

Architecture for Beyond 5G Services Enabling Cross-Industry Orchestration

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SUMMARY Beyond 5G is the next generation mobile communication system expected to be used from around 2030. Services in the 2030s will be composed of multiple systems provided by not only the conventional networking industry but also a wide range of industries. However, the current mobile communication system architecture is designed with a focus on networking performance and not oriented to accommodate and optimize potential systems including service management and applications, though total resource optimizations and service level performance enhancement among the systems are required. In this paper, a new concept of the Beyond 5G cross-industry service platform (B5G-XISP) is presented on which multiple systems from different industries are appropriately organized and optimized for service providers. Then, an architecture of the B5G-XISP is proposed based on requirements revealed from issues of current mobile communication systems. The proposed architecture is compared with other architectures along with use cases of an assumed future supply chain business.

key words: *Beyond 5G, 6G, architecture, orchestration, mobile communication systems*

1. Introduction

The latest mobile communication system has reached the 5th generation (5G), the services of which were launched after 2020 in major countries. The current system was developed through a long history because of accumulated contributions of research on advanced technologies, development of framework architecture and products, regulations, and standardizations. This mobile communication system is now essential for normal social life. Services after the 2030s will require widely distributed features from different industries. The system is going to be composed of an increasing number of subsystems from different industries in the fields of service management and applications as well as networking. Subsystems include not only the systems that make up the network, but also systems in other industries. As the number of systems to be handled is drastically increasing, it is time to reconsider the concept of mobile communication systems.

Society 5.0 [1] was proposed by the Japanese government as a concept of society in the 2030s in which new styles of human life are assumed to bring new value supported by harmonization of cyber and physical spaces. Cyber space is a virtual world actualized on computers that acquires and accumulates sensing data from physical space, analyzes and

predicts future phenomenon, and actuates the physical space. Physical space is the real world in which actual human activities are performed. The concept of optimally actuating human activities in cyber space is called the cyber physical system (CPS) and gives a basic direction of social infrastructure. The CPS is expected to optimize the use of various resources from wider perspectives. Many functions of the CPS must be integrated from different industries on mobile communication systems. However, such a cross-industry scheme has not been extensively investigated. A specific architecture needs to be designed for future social activities.

To address the issues mentioned above, a new platform is necessary for the next generation mobile communication system, i.e., Beyond 5G. Beyond 5G is assumed to be actualized around 2030 and its research and development research and development (R&D) activities have already started. Although it is believed that one of the key features of Beyond 5G will be to offer new value from the creation of cross-industry services, an architecture focused on this feature has not been sufficiently investigated.

In Japan, the roadmap towards 6G was issued by the Ministry of Internal Affairs and Communications (MIC) of Japan. Based on the roadmap, Beyond 5G R&D promotion project has been launched to improve Japan's international competitiveness concerning Beyond 5G. To accelerate the R&D, National Institute of Information and Communications Technology (NICT) has established a Beyond 5G R&D fund to grand R&D projects of research organizations in Japan [2]. Totally 44 projects were accepted in 2021 for multiple-year period, targeting wide area of technologies from optical and wireless communications to edge computing. In 2022, 20 projects were additionally accepted extending research area including virtualization and digital twin. As such, wide area of cutting-edge technologies is expected to be achieved in the future. Such technologies are combined appropriately with innovations and going to be utilized to realize new values in future services.

In ITU-T Focus Group on NET2030 [3], an architecture with detailed functions is presented for end-to-end service management and orchestration [3]. It focuses on networking, but the viewpoint of cross-industry service management is unfortunately missing. The 5G Infrastructure Public Private Partnership (5G-PPP), a joint public-private project in Europe, is considering a 5G architecture to achieve end-to-end (E2E) service management [4]. The Hexa-X project [5] is also focusing on the vision of connecting human, physi-

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cal, and digital worlds, which is in line with the CPS concept. However, they also do not meet the cross-industry perspectives. The 6G flagship project in Finland provided the world’s first white papers on 6G in 2019 [6]. However, architecture for integrating multiple industries with mobile networking is not specifically given. Germany has large national projects, 6G-life, 6G-RIC, 6GEM, Open6GHub, and 6G Platform [7]–[11] that cover a wide range of use cases and advanced technologies, but an architecture to address the cross-industry issue has not been investigated as their main topics.

In this paper, the concept of the Beyond 5G cross-industry service platform (B5G-XISP) is introduced to create an optimized service environment from systems provided by different industries. Then, an architecture of the B5G-XISP is proposed based on the requirements extracted from issues of current mobile communication systems. Note that “Beyond 5G” in this paper covers the concept of a new social infrastructure in addition to conventional mobile communication systems. Technologies for 6G are assumed included in Beyond 5G.

The major contributions of this paper are as follows.

- The concept of the B5G-XISP is introduced where systems from different industries organize service environments.
- The B5G-XISP is proposed based on requirements derived from issues with current mobile communication systems.
- The proposed architecture was verified by comparing it with other architectures along with use cases of a future supply chain business.

The remainder of the paper is organized as follows.

Section 2 introduces related technologies and activities. Section 3 introduces the concept of the B5G-XISP and the proposed architecture. Section 4 discusses the verification of the proposed architecture from multiple viewpoints. Finally, Sect. 5 concludes the paper and gives future issues to be addressed.

