz bands [Rahman et al. 2021].

Finally, according to [Rahman et al. 2021], 6G is expected to be introduced in Rel-21, beginning in 2027. Until then, we expect successive evolution in the current 5G specifications.

5. 6G: APPS, REQUIREMENTS AND ENABLERS

To estimate the need for a disruptive approach, we must look at what we expect from 6G. This requires a discussion of use cases, requirements, and enablers. The first view should be on the usage scenarios of 6G and expected use cases and applications intended for the needs for which 6G will address. Based on them, the system requirements should be defined, and then the enablers to fulfill these requirements should be identified.

5.1. 6G Use Cases Scenarios and Applications

To determine the main use case scenarios, we researched several recent papers related to 6G applications, some of which were comprehensive surveys. Some insights are shown below.

According to [Khan et al. 2020], 6G use cases will be further divided into seven new approaches: massive URLLC, human-centric services, haptics communication, holographic communication-based services, unmanned mobility, nano-Internet of Things, bio-Internet of Things. To [Dang et al. 2020], the potential scenarios for 6G use cases are: enhanced conventional mobile communications, accurate indoor positioning, high-quality

Table 1. Use cases versus KPI impact

Use CaseKPI Impact	Peak Data Rate	Latency	Mobility	Connection Density	Energy Efficiency	Reliability	Position Accuracy	Coverage
Tactile Communication	Mid	Highest	Mid	Low	Mid	Highest	Low	Mid
Global Ubiquitous Communication	Mid	Mid	High	Low	Mid	Mid	Low	Highest
Vehicles Communication	Mid	High	Highest	Mid	High	Mid	Highest	High
XR Communication	Highest	High	High	Mid	Mid	High	Low	High
IoE	Mid	Mid	High	Highest	Highest	Mid	High	High

onboard communications, worldwide connectivity, support to vertical industries, holographic communications, tactile communications, and human bond communications. Finally, [Samdanis and Taleb 2020] anticipates the following use cases for 6G: holographic communication, XR, biosensors, tactile internet, Internet of Everything (IoE), enhanced vehicular communications, and unmanned aerial vehicle services.

To proceed with the analysis, we will focus on the following five types of use cases, which will demand a high degree of network requirements: 1) Tactile (or haptics, or multi-sense) communication; 2) Global ubiquitous communication; 3) Vehicles communication, including high-speed in-vehicle data communication; 4) Extended Reality (including holographic and advanced AR/VR) communication; 5) Extreme IoT or Internet of Everything (IoE), including nano-IoT and bio-IoT.

5.2. 6G Expected Requirements

Based on the FG-NET-2030 white paper [FG-NET-2030 2021] and a vision provided by [Jiang et al. 2021], we have selected eight main requirement KPIs, which are shown in Table 1, associated with the five previously identified potential use cases. To each requirement, one use case was considered the highest demanding, so we will focus on the strictest case for each one.

Peak data rate: XR (which comprehends AR/VR) communication should require from around 1 Tbps peak data rate [Hu et al. 2020].

Air-interface latency: here, tactile communication is the highest demanding application. According to [Ray 2021], tactile IoT will require an end-to-end latency equal to or less than 1 ms.

Mobility: for 6G, the highest mobility is expected to reach 1,000 km/h, considering commercial airline users [Jiang et al. 2021].

Connection density: in matters of bio-IoT and nano-IoT, it is envisioned that 6G systems should support 10^7 devices per km^2 [Jiang et al. 2021].

Energy efficiency: the challenge of implementing functional nano-IoT devices resides mainly on the need for power consumption per bit, expected ten times less energy per bit in 6G [Sun et al. 2018].

Reliability: tactile communications applied to healthcare are the most critical application in terms of reliability that should be equal to or higher than 99.9999% according to [Ray 2021].

Position accuracy: some cases of autonomous UAV applications will require higher accuracy in localization, in the order of centimeters [Kang and Cha 2018].

Coverage: 6G is expected to be globally ubiquitous [Jiang et al. 2021], which can not be accomplished only with the terrestrial RAN approach.

5.3. 6G Enablers

After identifying some key requirements, we can analyze some of the enablers that should be needed to achieve them. Here we will point out the most relevant in the researched papers.

