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Development of Novel Network Architectures

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Abstract: The communication industry is crucial for promoting a country's network strength, leading scientific and technological innovation, and driving economic and social transformation. Novel network architectures are the core of the future network and communication industry, and require urgent research. This paper expounds on the implications of a novel network architecture and presents several representative architectures, including information center networks, expressive Internet architectures, low-Earth-orbit satellite networks, service customization networks, full-dimensional definable networks, and multimodal networks. Moreover, the development trends for novel network architectures are summarized, including policies and regulations, industrial development, and challenges. Key technologies such as deterministic networking, segmented routing, cloud computing, and cloud network integration are discussed, and measures to tackle critical problems are proposed, such as launching special science and technology projects and promoting application demonstrations. Furthermore, we suggest that China should enhance the coordinated implementation of policies, laws, and regulations; cultivate a benign development ecology for the novel network architecture industry; promote in-depth cooperation among industry, universities, and research institutes; and build comprehensive and innovative research teams.
Keywords: novel network architecture; revolutionary and evolutionary networks; deterministic network; segment routing; cloud-network integration

1 Introduction

The communication industry is the core force leading scientific and technological innovation, and driving economic and social transformation and development. Thus, it is the core support for building a strong country in relation to science, technology, and networking. The development of the communications industry is essential for promoting modernization and industrialization, fostering strategic emerging industries, and improving a nation's communication security capacity and international competitiveness. With the rapid increase in the type of services carried by the Internet, the network has become not only a data transmission channel but also an information platform for the collection, transmission, storage, and processing of data, and the related novel technologies, architectures, and applications are flourishing. Technologies and scenarios, such as satellite communications, fiber optic communications, fifth-generation mobile communications (5G), and virtual reality/augmented reality (VR/AR), also provide additional support for the innovative development of the communications services industry.

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With the rapidly developing trend of novel networks, the demand for network architectures and technologies has diversified. In network development and innovation processes, there are two phases of problems that have always constrained the industry. (1) The problem of depleted Internet Protocol (IP) addresses can be solved using Classless Inter-Domain Routing (CIDR) [1] and Internet Protocol version 6 (IPv6) technologies [2]. The former introduces network prefixes to divide super nets to perform route aggregation and reduce routing table entries, and the latter increases the number of IP addresses by increasing the IP-coded address space to 128 bits. However, IPv6 technology has not been deployed on a large scale since its emergence, and it has not been able to solve the original problem at the architectural level. (2) To address the problems of network traffic explosion and the explosive growth of routing table entries, content delivery networks (CDNs) [3] reduce network forwarding traffic by deploying caching nodes in multiple regions. However, node deployment is expensive and can only be optimized for specific service traffic, which is not a universal solution. The "patching" of a network cannot solve the critical problems that limit its development, but bloat the network.

Countries worldwide are actively developing critical technologies for network communication, and the communication industry is in a critical period of carrying forward and starting up. Novel network architectures and technologies that address future needs have received widespread attention from both the academic and industrial communities. Novel network architectures and technologies such as information center network (ICN), software defined network (SDN), cloud computing, and white boxes are gradually entering the ecosystem of the global network and communication industry. Related research and innovation are rapidly developing under an atmosphere of competition and cooperation, gradually forming an international industrial wave [4]. Novel network architectures and communication technologies are not only disruptive, but also support the emergence of many novel models, applications, and industries, which will trigger a new round of industrial technology revolution and even become the main driving force of economic development. To address the above issues, this study considered the future development of novel network architectures, networks, and communication technologies as a research entry point and investigated the current situation and needs. Moreover, this report describes typical network architectures, key technologies, and solution initiatives to provide an essential reference for macroscopic research on the communication industry and network technologies.

2 Implications and primary forms of novel network architecture

2.1 Implications of novel network architecture

A novel network architecture refers to a system that relies on relevant technologies with significant prospects for a future revolution in the field of novel networks and communications. As an important development direction for strategic emerging industries, it has new features such as agile perception, convenient control, quality service, flexibility, and scalability. Meanwhile, it will profoundly impact technology fields such as intelligent manufacturing, the Internet of Things (IoT), and space–ground integrated networks.

