6G Network Architecture

Weihua Qiao

Ofinno • ofinno.com • March 2021

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Abstract

With the commercialization of fifth generation (5G) technologies, the communications industry has started research activities on a sixth generation (6G) communication system. This article discusses services and requirements of 6G as well as possible network architectures to support these requirements.

6G Services and Requirements

1) Holographic Type Communications

Holographic-Type Communications (HTC) is a new type of communication where holographic applications communicate holographic data remotely and render the holograms locally [1]. For example, HTC provides the communications of multiple service data flows from multiple view cameras and so that holograms can be rendered locally. With a holographic display, the hologram can present gestures and facial expressions [2].

For 6G, there are some challenges to support HTC. For example, 6G will need to support very high bandwidths (e.g., TeraBits Per Second, Tbps) to transmit the large volume of data required for high-quality holograms. This is one of the reasons why HTC is not widely used in 5G. The quality of a hologram involves color depth, resolution, and frame rate as in the video, but holograms also involve the transmission of volumetric data from multiple viewpoints to account for shifts in tilt, angle, and position of the observer relative to the hologram ("Six Degrees of Freedom") [1].

2) Artificial intelligence (AI)

According to a definition of Techopedia, AI analyzes an environment and then makes decisions based on those analyses. To analyze an environment, the AI uses either predetermined rules and search algorithms, or pattern recognizing machine learning models. The AI plays an important role in 6G. For example, AI may be applied to semantic communications, machine learning and deep neural networks [4]. With learning and big data training, AI techniques can provide intelligence for wireless networks. AI will be an innovative technique for designing 6G autonomous networks [3].

In addition to a high computing capacity, support for AI will also require a high-bandwidth and low-latency network.

3) Multi-Sense Networks

Multiple senses include touch, hearing, sight, smell, and taste. Multiple sense networks apply HTC for tactile and haptic applications (e.g., the tactile Internet) to provide a multiple sense experience. A high throughput (e.g., Tbps) and low latency will be required to support multiple sense networks [3].

4) High-Precision Manufacturing

High-precision manufacturing is very important to the Industry 4.0. Industry 4.0 uses smart technologies to automate traditional manufacturing and industrial practices. To implement high-precision manufacturing, 6G will need to be support: high reliability (e.g., up to the order of 10^{-9}), low latency (e.g., in the order of 0.1 to 1ms round trip time), and low delay jitter (e.g., in the order of 1µsec) [4].

5) Truly Immersive Extended Reality (XR)

XR is a new technology that combines Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). XR may be used for entertainment, medicine, science, education, and manufacturing industries [2]. The challenges of XR will require 6G to support extremely high throughput and low latency.

KPI	5G	6G
Traffic Capacity	10 Mbps/m^2	~ 1-10 Gbps/m^3
Data rate DL	20 Gbps	1 Tbps
Data rate UL	10 Gbps	1 Tbps
Uniform user experience	50 Mbps 2D everywhere	10 Gbps 3D everywhere
Latency (radio interface)	1 msec	0.1 msec
Jitter	/	1 μsec
Reliability (frame error rate)	10^{-5}	10^{-9}
Energy/bit	/	1 pJ/bit
Localization precision	10 cm on 2D	1 cm on 3D

TABLE. 1 Comparison of 5G and 6G KPIs

6) Comparison of 5G and 6G Key Performance Indicator (KPI)
To support applications and services mentioned above, 6G should support higher KPIs than 5G. Table 1 shows a comparison of example 5G and 6G KPIs [4].

Network Architecture of 6G

To support 6G services and applications, and to meet the requirement of 6G higher KPIs, a new network architecture is needed. The new network architecture should have a new control plane, a new user data plane, and a new management plane. The new control plane will enable efficient signaling and path routing protocols to establish sessions and to enable high precision manufacturing. The new user data plane will enable efficient user data transmission (e.g., low delay) and adapt to different operating modes [4].

1) Network Architecture Evolution from 4G to 5G
Fig. 1 shows the network architecture of 4G (i.e., Long Term Evolution (LTE) / System Architecture Evolution (SAE)). Fig. 2 shows the network architecture of 5G. The network architecture underwent several changes from 4G to 5G:

A. A service-based architecture (SBA) is used for the control plane of the 5G core network. This enables operators to deploy new services without adding new interfaces to the network, and accordingly deliver the services to users rapidly.