2. Background

2.1 System Diversity in 2030s

Mobile communication systems until 5G have been dedicated to sophisticated networking. Therefore, they are composed of wireless and wired networking equipment and computers. In addition to these components, Beyond 5G is going to have to handle a drastically increased number of components from different industries because it is expected to play a role as a social infrastructure based on the concept of the CPS where various applications are implemented.

Example system components for implementing Beyond 5G services are shown in Fig. 1 [12]. With such services, remote avatar-robot manipulations over the air, on the ocean, at disaster sites, and even on the moon are assumed. The system components are realized by terrestrial network (TN), non-terrestrial network (NTN), and application systems. TN systems include public and private cellular systems, terahertz band communication systems, optical fiber networks for universal and high-capacity communications, and edge computing systems. NTN systems include geostationary earth orbit (GEO) and low earth orbit (LEO) satellites and high-altitude platform stations (HAPSs) for wide coverage and three-dimensional communications. Applications systems include robot-management systems and space-time resource-

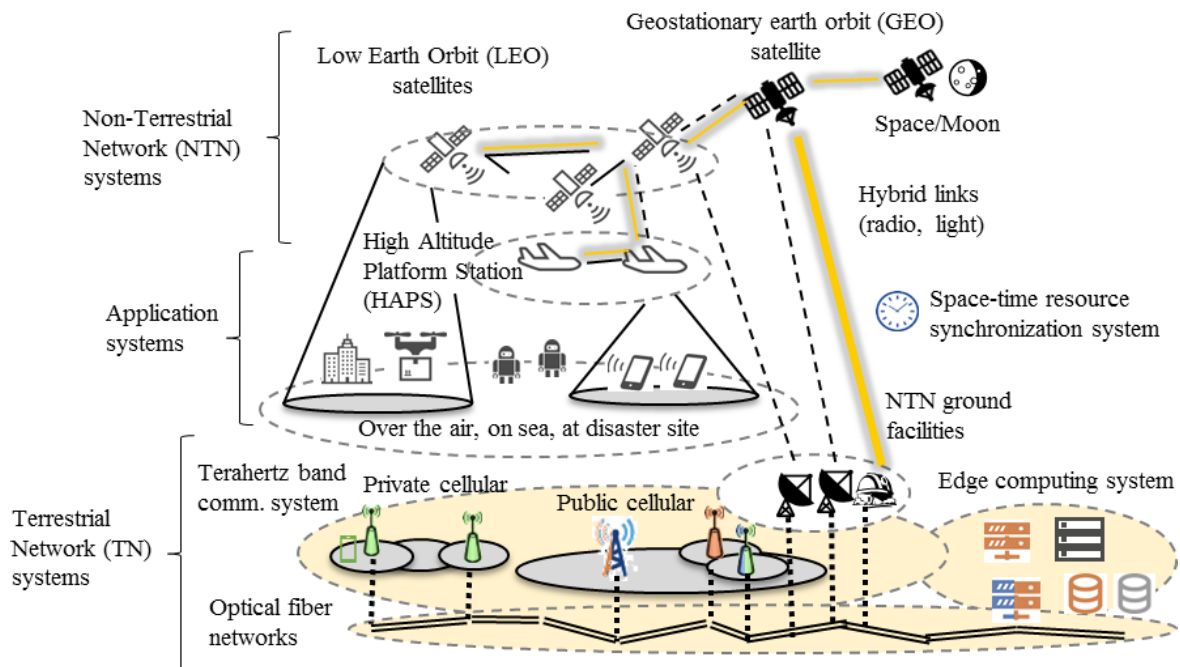


Fig. 1 Variety of systems as functions of Beyond 5G services.

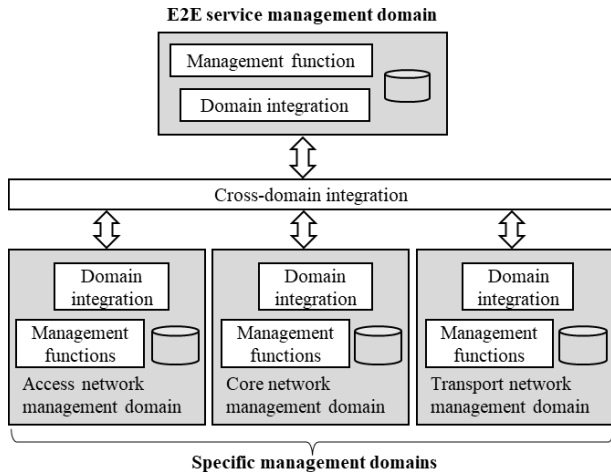


Fig. 2 Zero-touch network and service management (ZSM).

synchronization systems for accurate and flexible movements of avatar robots.

As for the services assumed above, several system components must be handled. The components are provided by different industries, satellite operation, avatar robot management as well as terrestrial mobile operation. Since all components are not always required for a specific service, a method for coordinating functions across different industries is necessary.