The core of the novel network architecture system is the design of an efficient, scalable, and large-scale typical infrastructure network architecture that supports the convergence of heterogeneous network technologies. Existing technological solutions are categorized into evolutionary and revolutionary solutions. Researchers advocate "fixing" the existing network architecture, such as by modifying network devices or topologies, updating existing network communication protocols, or applying novel technologies such as artificial intelligence (AI), blockchain, and big data to the existing network. The above measures can temporarily solve various problems in the current network and adapt the existing network architecture to novel development requirements to a certain extent. As revolutionary solutions, researchers advocate strategies for redesigning the network, seeking a novel network architecture, and redesigning the network protocols [5] to fully adapt to future requirements.

It is noteworthy that revolutionary solutions can better meet future network demands but are relatively difficult to implement, while evolutionary solutions are easy to deploy but will cause the network to bloat. In terms of existing novel network architectures, the ICN and eXpressible Internet Architecture (XIA) are revolutionary solutions. At the same time, the low-Earth-orbit (LEO) satellite network, service customized network (SCN), full-dimensional definable network, and multimodal network are evolutionary solutions.

2.2 Representative novel network architectures

2.2.1 ICN

The ICN architecture was originally designed to better support content distribution by replacing the traditional address-centric network communication model with a content-naming approach, as shown in Fig. 1. The ICN

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enables users to search and access information, enhances the security of the Internet, and simultaneously supports the demand for mobile applications and improves data distribution and collection capabilities. The centralized ICN architecture uses flat naming, meaning that a content hash is embedded in the name. Unreadable names require a centralized name resolution service to obtain routing and forwarding paths. The distributed ICN architecture uses a hierarchical naming approach, similar to the structure of the uniform resource locator. The hierarchical root path is the content publisher's name prefix, which is directly routed based on the content name, without any parsing process.