B. The control plane and the user plane are separated in 5G. This enables the operator to scale the control plane and user plane independently. On the other hand, the dedicated user plane can implement high-speed packet processing and forwarding, and large throughput. This is critical to support different kinds of services and applications for different users in 5G.

NOTE: In 4G, since release 14, the Control and User Plane Separation (CUPS) can be supported by the Serving Gateway (SGW) and the Packet Data Network Gateway (PGW) [5].

C. In 4G, the Mobility Management Entity (MME) comprises both the mobility management function and the session management function. In 5G, the mobility management and the session management are separated. The Access and Mobility Management Function (AMF) is responsible for mobility management, and

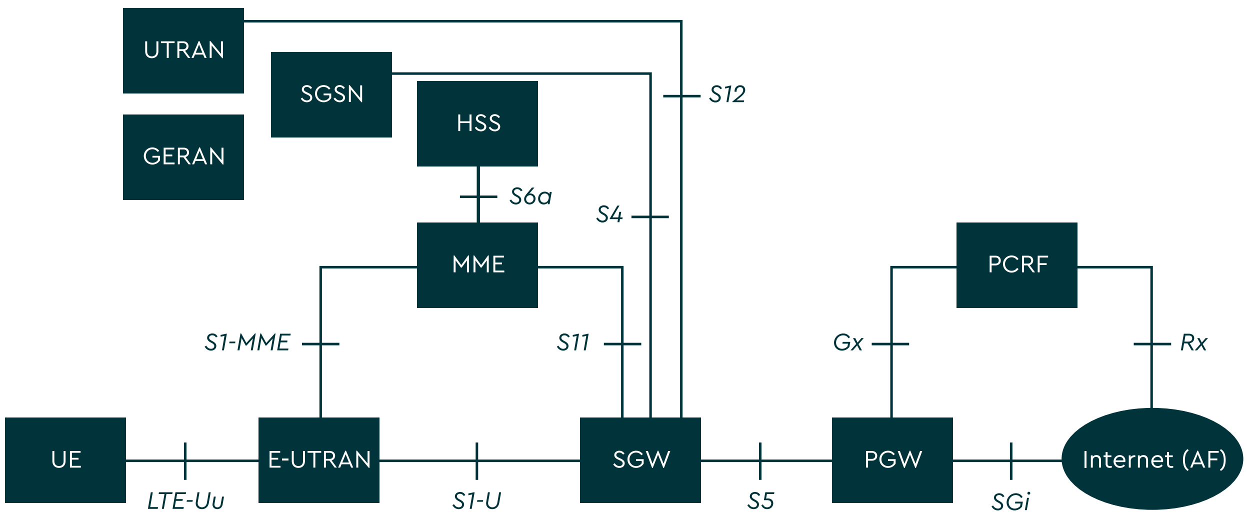

FIG. 1 4G Network Architecture [6]

the Session Management Function (SMF) is responsible for session management.

D. In 4G, the user data is transferred between the user equipment (UE) and application server via the Radio Access Network (RAN), SGW, and PGW. In 5G, the user planes of SGW and PGW are combined to one user plane function (UPF). The user data is transferred between the UE and application server via the (R)AN and the UPF. This can decrease the end-to-end packet delay providing the user with a better experience.

2) Proposed 6G Architecture

Although the 5G network architecture is more optimized than 4G, the 5G network architecture still need to be further optimized to support 6G services. For example, the 5G network comprises