2.2 Coordination between Systems

Various network resources have become available by separating hardware and software, and the virtualization of network functions has been promoted. The function to enable more flexible operation management, such as quick configuration, automation, and optimization of various network services by slicing technology that divides and uses these virtualized network resources, is called orchestration. The framework has been considered in Network Function Virtualization (NFV) of European Telecommunications Standards Institute (ETSI). It is defined as an NFV Management and Orchestration (MANO) [13]. The NFV is an Industry Specification Group (ISG) in the ETSI.

By extending this orchestration, as shown in Fig. 2, a framework for quickly configuring and automating E2E services across multiple management domains, such as access network management, core network management, and transport network management, is being considered. This is called zero-touch service and management (ZSM) [14].

2.3 Providing Common Functionality to Applications

In the real world, there is a group of industries and companies that use the network resources described above to provide various services and products, such as smart factories, drones, and vehicle to everything (V2X), which are called verticals. It is considered that there is a function commonly used when various verticals execute various appli-

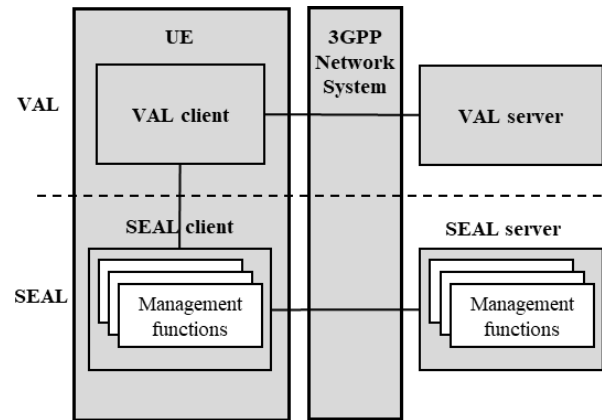


Fig. 3 Functional model of SEAL architecture.

cations. In the 3rd Generation Partnership Project (3GPP), SA6 (Service & System Aspects 6), which is one of several Technical Specification Groups (TSGs) studied on a technical basis, deals with application enablement and critical communication applications, and standardizes common functions in mission critical communications. In SA6, the layer that provides this common function is called the service enabler architecture layer (SEAL) [15], as shown in Fig. 3, and the study on this architecture is in progress. The vertical application layer (VAL) interfaces with several vertical applications such as V2X and UAS. The VAL sits on top of SEAL, uses SEAL as a common function to run applications for each vertical. The SEAL architecture uses a server client model with a SEAL client that implements the client-side functions of the user equipment (UE) and a SEAL server on the network. The SEAL client and server have common management functions related to services, such as group, location, configuration, identity, key, and network resource management. These common functions are provided in a framework that can be used by applications in each vertical as needed.

2.4 Future Network Design Goals

In Beyond 5G, functions that can respond to numerous services, such as the above linking functions between systems and the provision of common functions to applications, are considered essential. ITU-T has set goals for the design of future networks, including Beyond 5G, as Y.3001 [16]. The objectives of the future network are said to include service oriented, data oriented, environment oriented, and socioeconomic perspectives.

Service awareness includes functional flexibility to provide services, resource virtualization, and network management as design goals. Data awareness design goals include the ability to properly access substantial amounts of data and identify scalable support for the relationship between mobility and data. These design goals will need to be considered when designing the B5G-XISP.

3. Architecture for Beyond 5G Cross-Industry Service Platform

In this section, the concept of the B5G-XISP is introduced for service creation from a variety of subsystems provided by multiple industries. Then, its issues are clarified, and the requirements of the architecture are derived. Finally, the architecture of the B5G-XISP is proposed that satisfies the requirements.

3.1 Concept

The role of mobile communication system in the era of Beyond 5G is shifting from just a mobile networking to a service infrastructure for creating variety of services crossing industries. In other words, services that Beyond 5G realizes is composed of multiple systems (hereinafter referred to as subsystems). In this paper, a subsystem is defined as a part of system supposed to be combined to realize services. Each industry may operate multiple subsystems with different functions and performances. The subsystems are connected across industries. Services are implemented on a service environment which is composed of the subsystems.

Figure 4 shows the concept of subsystem combination

for future services creation assuming an online shopping service as an example. The online shopping service provides unmanned super rapid delivery by drones and robots. Packets are delivered from a warehouse to rendezvous center by drones and delivered by robot to the destination. provided by robot control system (subsystem A). Then, a drone takes the packet to deliver to the customer supported by air traffic monitoring system for drones (subsystem B) and non-terrestrial network (NTN) system with low-latency option (subsystem C). In this case, the subsystem A, B, and C are virtually combined getting together from different industries and set up “service environment 1”. On the service environment, multiple services are going to be generated, for example, service A for supermarket A and service B for supermarket B.

The key feature of the concept is to enable creation of service environments crossing industries independently operated. Subsystems are picked up based on service requirements and then combined.

