

Research on the convergence architecture of 5G and industrial communication

Zhen Wang^{1,*}, Dantao Han¹, Yanjie Gong¹, and Yanling Zhao¹

¹Instrumentation Technology and Economy Institute (ITEI), Beijing 100055, China

Abstract. As the next generation of mobile communication technology, 5G has the characteristics of enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low latency communication (URLLC), which are critical technologies for the future development of industrie 4.0. So far, these technologies have been explored and applied in industry, however, there is still a lack of general architectures. This paper presents a 5G and industrial communication convergence architecture and elaborates on the implementation methods from the aspects of device access technology and network configuration strategies, and discusses the transparent transmission and mapping methods adopted by 5G terminal access technology as well.

1 Introduction

The emergence of smart factories requires industrial wireless communication technology to have better performance in terms of bandwidth, delay, reliability, etc. As a new generation of wireless communication technology, 5G took the high demands of industrial applications into consideration at the beginning of its design. eMBB can meet the transmission needs of industrial big data, such as visual inspection, predictive maintenance, etc. URLLC can facilitate highly critical applications with very demanding requirements in terms of end-to-end (E2E) latency, reliability and availability. However, integrating 5G into the existing industrial system and combining 5G with the current industrial communication technology remains a problem for industrialists.

After the release 15 of 5G technology in 2018, studies on application of 5G in industry began to emerge. Researchers analyzed the remarkable impact of 5G technology in advancing industrial change from the perspective of industrial evolution and proposed typical industrial application scenarios of 5G technology [1]. The integration and application of 5G technology and existing industrial communication technology will be the main direction of the future 5G industrial applications according to [2] and [3], in which the implementation of 5G and industrial network hybrid topology architecture is proposed. In [4], the 5G system and TSN technology are further analyzed and the improvements of 5G network are proposed to meet industrial end-to-end application requirements. But until now, the research of 5G and industrial communication integration application is still at an early stage. 5G technology is mainly used as the link of industrial communication to realize the

* Corresponding author: wangzhen@tc124.com

transparent transmission of industrial data, which is relatively simple. Based on the analysis of wired and wireless communication technology, this paper proposes a 5G and industrial communication technology integration application architecture and several application scenarios. The research is still in its infancy, but it is expected to contribute to the industrial application of 5G technology.

This paper is divided into four sections. The rest is organized as followed, section 2 deals with the theoretical foundations for the development of the research, including real-time communication technology, 5G network architecture and protocol. Section 3 describes 5G and industrial communication technology integration application architecture and use cases. In the end, the conclusion along with the next steps are presented in section 4.

2 Approach

With the involvement of automation, process control and artificial intelligence, industrial systems have required more sophisticated real-time and reliable communication infrastructure. For now, the current industrial network technology can easily meet these requirements, such as CC-LINK, PROFINET RT/IRT. Industrial wireless networks have been widely investigated to support industrial application, for example, zigbee, WI-FI, Bluetooth, etc. However, the high interference in industries makes the desirable communications reliability very challenging. After the release 15 of 5G, the proposed feature in 5G networks offers a potential technology to industrial systems with the assurance of low-latency and reliable communications, but integrating 5G with industrial communication technology is still a problem. This chapter introduces the current technical solutions of industrial communication and focuses on the analysis of the 5G network architecture and communication protocol.

2.1 Industrial ethernet networks

In the last decade, some of the well-known and commonly implemented wired communications solutions can offer the desired real-time, reliability and availability, such as Ethernet/IP, PROFINET RT, EtherCAT and CC-Link IE, etc. In order to fulfill real-time and reliability, the industrial Ethernet network technologies adopted various approaches to the IP and/or MAC layer, achieving the deterministic communication. Industrial Ethernet network technologies can be divided into three classes to meet different requirements of industries network performance. The first class uses standard Ethernet hardware and standard TCP/IP software stacks for industrial communication. As the simplest approach, it is widely used in industry field, e.g. Ethernet/IP and Modbus TCP. The second class uses standard Ethernet controllers, in stead of using TCP/IP stacks, it deploys a professional data protocol for communication, such as PROFINET RT, POWERLINK and EtherCAT. The third class uses dedicated hardware down to MAC layer, such as EtherCAT, PROFINET IRT, Sercos III and CC-Link IE [5].