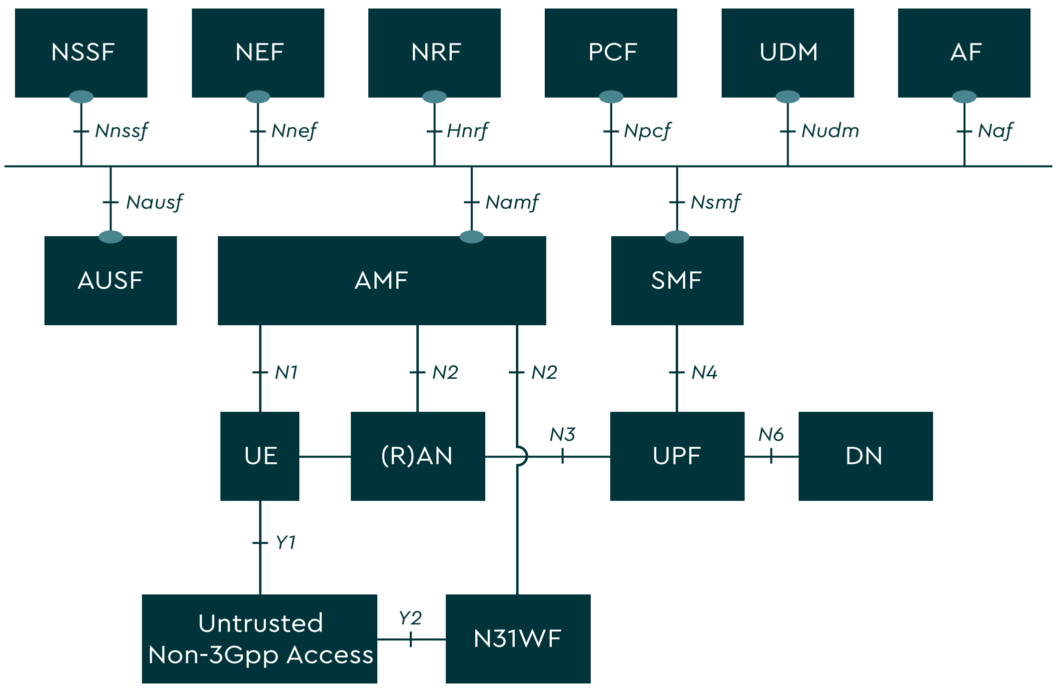

FIG. 2 5G Network Architecture [7]

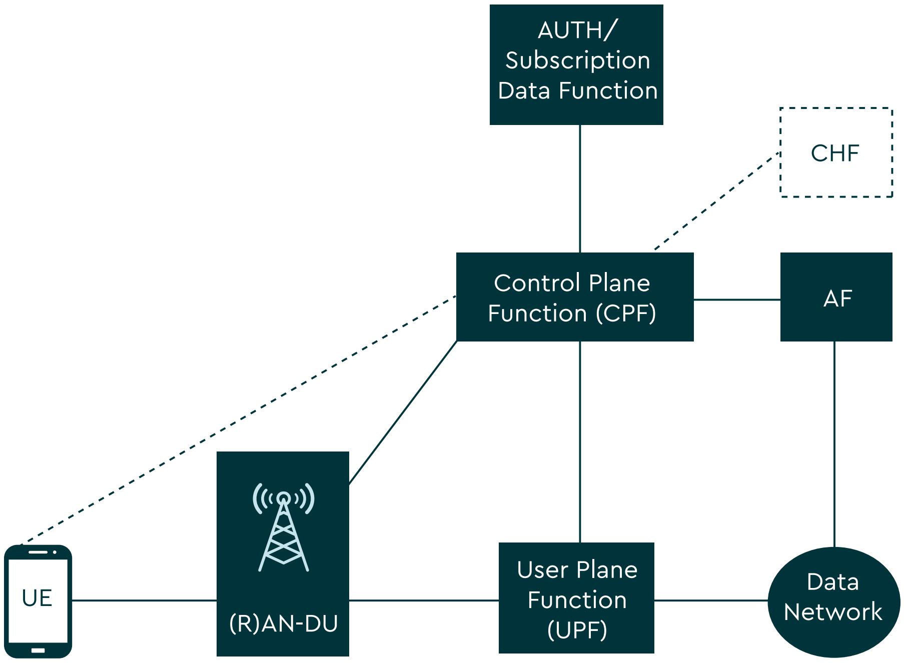

FIG. 3 Network Architecture for 6G Communication System

many network functions, e.g., UE, (R)AN Distributed Unit ((R)AN-DU), (R)AN Central Unit Control Plane ((R)AN-CU-CP), (R)AN Central Unit User Plane ((R) AN-CU-UP), AMF, SMF, Policy Control Function (PCF), UPF, Unified Data Management (UDM), Authentication Server Function (AUSF), Charing Function (CHF), Application Function (AF), Network Slice Selection Function (NSSF), Network Exposure Function (NEF), and Network Repository Function (NRF). This large quantity of network functions makes it very complex to construct a communication network. For the 5G control plane, significant signaling is required between network functions to register the UE to the network. Additionally, significant signaling is needed to establish a PDU session for a UE. For the 5G user plane, the user data packet is transferred between the UE and the application server via (R)AN-DU, (R) AN-CU-UP and UPF. The end-to-end delay still needs to be optimized by decreasing the hops between the UE and the application server.