3.2 Clarification of Issues

In this section, the issues with current mobile communication systems are clarified to design the architecture of the B5G-XISP. Figure 5 shows the overview of requirements to B5G-XISP. First, it is necessary to realize the sensing and

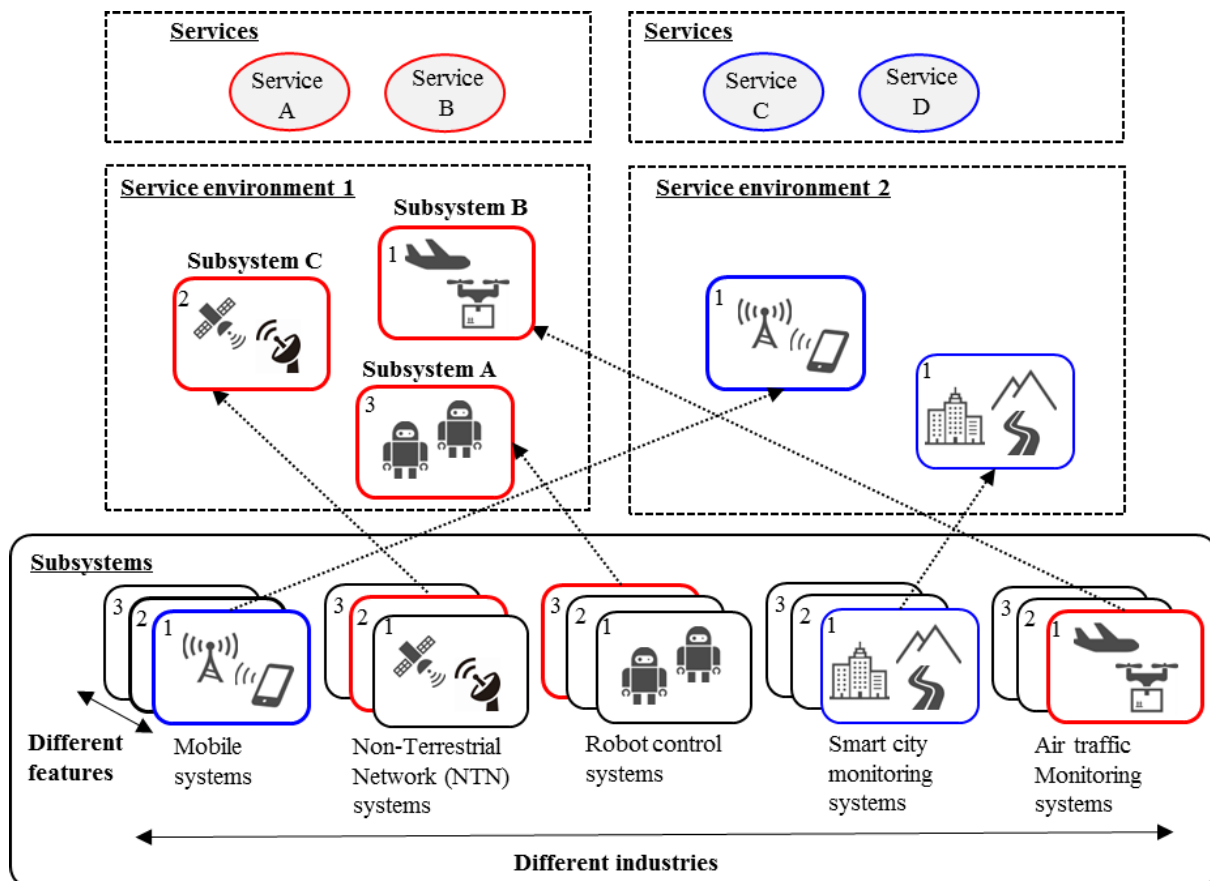


Fig. 4 A concept of B5G-XISP.