As can be seen from above, Industrial communication technology is based on the TCP/IP protocol. However, the TCP/IP protocol stack is designed mainly for the reliability of communication, and a large number of redundant mechanisms are used, hence the real-time performance can not meet the needs of industrial applications. As the TCP/IP protocol conforms with OSI model, the application data need to pass through the transport layer, IP layer and MAC layer step by step, so as to realize the real-time and reliability demands of industrial application, such as PROFINET RT and IRT. The 5G technology should reference the evolution of industrial wired network technology to meet more demanding industrial application requirements.

2.2 5G system architecture

The 5G system architecture described in [6] was explained, see Figure 1. The data of the user equipment is first sent to the gNB, then the 5G core network, and finally the Internet. Between the user equipment and the gNB, the data is transmitted through wireless signals. Between the gNB and the core network, the data is transmitted through optical fiber networks.

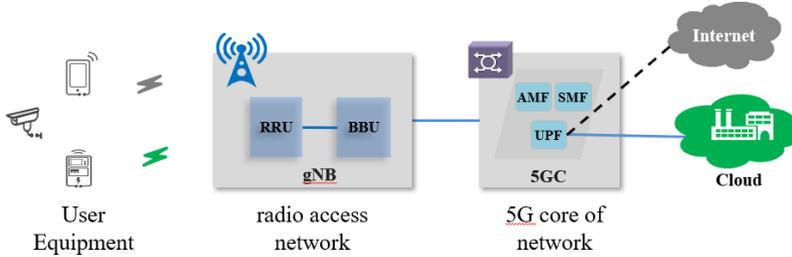


Fig. 1. The typical scenario of the 5G system.

The abstract representation of the 5G system is shown in Figure 2. It mainly explains the 5G system architecture from the perspective of 5G functions. the Access and Mobility Management Function (AMF) is in charge of registration and connection management functions. The Session Management Function (SMF) is in charge of establishment, modification and release of PDU session including tunnel management between the (R)AN node and the User Plane Function (UPF). The UPF is in charge of downlink and uplink packet buffering and data notification triggering as well as packet routing and forwarding [7].

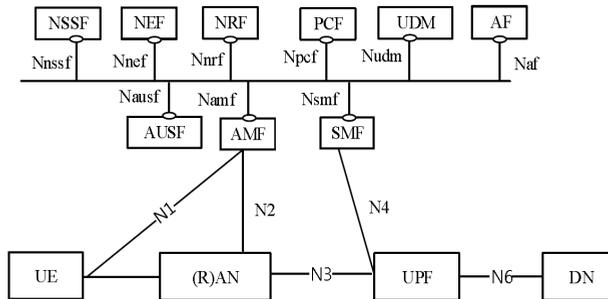


Fig. 2. The function model of 5G System.

As can be seen from figure 2, the original intention of 5G network is to realize separation of the control plane and the data plane, minimum dependencies between the Access Network (AN) and the Core Network (CN), flexible and efficient network slicing in addition to decouple of the "compute" resource and the "storage" resource, based on which 5G systems establish the next generation mobile communication network. Thereby it can support eMBB, mMTC, and URLLC.

2.3 5G communication protocol

5G communication protocol is separated to the control plane and the data plane, as shown in Figure 3 and 4 respectively. The user equipment side of 5G communication protocol mainly consists of PHY, MAC, RLC and PDCP, on the higher level, SDAP operations will be performed on the data plane, while RRC operations will be performed on the control

plane. In addition, the 5G protocol architecture and corresponding functions are explained as below.

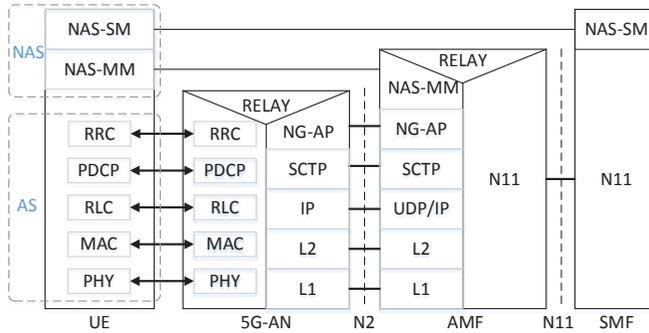


Fig. 3. Control plane protocol.