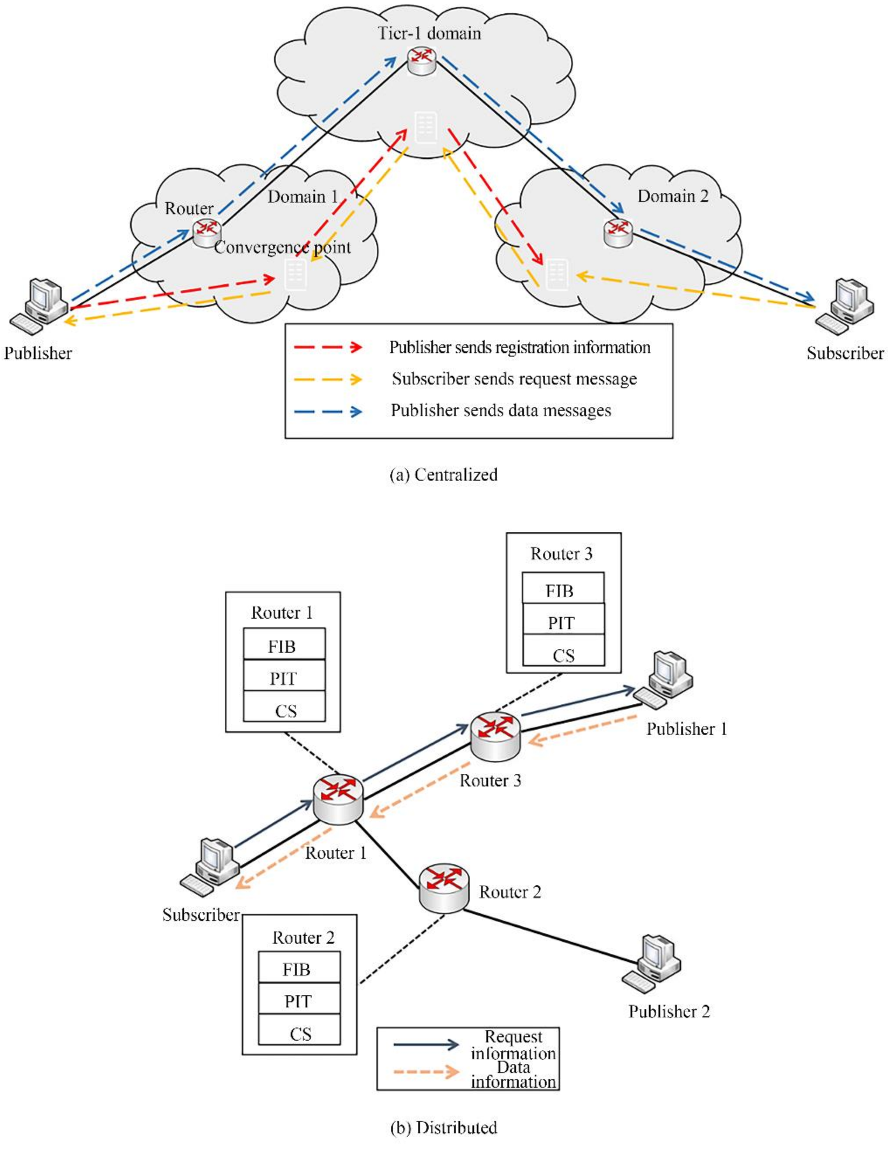

Fig. 1. Basic model of ICN architecture.

Note: FIB refers to forwarding information base; PIT refers to pending interest table; CS refers to content store.

2.2.2 XIA

The XIA can provide diverse network usage models to meet the demand for reliable communication services while effectively coordinating all the parties to provide network services in unison (Fig. 2), with evolutionary, trustworthiness, and flexible routing features. The network's senders and receivers are considered to be different communication subjects. Routers use different processing methods to achieve different network functions, and the same application can contain several different communication subjects, thereby achieving multiple network functions[6].

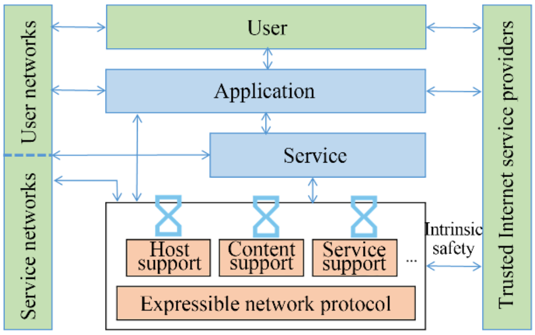

Fig. 2. Network architecture of XIA.

2.2.3 LEO satellite network

The LEO satellite network system consists of space, ground, and user segments (Fig. 3). The space segment is divided into LEO satellites and inter-satellite links that use onboard processing technology to support onboard independent networking and routing. The ground segment is divided into gateways and network control centers, which realize system operation and maintenance, interconnections with ground communication networks, and other functions. The user segment covers all terrestrial terminals such as vehicles, shipboard terminals, and satellite phones. The LEO satellite network has the advantages of a large spatial span, comprehensive coverage, and good damage resistance. Coupled with the low orbital altitude of LEO satellites, short transmission delay, and low path loss, a constellation composed of multiple satellites can realize global broadband satellite service capabilities in the true sense.

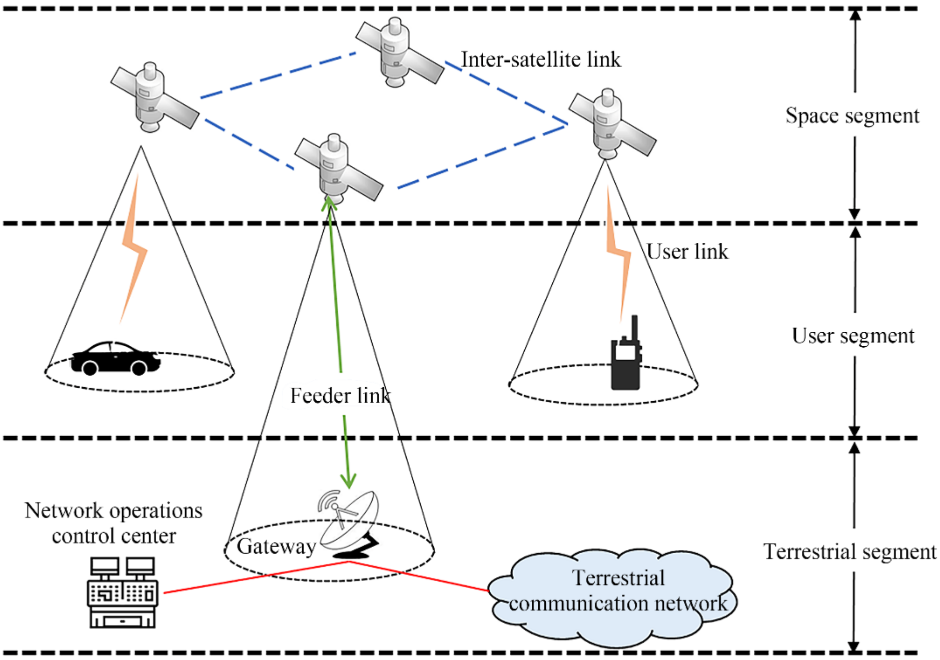

Fig. 3. Low-orbit satellite network architecture.