Fig. 3 is an example network architecture for a 6G communication system. This 6G communication system includes a UE, a DU of a base station (e.g. (R)AN-DU), a control plane function (CPF), a user plane function (UPF), an AUTH/Subscription Data Function, a CHF, an AF, and a data network. The CPF includes a CU-CP of a base station. The CU-CP of the base station includes an RRC layer/function and a Packet Data Convergence Protocol (PDCP) layer/ function. The CPF includes an access and mobility management function, a session management function, a policy and charging control function, and a charging function. The UPF includes a CU-UP of a base station. The CU-UP of the base station includes a Service Data Adaptation Protocol (SDAP) layer/ function and the PDCP layer/function.

FIG. 4 shows a control plane protocol stack for a 6G communication system. As shown in Fig. 4, the UE includes the following protocol layers: Physical (PHY), Media Access Control (MAC), Radio link control (RLC), Packet Data Convergence Protocol (PDCP), Radio Resource Control (RRC), and Non Access Stratum (NAS). The PHY, MAC, and RLC protocol layers can be used by the UE to communicate to an (R)AN-DU. The PDCP, RRC, and NAS protocol layers can be used by the UE to communicate to a CPF. The (R) AN-DU uses the PHY, MAC, and RLC protocol layers to communicate to the UE. The (R)AN-DU uses the L1, L2, Stream Control Transmission Protocol (SCTP) / IP, and Application Protocol (AP) protocol layers to

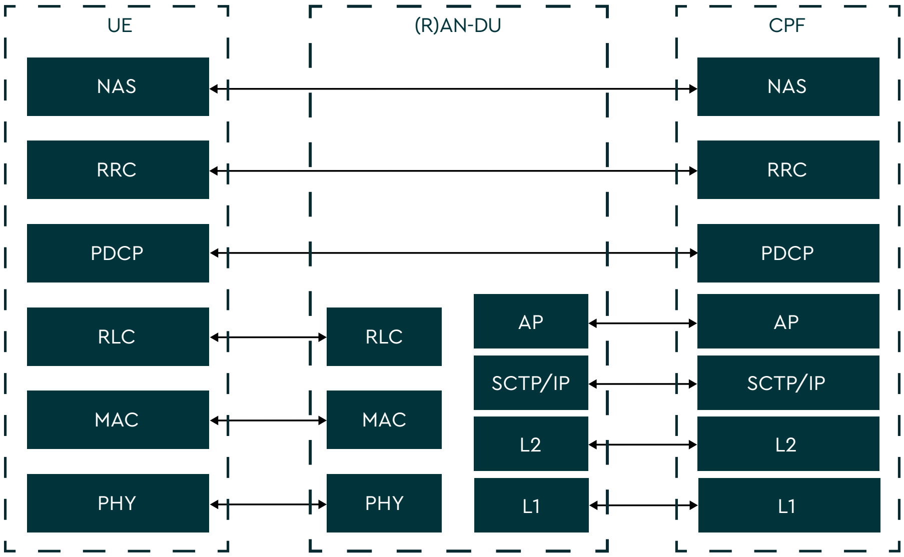

FIG. 4 Control Plane Protocol Stack for 6G Communication System

communicate to the CPF. The CPF includes the L1, L2, SCTP/IP, AP, PDCP, RRC, and NAS protocol layers. The L1, L2, SCTP/IP, and AP protocol layers can be used by the CPF to communicate to the (R)AN-DU. The PDCP, RRC, and NAS protocol layers can be used by the CPF to communicate with the UE.

FIG. 5 depicts a user plane protocol stack for a 6G communication system. As shown in Fig. 5, the UE includes the following protocol layers: PHY, MAC, RLC, PDCP, SDAP, IP/Non-IP/Ethernet, and Application. The PHY, MAC, and RLC protocol layers can be used by the UE to communicate to an (R)AN-DU. The PDCP, SDAP, and IP/Non-IP/Ethernet protocol layers can be used by the UE to communicate to a UPF. The Application layer can be used by the UE to communicate with an application server. The (R) AN-DU uses the PHY, MAC, and RLC protocol layers