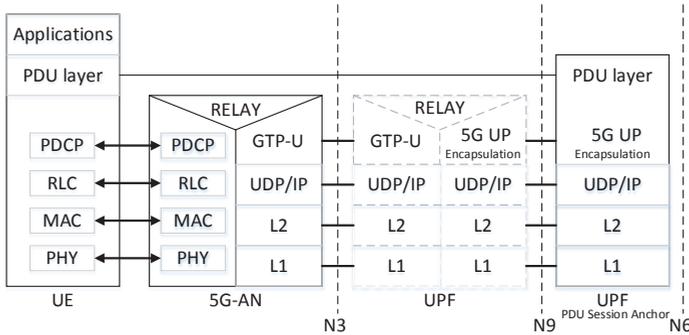


Fig. 4. Data plane protocol.

As Figure 5 shows, RRC is in the control plane while SDAP is in the user plane. PDCP is responsible for IP header compression and decompression as well as encryption and decryption of the data over the radio interface. Next, PDCP feeds the stack down to the RLC layer, which is responsible for error correction with ARQ, concatenation and segmentation, in sequence delivery and protocol error handling. Down to the MAC layer, which is responsible for multiplexing and de-multiplexing, hybrid ARQ error correction, scheduling and transport format selection. Finally, the physical layer is responsible for modulation and demodulation of physical channels, frequency and time synchronization, power weighting of physical channels, MIMO antenna processing and RF processing [8].

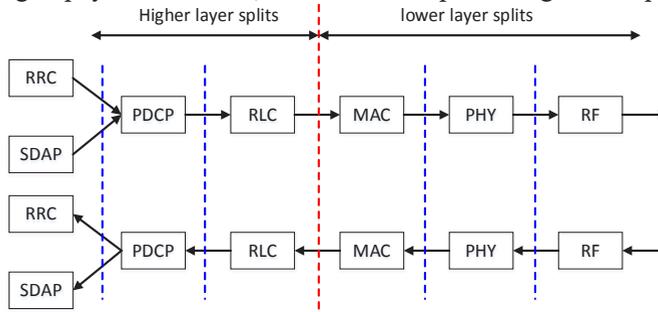


Fig. 5. 5G protocol architecture.

By analyzing the 5G network architecture and communication protocol and comparing 5G wireless network with the wired industrial communication network, the 5G system architecture can be simplified as shown in Figure 6. The 5G system can be a router and the control function of the 5G network can be routing rules. Meanwhile, 5G communication protocol can be decomposed according to the OSI standard. SDAP and RRC are communication application layers, PDCP and RLC are IP layers, and the MAC layer and PHY layer have the same functions. Based on this theory, a new architecture for the integration of 5G and industrial communication applications is proposed.

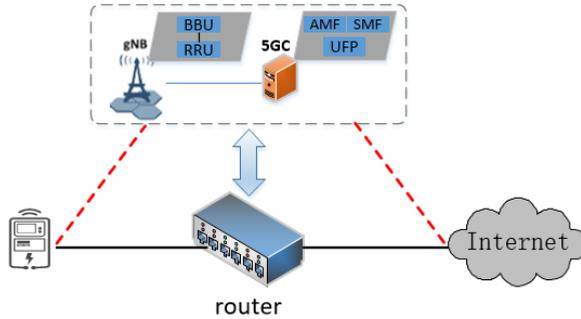


Fig. 6. Abstract model of 5G system architecture.

3 Results

3.1 Converged architecture

The integrated architecture of 5G technology and industrial communication includes two aspects. In terms of 5G network architecture, the control plane of the 5G system can provide high-precision synchronous clocks and functional adaptation modes according to the business needs of industrial applications, while the data plane of the 5G system can realize fusion transmission with industrial communication data, priority transmission and real-time transmission and provide different types of data carrying capabilities as well, see Figure 7.

In terms of communication protocol, some flexible use fields are provided at the protocol layer to realize flexible configuration of network functions. Thus, it is compatible with different industrial communication technologies and can realize functions such as priority transmission of data, real-time transmission and clock synchronization of user terminal equipment.

In practice, the converged architecture is mainly embodied in 5G network system adaptation technology and user terminal convergence technology. In Figure 8, the user terminal as the basis for the integration of industrial communication, needs to be compatible with different industrial communication technologies. When the user terminal initiates different service requests, the 5G network system performs functional reconfiguration to meet different industrial applications demands.