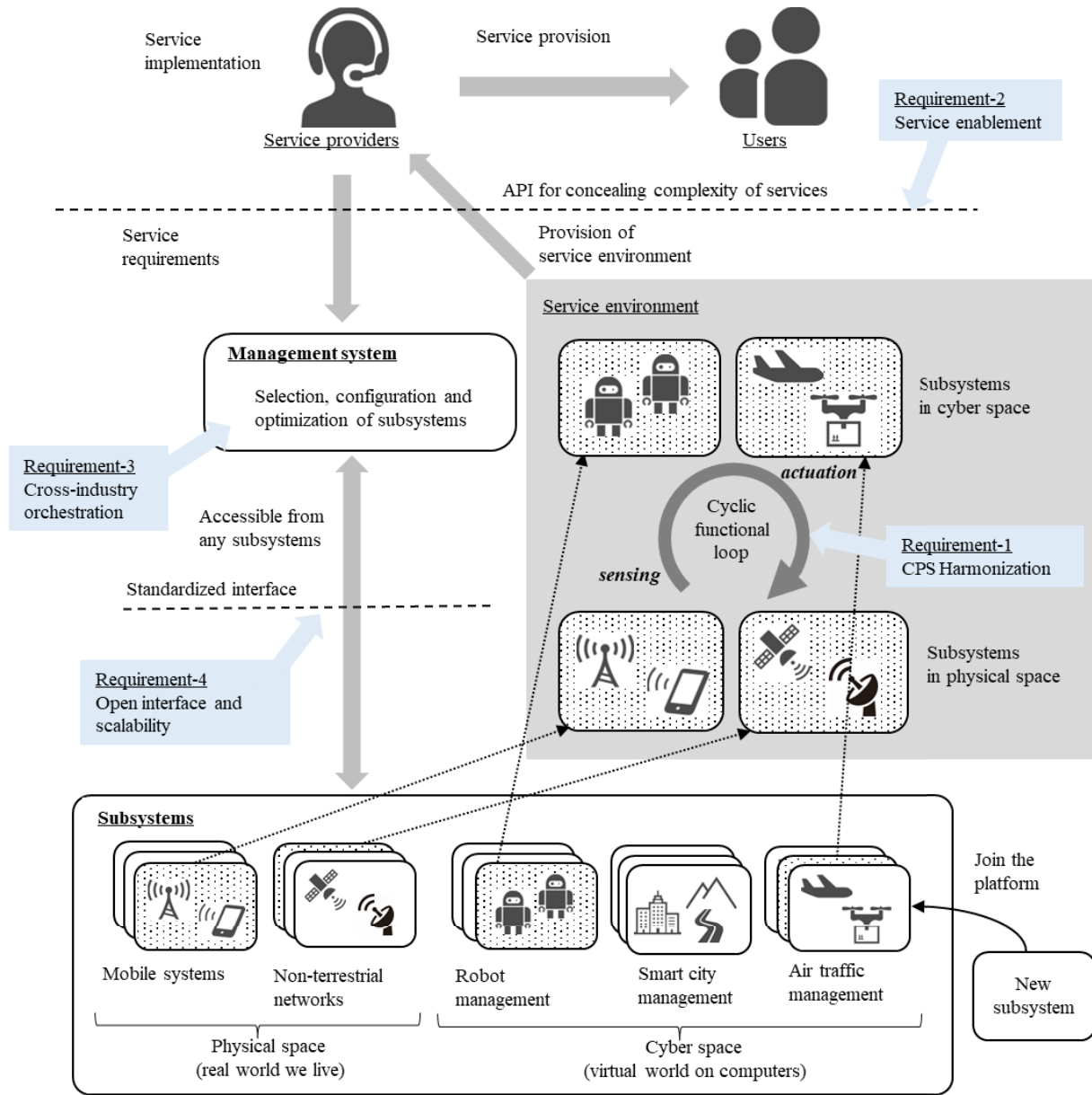


Fig. 5 Overview of requirements to B5G-XISP.

actuation loop over the physical space and the cyber space in the service environment. Second, the service provider should be able to develop the system without understanding the details of the target subsystem. Third, the management system needs to be able to optimize across the selected subsystems. Finally, the interfaces between the various subsystems and the management systems that manage them must be open and scalable.

Issue 1: Platform to deal with CPS

Technologies to harmonize physical and cyber spaces have not been established. Physical space needs to provide its sensing data to cyber space, and cyber space needs to analyze collected data. However, a platform for this cyclic process between the two spaces has not been sufficiently investigated. Y.3001 does not sufficiently define functions for resource

virtualization and data accessibility in the context of the CPS.

Requirement-1: CPS harmonization

- Subsystems in physical and cyber spaces need to be managed by a consist function.
- Subsystems need to be selected for service environments where the CPS is implemented.

Issue 2: Utilization of service environment

For service providers to develop various services, it is necessary to understand the functions and interfaces of each subsystem, which is unrealistic for a platform that has a variety of subsystems from different industries. In a platform to handle such a variety of systems, the interfaces should be disclosed to any subsystem to join as a module of the service.

As Y.3001 suggests, diversity of services and flexibility of functions need to be secured as a design goal. Although the SEAL in 3GPP defines common functions for mission critical applications, the interfaces are not flexible enough to add and replace various functional modules.

Requirement-2: Service enablement

- Service providers need to be able to implement services on the service environment and provide the services to their users.
- An application programming interface (API) needs to be provided between the service providers and management system to conceal the technical complexity of the platform from users.
- Via the API, a service provider needs to give service requirements to the management system, and the management system need to set up a service environment for the service providers.

Issue 3: Optimization across subsystems

Currently, resources such as frequency band and optical network capacity are split into pieces and allocated to different subsystems. Each subsystem optimizes the utilization of allocated resources within the subsystem. However, resources in the platform include computation, electricity space, and time as well as the above-mentioned resources. The orchestration function of ETSI ZSM manages network slicing beyond different types of network domains, but it does not provide a scheme to use resources of various subsystems from the perspective of the entire system efficiency. Y.3001 does not sufficiently consider functions for system optimization.

Requirement-3: Cross-industry orchestration

- The management system needs to select a set of subsystems and organize a service environment.
- The subsystems needs to be configured from the viewpoint of total optimization of the service environment such as resource utilization and service performances.

Issue 4: Flexibility of subsystems

Since each subsystem has its original interface, if multiple subsystems are coordinated by a management system, it is necessary to implement all the interfaces to accommodate the subsystems. If the platform is open and several subsystems are going to be handled, implementation of the management system is impossible. For Beyond 5G, the subsystems span from networking to applications such as terrestrial communication, NTN, flight management, avatar robot management, and smart city management. This is the reason only a limited number of subsystems are integrated in current mobile communication systems.

Requirement-4: Open interface and scalability

- The management system needs to be accessible openly from any subsystem through a common interface.
- The management system needs to work properly regardless of the number of subsystems.