2.2.4 SCN

An SCN mainly adopts SDN technology, which allows it to take advantage of its outstanding advantages, including data decoupling, a control plane, and network programmability. Moreover, it can improve network virtualization and intelligent content scheduling based on the current network situation [7]. Big-Data analysis and AI technologies provide adequate support for network information scheduling and intelligent management. The application of an SCN architecture is expected to meet the practical demands of the rapid development of Internet services, rapid growth of traffic, differentiation of user needs, and integration of the real economy and Internet. A general SCN scheme has been developed in China (Fig. 4).

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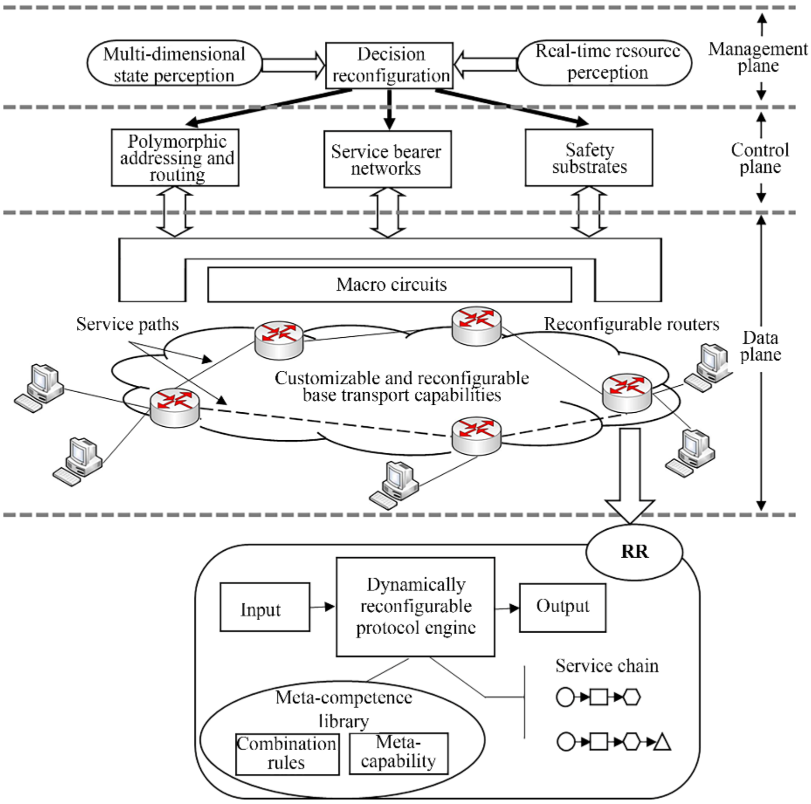

Fig. 4. Service customization network framework.

2.2.5 Full-dimensional definable network

The full-dimensional definable network architecture is based on the SDN, network function virtualization (NFV), and other technological innovations. It uses software-defined routing, software-defined interconnections, hardware, software-defined protocols, software-defined chips, and other modules to define the topology, protocols, software/hardware, and interfaces of the underlying network. Based on this foundation, open network element devices, open protocol control, open network resources, open node capacity, open network interfaces, open routing control, open storage methods, and other models [8] have been developed to provide users with refined and diversified services for self-defined applications (Fig. 5). The full-dimensional definable network architecture also provides a virtual environment for breaking closed monopolies, removing technical barriers, transforming the network infrastructure, and testing and applying network architectures.