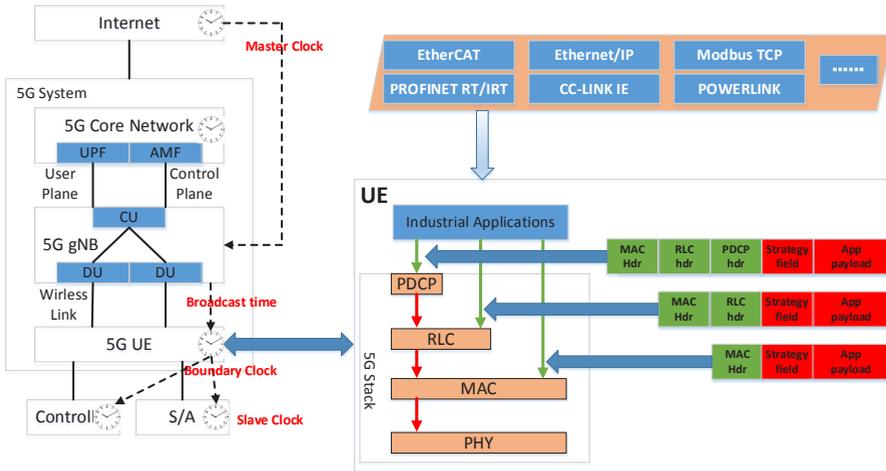


Fig. 7. Converged architecture of 5G system.

3.2 Terminal access

For the 5G user terminal integration application mentioned above, two technologies can be used to achieve the deep integration of 5G technology and industrial communication, namely, transparent transmission and mapping of industrial communication.

3.2.1 Transparent transmission

5G transparent transmission technology, that is, 5G as a channel for industrial data transmission, which can realize transparent transmission of industrial data from the industrial application layer, IP layer and MAC layer on the 5G network. For example, if industrial communication adopts the standard TCP/IP protocol, the source IP layer data packet can roam on the 5G system and be delivered to the destination through transparent transmission. After that, the source IP layer data packet is reconstituted at the destination to complete the TCP/IP protocol analysis and application layer processing, see Figure 8. The transparent transmission method can realize the seamless integration of 5G and the existing industrial communication network system and the rapid upgrade and transformation of the industrial system. At present, transparent transmission is widely adopted for the integration of 5G and industrial applications.

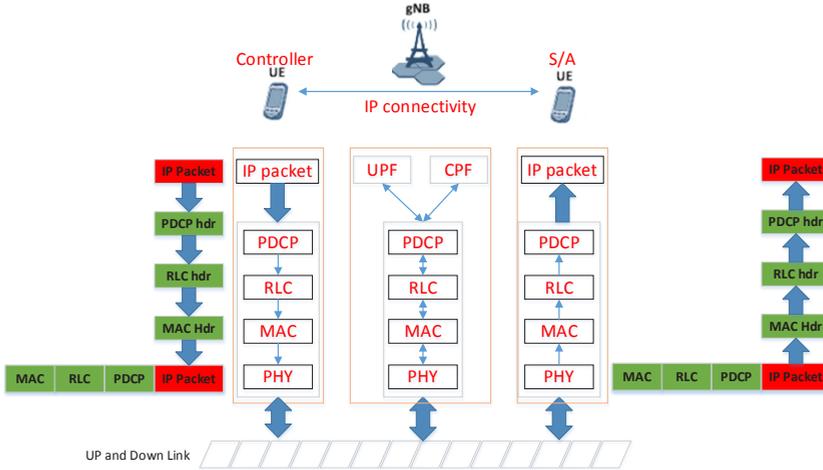


Fig. 8. Data flow diagram of transparent transmission (from controller to s/a).

3.2.2 Mapping

The mapping technology of 5G aims to realize the requirements of industrial communication technology on the 5G system, such as data priority scheduling mechanism, time scheduling strategy, etc., thereby 5G technology can meet the priority transmission and delay of industrial applications. Compared with transparent transmission technology, 5G mapping combines the requirements of industrial communication technology with the mechanism of 5G, which can give full play to the technical advantages of 5G. For example, the 5G network is used as the MAC layer of the industrial communication network, see Figure 9. The priority scheduling and delay strategy of the industrial network communication technology are mapped to the transmission mechanism of the 5G network, hence the priority of industrial applications is guaranteed through the 5G network transmission, which can greatly shorten the processing of real-time messages in the protocol stack and improve real-time performance. So far, some organizations have carried out the mapping research work of 5G+OPC UA, 5G+TSN and other related technologies.