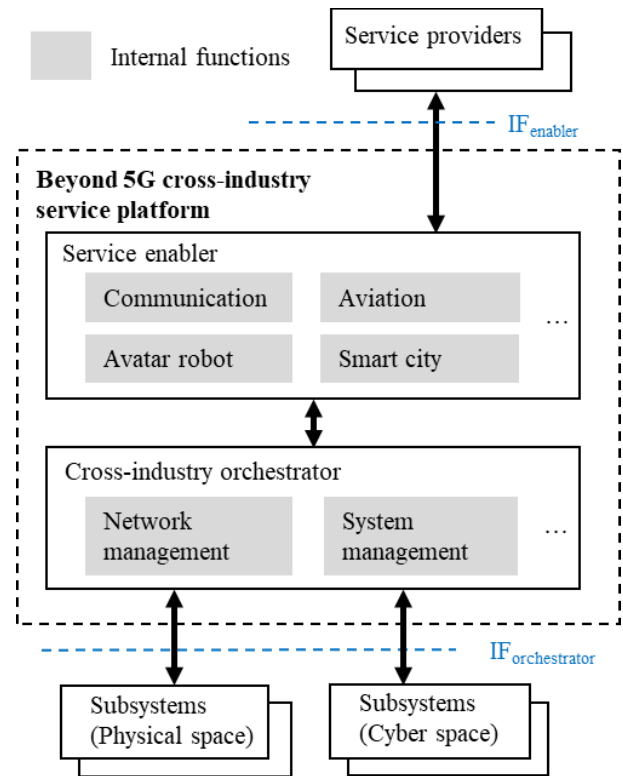


Fig. 6 Architecture of B5G-XISP.

3.3 Proposed Architecture

The proposed architecture of the B5G-XISP is shown in Fig. 6. The platform is composed of a service enabler and cross-industry orchestrator. The service enabler is a front end to the service providers and communicates with the cross-industry orchestrator to create a service environment. The cross-industry orchestrator is a front end to the subsystems and manages them based on the requests from the service enabler.

The platform accommodates service providers and subsystems with the common interfaces $IF_{enabler}$ and $IF_{orchestrator}$, respectively. Table 1 summarizes north and south bound messages to be exchanged via these interfaces.

The service provider provides Beyond 5G services to their users. To set up such services, the service provider requests the service enabler to prepare a service environment. The service environment is a set of selected subsystems with optimized configurations for specific Beyond 5G services. On receiving the request, the service enabler interprets the received requirements and communicates with the cross-industry orchestrator to select the necessary subsystems, make appropriate combinations, and configure them to set up as a service environment.

A subsystem is operated outside the platform and composes service environment. A subsystem is registered to the cross-industry orchestrator with its detailed descriptions of functionality, specifications, and conditions for use. With

Table 1 Interfaces of B5G-XISP.

	North bound (↑)	South bound (↓)
IF _{enabler}	Notify configured service environment	Request for service environment
IF _{orchestrator}	Register to be used for service environment	Request for configuration and contract coordination

Table 2 Example functions in service enabler.

Target services	Functions
Communication	<ul style="list-style-type: none"> ➤ aerial communications with reliability ➤ maritime communications with wide coverage
Aviation	<ul style="list-style-type: none"> ➤ highly precise positioning ➤ optimized flight routing
Avatar robots	<ul style="list-style-type: none"> ➤ virtual reality cooperation ➤ super realistic sharing ➤ personal authentication
Smart city	<ul style="list-style-type: none"> ➤ digital twin management ➤ people flow monitoring

Table 3 Example functions in cross-industry orchestrator.

Management category	Functions
Resource allocation	<ul style="list-style-type: none"> ➤ communication quality management ➤ frequency resource management ➤ autonomous disaster recovery
Subsystem optimization	<ul style="list-style-type: none"> ➤ edge computing resource management ➤ low power consumption management
Incentive exchange	<ul style="list-style-type: none"> ➤ short term contract management ➤ policy harmonization

this registration of subsystems, the cross-industry orchestrator obtains the information of all the connected subsystems.

Examples functions to be implemented in the service enabler and cross-industry orchestrator are listed in Tables 2 and 3, respectively. Implementation of the service enabler could be as software libraries for service providers. Functions of the cross-industry orchestrator are to coordinate the subsystems from the perspectives of resource allocation, subsystem optimization, and incentive exchanges. These functions are investigated through a set of use cases in Sect. 5.

Requirement-1 is addressed by the cross-industry orchestrator as it manages all the subsystems of both cyber and physical spaces. Requirement-2 is addressed by the service enabler and IF_{enabler} as they are the only function and interface exposed to the service providers, by which the service provider does not consider subsystems. Requirement-3 is addressed by the orchestrator, which configures subsystems to be optimized. Requirement-4 is addressed by IF_{orchestrator}, which is a common interface for subsystems, therefore, any subsystem can join as long as the interface is implemented. Scalability of the subsystems are also done by the orchestrator since a limited set of subsystems is selected for a required service environment and the others do not consume resources for networking and computation.

Table 4 Comparison of Beyond 5G/6G architectures.

Beyond 5G/6G Architecture		NET2030 [3]	Hexa-X [5]	B5G-XISP
Requirement-1 (CPS harmonization)	Application		✓	✓
	Network Service	✓	✓	✓
Requirement-2 (Service enablement)	Application			✓
	Network Service	✓	✓	✓
Requirement-3 (Cross-industry orchestration)	Application			✓
	Network Service	✓	✓	✓
Requirement-4 (Open interface and scalability)	Subsystem Level			✓

4. Comparison with Other Architectures

In this section, the proposed architecture is compared with other architectures in terms of above-mentioned requirements. The other architectures covered include those considered by the ITU-T Focus Group on NET2030 [3] and those under consideration by the European Hexa-X [5] project. Comparisons of functions corresponding to each of the above requirements is shown in Table 4.