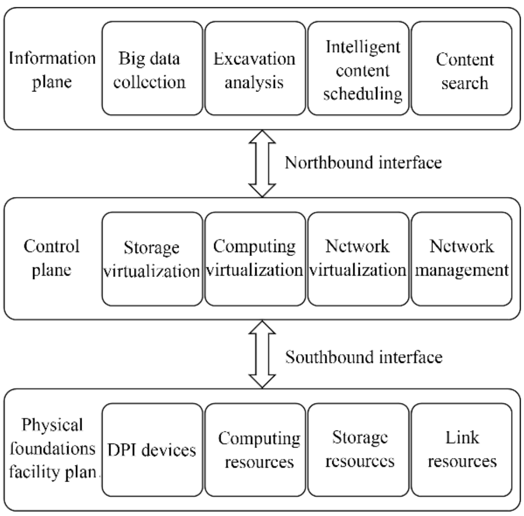

Fig. 5. Full-dimensional definable network.

Note: DPI refers to deep packet inspection.

2.2.6 Multimodal networks

The multimodal network architecture establishes a fully definable, flexible, and universal network structure that enables the functions of the network from the bottom to the top layer to be presented in a multimodal manner (Fig. 6) [8]. Therefore, it can eliminate the rigid network structure, single IP carrier, unknown threats that are challenging to suppress, and other fundamental problems that exist in network infrastructure and related technology systems. In the multimodal intelligent network model, the data layer uses software-defined interconnection and forwarding technology to increase the flexibility and programmability of full-dimensional definability. The control layer implements software-defined multimodal addressing and routing functions to address the differentiated quality of service requirements of different services. The service layer combines fine-grained sensing and the adaptation of users and services to achieve software-defined resource management and functional orchestration to support intelligent network decision-making.

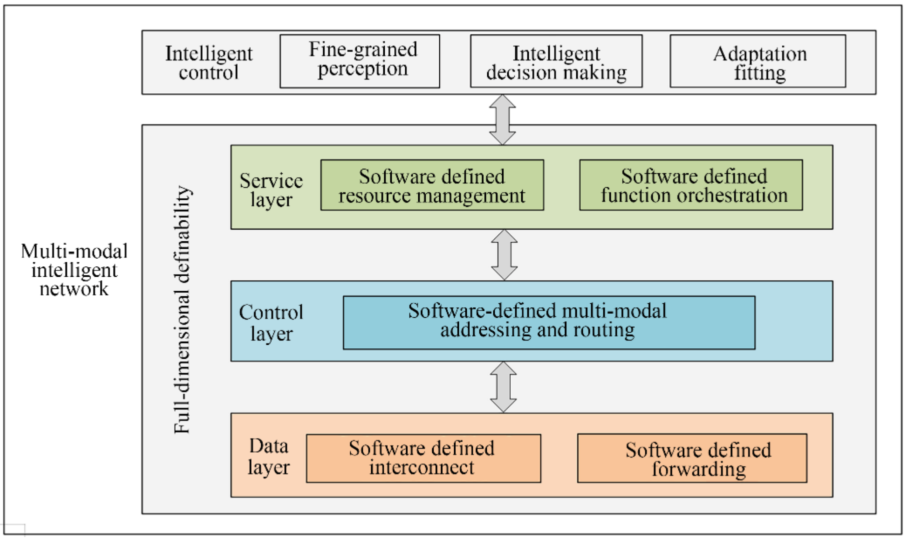

Fig. 6. Multimodal intelligent network model.

3 Novel network architecture development trends

3.1 Policies and regulations

Novel network architecture technologies will significantly affect economic and social development. Countries are actively issuing policies and regulations to guide the breakthroughs and applications of related technologies, leading to a new round of fierce competition among global information networks and communication technologies. In the United States, the Center for Strategic and Budgetary Assessments has developed an abstract concept for "decision-centric warfare" based on "mosaic warfare" (2020) to address the limitations of tactical communications networks for "network-centric warfare" in a robust adversarial environment. The Defense Advanced Research Projects Agency launched the PRONTO Network Research Program (2021) to develop networked, fine-grained, visible, verifiable, closed loop controlled "network testbeds" to support a wide range of scientific research and experimentation and to drive network technology innovation. The European Union H2020 program group proposed several novel network architectures. The CORRELATION project characterizes and predicts future slicing and network service level traffic. The PRISENODE project proposes solutions to privacy and security awareness issues in software-defined fog datacenters. The SEMANTIC project investigated end-to-end slicing and data-driven automation technologies for next-generation cellular networks with mobile edge clouds.