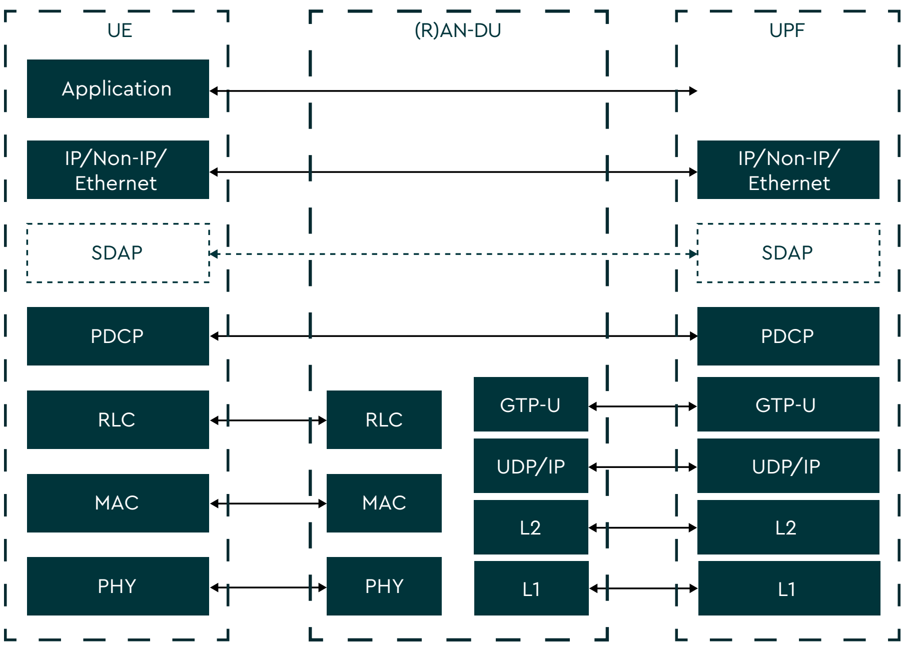

FIG. 5 User Plane Protocol Stack for 6G Communication System

to communicate to the UE. The (R)AN-DU uses the L1, L2, UDP/IP, and the GTP-U protocol layers to communicate to the UPF. The UPF includes L1, L2, UDP/IP, GTP-U, PDCP, SDAP, and IP/Non-IP/Ethernet protocol layers. The UPF uses the L1, L2, UDP/IP, and GTP-U protocol layers to communicate to the (R)AN-DU. The UPF uses the PDCP, SDAP, and IP/Non-IP/Ethernet protocol layers to communicate to the UE.

Conclusion

This article discusses some new services and applications for 6G. To support 6G services and applications, and to meet the requirement of higher KPIs of 6G, a new network architecture is proposed. A control plane protocol stack and a user plane protocol stack are also proposed.

Acronym List

3GPP	3rd Generation Partnership Project
5G	Fifth Generation (Communication System)
6G	Sixth Generation (Communication System)
AF	Application Function
AMF	Access and Mobility Management Function
AP	Application Protocol
AUSF	Authentication Server Function
CHF	Charging Function
CP	Control Plane
CU	Central Unit
DL	Down Link
DU	Distributed Unit
GTP	GPRS Tunneling Protocol
L1	Layer 1 (physical layer)
L2	Layer 2 (data link layer)
LTE	Long Term Evolution
MAC	Media Access Control
MME	Mobility Management Entity
NAS	Non Access Stratum
NEF	Network Exposure Function
NRF	Network Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PGW	Packet Data Network Gateway
PHY	physical layer
(R)AN	Radio Access Network
RLC	Radio link control
RRC	Radio Resource Control
SAE	System Architecture Evolution
SCTP	Stream Control Transmission Protocol
SDAP	Service Data Adaptation Protocol
SGW	Serving Gateway
SMF	Session Management Function
TCP	Transmission Control Protocol
UDM	Unified Data Management
UDP	User Datagram Protocol
UE	User Equipment
UL	Up Link

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[4] Emilio Calvanese Strinati, et al. "6G: The Next Frontier", arXiv:1901.03239v2 [cs.NI], May 2019

[5] 3GPP TS 29.244: "Interface between the Control Plane and the User Plane Nodes."

[6] 3GPP TS 23.401: "Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access."

[7] 3GPP TS 23.501: "System architecture for the 5G System (5GS)."

About the Author:

Weihua Qiao has 20 years of experience in the research and development of communication systems, from 3G to 5G. His research areas include Policy and Charging Control, Network Slicing, Handover, Positioning Service, NPN, and 6G services and network architecture. He is an expert on core network, especially on Policy (e.g., QoS) and Charging Control, Network Slicing, and Data Communication. Weihua has 10 years of experience on 3GPP standardization and has served as 3GPP CT3 chairman for 4 years. Weihua has joined Ofinno since 2017, and Ofinno is a Founding Member of Next G Alliance: https://nextgalliance.org/.

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