Regarding the linkage between cyber and physical spaces to satisfy Requirement-1, Hexa-X provides a mechanism for feeding back data sensed from physical space to physical space by artificial intelligence/machine learning (AI/ML) processing in cyber space, and the linkage of CPS functions is being attempted. To provide common service functions to satisfy Requirement-2, although Hexa-X provides a mechanism to provide common services by SBA (Service Based Architecture), the target is limited to networks and network services. The proposed architecture, however, provides common functions for various applications of Beyond 5G as well as for network services. To satisfy Requirement-3, regarding cross-industry orchestration, NET2030, and Hexa-X consider cross-network orchestration based on ETSI MANO, etc. However, the proposed architecture includes orchestration and optimization at the level of various cross-industry Beyond 5G applications as well as at the network level.

In terms of system scalability to satisfy Requirement-4, only the proposed architecture ensures scalability of subsystem level.

5. Case Study

In this section, we examine, for each industry, how the proposed architecture works in relation to the supply chain from production to consumption in the four industry use cases of

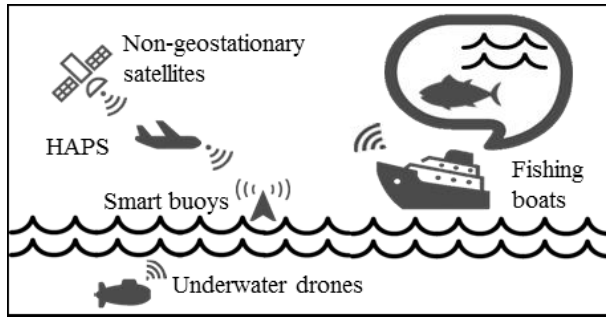


Fig. 7 Fishing industry.

fishing, seafood processing, seafood transport, and seafood retail, which are the processes through which sea life is caught, distributed on the market, and consumed. We introduce a mechanism that can, for example, reduce food loss by promoting the solution and optimization of social issues in cooperation with related industries through the optimization function of the cross-industry orchestrator.

5.1 Use Case 1: Fishing Industry

In the fishing industry in Beyond 5G, as shown in Fig. 7, expanding the coverage of communication areas has made it possible to communicate at sea using NTN systems such as satellites and HAPS, which are used for communication between fishing vessels as well as land and automatic navigation of fishing vessels.

To satisfy Requirement-2, a service enabler function is used to collect information from smart buoys and underwater drones by various functions of wide area maritime communication and exceptionally reliable aerial communication in the communication system. The collected information on fish schools is accumulated in cyber space in accordance with Requirement-1 and analyzed by AI, which makes it possible to select the optimum fishing ground for fishing vessels to operate. To satisfy Requirement-4, with the expansion of coverage over the sea, data sensing using HAPS and satellites and actuation based on this will become possible. To satisfy Requirement-3, the frequency resource management function of the used frequency is used by the movement of HAPS and the orbit of the satellites, and sustainable communication is possible even at sea.

5.2 Use Case 2: Smart Factory Industry

In the smart factory processing sea life such as fish are automatically processed by processing machines, as shown in Fig. 8.

To satisfy Requirement-2, the virtual reality cooperative work function of the avatar robot and the ultra-realistic sharing function of the work environment are used as service enablers so that the avatar robot working in the smart factory can work in cooperation from a remote location. The avatar robot may be able to execute more delicate processing with the super-realistic sensation sharing function. To sat-

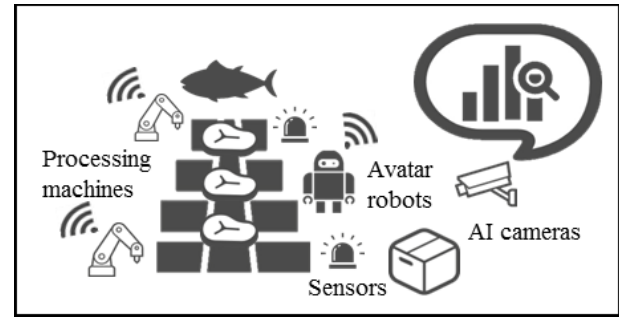


Fig. 8 Smart factory industry (food processing).



Fig. 9 Transportation industry.

isfy Requirement-3, the cross-industry orchestrator enables the low-power-consumption control function of the idle processing lane of the smart factory and the allocation control of the edge computing resources to where the operation is temporarily concentrated in the factory.

5.3 Use Case 3: Transportation Industry

A carrier transports fresh and processed seafood to retailers and consumers, as shown in Fig. 9.

In this case, smooth traffic control can be achieved by forming a digital twin for traffic management in accordance with Requirement-1. When delivery by drone is considered, the optimum flight path of the flight system is used as a service enabler in accordance with Requirement-2. To specify the optimum route at the time of transportation to satisfy Requirement-3, open data, such as road congestion information and disaster situations, are used, and an AI/ML function and distributed processing function are used by an orchestrator.