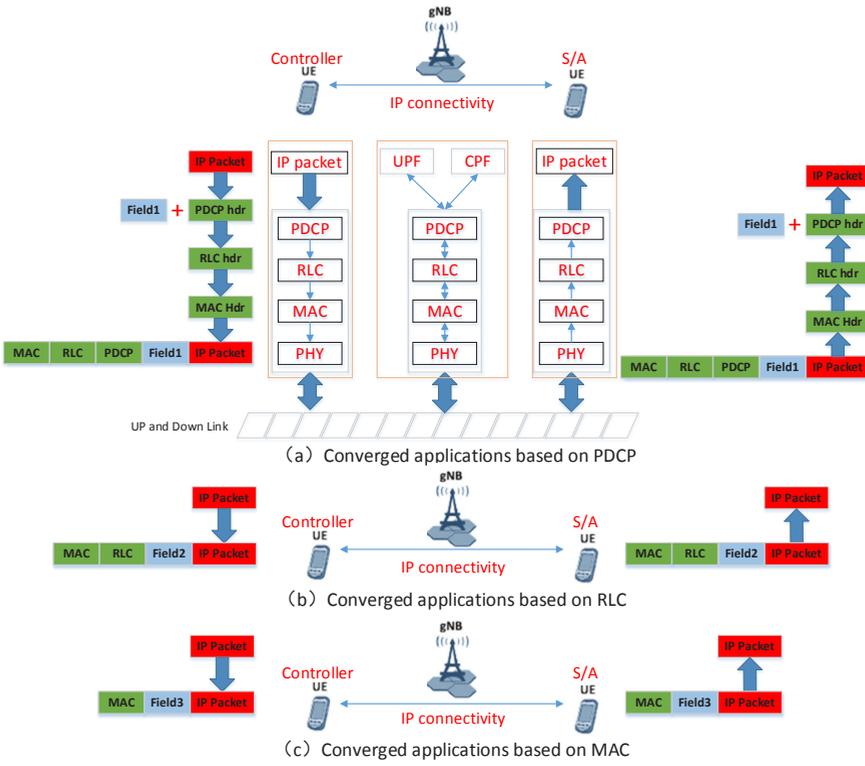


Fig. 9. Data flow diagram of mapping (from controller to s/a).

3.3 Control rules

With 5G fusion application technology, user terminal can realize the rapid access of industrial communication, but it cannot completely solve the problems of 5G industrial application, such as synchronous clock, priority etc. 5G network should also support various business needs of the industry, just like industrial routers, using excellent routing strategies and clock synchronization mechanisms to support industrial applications, which can be introduced to 5G networks, including:

- Synchronous clock strategy, realizes the time synchronization of the equipment in the 5G system, which is a key indicator for realizing deterministic communication in industrial applications. There are two solutions for clock synchronization. One is that the 5G system periodically initiate a system time synchronization calibration function to calibrate the terminal equipment and routing equipment connected to the 5G system, the other is the user terminal initiate clock synchronization when connecting to the 5G network for the first time.
- Routing strategy, the 5G system use different communication routing strategy identifiers for different types of communication services as a basis to mobilize the resource allocation of the 5G system for industrial applications. For transparent transmission services, system resources can be easily configured. For high-real-time services, network slicing resources and edge computing resources are allocated, and the UPF function is sunk to the device side, etc. By recombining different resources, 5G system can meet real-time requirements of industrial applications.

To realize the industrial application of 5G technology, there are still many difficulties. Industrial applications could make full use of 5G network and its communication protocol to achieve the integration of industrial communication and 5G. At the same time, use terminal access mode and 5G configuration strategy to flexibly organize the 5G network to solve practical problems.

4 Conclusion

Some of the existing industrial Ethernet technologies have been able to provide solutions that meet the high real-time and reliability requirements of industrial applications. Learning from its success and combining with the characteristics of 5G technology, this paper proposed a converged architecture of 5G and industrial communication and introduced the implementation methods from the aspects of device access technology and network configuration strategies, meanwhile, the transparent transmission and mapping methods adopted by 5G terminal access technology was introduced. The transparent transmission technology can reuse the existing industrial communication technology and equipment, while making minor changes to 5G and making full use of the existing 5G technologies such as network slicing, QoS etc., thus satisfying the needs of industrial applications such as flexible networking and flexible production. Therefore, transparent transmission technology of 5G is the main direction of the integration of 5G and industrial communication in a short time. The mapping methods of 5G technology, as long as equipped with a dedicated 5G communication module for network frame analysis and processing, it can meet the strict real-time requirements of industrial applications. Currently, transmission and mapping methods of 5G technology have been explored and applied in some industrial fields, however the control strategy for industrial applications of 5G systems still needs to be improved, which can be a subject for future research.

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