To achieve the challenge of 1 Tbps peak data rate, both terahertz (THz) communication and optical technology shall be important enablers. Shahraki, A. et al. [Shahraki et al. 2021] points terahertz bands, ranging from 100 GHz to 10 THz, and optical wireless communication (OWC), from infrared to ultraviolet spectrum will be widely used.

While mobile edge computing (MEC) will mainly address the need for low latency in 5G, the target of 0.1 ms latency imposes a deeper challenge. Quantum communication is one of the enablers proposed to overcome it [Ferrara et al. 2021], together with other techniques such as free-space optical systems (FSO) and haptic specific protocols.

For the extreme high-density problem, there are more conventional approaches: ultra-dense networks (UDN), device-to-device (D2D) connection, ultra massive MIMO, and fast, accurate beamforming among them [Yastrebova et al. 2018].

The energy efficiency challenge for IoE devices should be addressed by energy harvesting techniques [Sun et al. 2018] and, in the same direction, a specific implementation should overcome the need for centimeter position accuracy on devices that requires this feature; therefore, both not depending on 6G specification.

The use of artificial intelligence may increase reliability applied to network configuration, together with end-to-end redundancy, including coordinated multi-point (CoMP) [Jiang et al. 2021].

Finally, the problem of worldwide coverage could be overcome with the integration of above mentioned NTN with the conventional terrestrial networks.

6. BEST ARCHITECTURAL APPROACH TREND

Finally, it is time to answer the proposed question: is it possible to have a 6G architecture with a more simple evolutionary point-of-view, or does it need a more extreme disruptive approach? The answer will be separately addressed to the RAN and the core sides, but, in general, we anticipate that this greater complexity leads to several types of approaches in parallel, and there will not be a "one-size-fits-all" architecture.

From the perspective of the radio access network, which is usually one of the main bottlenecks of the system, we can point out some of the most important enablers as the use of terahertz and OWC bands. As mentioned, these two technologies will bring harder technical challenges that are not yet addressed in current network architectures, nor are expected to be so in the short and mid-term so that a disruptive network approach will be necessary not only in the implementation of solutions but also in the integration with conventional RAN. On the other hand, important enablers are already used in 5G or even 4G, so an evolutionary approach will complement the RAN solution, such as UDN, D2D communication, CoMP, AAS, ultra massive MIMO, and better and faster beamforming.

Also, the use of LEO to complement coverage, especially in remote locations, is already being addressed in the 3GPP Rel-17 specifications and should have an evolutionary approach.

Thus, in general, we will observe both evolution and disruption in the architectural model of RAN. Traditional terrestrial systems, although will still prevail, will not be enough to meet the requirements of 6G, so new forms of implementing RAN will complement them with entirely new technology approaches.

The network core architecture will also depend a lot on the application. A more realistic approach would be to have a model closer to the 5G traditional one – thus, based on evolution – for more conventional applications. In contrast, the enablers that will support applications with the extreme stricter specific requirements will have to be implemented from the perspective of totally disruptive architectures, like quantum communication/-computing and haptic protocols. There is still no architecture that can evolve to serve as a framework for implementing these enablers, so both their conception and the way to interconnect with legacy networks will have to be designed from scratch. However, legacy networks will also evolve to complement the 6G solution portfolio. MEC frameworks and architectures, for example, will continue to support low-latency applications and help overall network efficiency.

So, in the same way as the access side, the network core architecture will also have evolutionary and disruptive components, acting in complementarity according to the use case.

7. CONCLUSIONS

In this paper, we sought the answer an essential question: should 6G architecture be based on evolutionary terms, following the trends of the current path traced by 5G and 5G-Advanced, or should it be a new and disruptive proposal? After looking deeply into applications, requirements and enablers, we see that the trend seems to mix evolutionary and disruptive approaches, with networks complementing each other. The evolution of 5G terrestrial network architectures will likely meet some of them, requiring less investment in networks. In contrast, more demanding applications will require more disruptive solutions, and there may even be synergies between specialized operators in different markets niches. Future works may investigate each approach independently, focusing on how evolutionary or disruptive aspects addresses each enabler individually.

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