5.4 Use Case 4: Retail Industry

In Beyond 5G, the retail industry is expected to sell products at Metaverse stores in cyber space in addition to physical stores, as shown in Fig. 10.

In this case, it is possible to set up a Metaverse type store on the cyber space in addition to the real store to satisfy Requirement-1. To satisfy Requirement-2, the cooperative work function of the avatar robot is used as a service enabler so that consumers can remotely control the avatars for

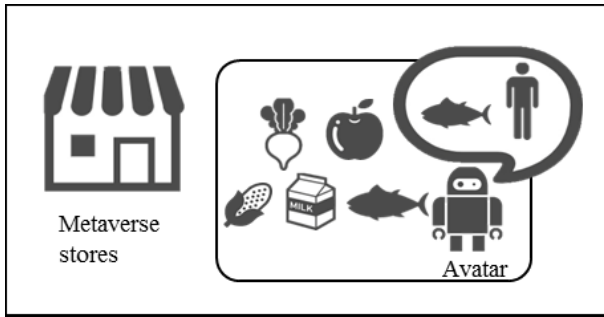


Fig. 10 Retail industry.

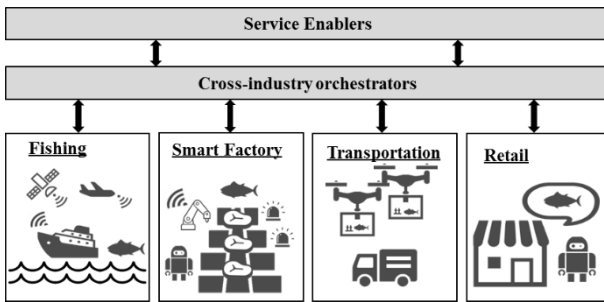


Fig. 11 Cross-industry orchestration enabling total optimization.

shopping at a Metaverse store in cyber space. In addition to being able to see the products one wants to purchase in high-definition images, it is believed that super realistic sensation sharing functions, such as conveying the feeling of touching and even smell, will become increasingly important. To satisfy Requirement-3, when a limited time sale is carried out in a Metaverse store, since it is assumed that there will be many customers using many avatars, computing resources can be temporarily and intensively allocated by the edge computing resource management function as an orchestrator.

5.5 Cross-Industry Orchestration

It is also possible to carry out optimization throughout the entire supply chain by the cross-industry orchestrator to satisfy Requirement-3 across various industries, as shown in Fig. 11.

For example, in the fishing industry, it is possible to prevent food loss due to excessive fishing and a decline in transaction prices that is disadvantageous to producers by sharing the demand through cooperation with retailers and transport businesses. By determining the number of fish caught in advance, smart factories will be able to allocate appropriate personnel and produce products according to demand.

6. Scalability of Orchestrators

In this section, some implementation of our proposed B5G-XISP is presented as an example. The orchestrator should not be implemented as a single function but also for scalability

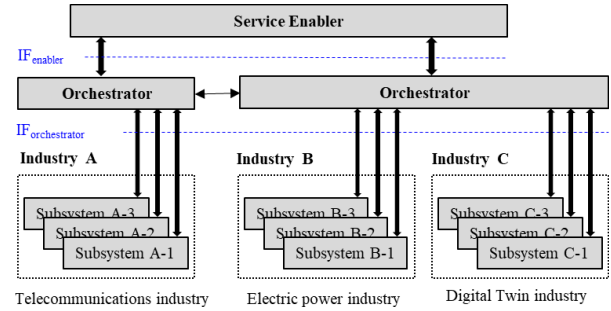


Fig. 12 Distribution and inter-connection of orchestrators.

in the number of subsystems. An example of a distributed orchestrator is shown in Fig. 12 in which industry A has its own orchestrator, and industries B and C jointly have another orchestrator. The orchestrators may be connected to each other, and industries A, B, and C are handled on the same platform.

The orchestrator may be further distributed in a hierarchical structure or in a mesh structure. The hierarchical structure is advanced in that total optimization of subsystems is easy by centralized management. For the mesh structure, standardized peer-to-peer communication protocols can be applied by which a hierarchical relationship to the orchestrators is not required.

To enable the distribution of the orchestrator, decentralized autonomous organization and Non-Fungible Token (NFT) of Web3 [17] might be applied to the architecture design. In any case, implementation of the architecture requires further discussion with potential stakeholders of Beyond 5G businesses.

7. Conclusion

This paper proposed an architecture of B5G-XISP to achieve a flexible and sustainable social infrastructure in the 2030s when many subsystems from different industries will be candidate components to create services. Research and development activities on Beyond 5G including 6G have progressed throughout the world, but this paper focused on the importance of cross-industry orchestration as a key issue. In the current trend of system openness in the information and communication business, discussion on the B5G-XISP is expected to enable researchers and engineers to get together for further discussions on it. The discussions would lead to and promote regulation updates and standardizations activities in ITU, 3GPP, and so on.

Future work includes investigation on detailed functions and interfaces of the orchestrator and service enabler along with potential Beyond 5G services. Methods and algorithms in the orchestrator are also required to enable the total optimization over subsystems. Proof of concept system will also be discussed with stakeholders across industries.

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