In parallel with the international progress of novel networks, China has launched several policies and plans to actively participate in international competition and cooperation in the field. Since 2020, China has accelerated innovative research and construction demonstrations related to novel network architectures, focusing on 5G, data centers, the industrial Internet, and other areas. The *Outline of the 14th Five-Year Plan and 2035 Vision for National Economic and Social Development of the People's Republic of China* proposes strengthening national strategic science and technology forces, focusing on developing information and communication technologies, and leading the development of various technological innovations [9].

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3.2 Industry development

Countries with high levels of network development have attached importance to the innovation of future networks at the national strategic level. The United States, the European Union, Japan, South Korea, and other countries and regions have implemented numerous research projects in network innovation environments with novel architectures and novel network technologies. Regarding the network innovation environment, the US National Science Foundation proposed the Global Network Innovation Environment Project (2005) [10] to build a novel, secure, and widely connected Internet as an experimental environment for large-scale global experiments. The European Union established the Future Networks Research and Experimentation Project (2007) in the Seventh Framework Program [11], which validates network architectures and protocols in physical and virtual network test environments. The novel network architecture includes ICN and SDN. Novel network technology involves NFV, big data, cloud computing, and edge computing.

Technology companies in China are actively conducting applied research on novel network architectures and technologies. The China Telecom Group Corporation focuses on network reconfiguration, promoting the expansion of cloud–network collaboration and the continuous expansion of network coverage. The China Mobile Communications Group Limited focuses on designing new-generation network architectures, emphasizing comprehensive network function optimization (e.g., traffic scheduling and network grouping design).

Shenzhen Tencent Computer Systems Co., Ltd. launched the data center network architecture version 5.0, introducing SDN/NFV technology to provide diversified and customizable services for private cloud customers. Alibaba Group Holdings Limited entered the edge computing industry through Ali Cloud, with its cloud–edge–end computing model as the core development path. The network-side deployment of Huawei Technologies Co., Ltd. aims at full cloudification and promotes SDN/NFV and network cloudification.

The Future Network Test Facility project is a national primary science and technology infrastructure in the communication and information fields in China. It provides a simple, efficient, and low-cost test and verification environment for studying the innovative architectures of future networks. A multimodal intelligent network system for 2035 will improve the diversity of network services and personalized adaptability to user needs through interconnections, suitable combinations, and seamless switching between various network modes [12].

3.3 Challenges

From an objective point of view, China's novel network architecture technology field still faces challenges in terms of in-depth development and efficient implementation. In terms of overall planning, the current network architecture deployment lacks comprehensive coordination and planning. Many localities and industries conduct R&D work on their own. In contrast, the industry has not formed a consensus on developing a novel network architecture, and a unified and common industry understanding, ideas, and construction solutions have yet to be formed. The national level has not yet formed a guideline to promote the construction of a novel sensing network infrastructure. An overall design for the layout, construction, protection, and coordinated development of various facilities is lacking. The solution to these problems requires the guidance and support of policies and regulations, and the timely promotion of standards development.

Regarding industrial technology, China's core technologies in hardware, computers, and communication networks lag behind those of developed countries, which causes the much-needed technical support for constructing novel network frames to be inffective. In relation to the IP, which is the core technology of the Internet, no new progress has been made for many years. The industrial base is relatively weak, and the key technologies and core software depend on an external supply, which carries the risk of being controlled by others. To address the shortage of industrial and critical technologies, it is necessary to accelerate the improvement of independent innovation capabilities.

4 Key technologies and development measures of novel network architecture

4.1 Key technologies

Typical scenarios for future networks include the consumer Internet (e.g., VR/AR, 3D video calls, holograms, interactive games), industrial Internet (e.g., precision manufacturing, remote industrial control, digital twin), and vehicular Internet (e.g., autonomous driving, vehicle-road collaboration). The emergence of these scenarios and applications requires a novel network architecture with keen sensing, flexible routing, simple network operation, and convenient control capabilities. The establishment of a novel convergent and scalable network-aware architecture can support network environment innovation with a higher speed, lower delay, controlled delay jitter, lower packet loss, and more flexible service deployment capabilities.

4.1.1 Deterministic network technologies

With the rapid development of network technologies, the need for network services has significantly changed. The diversity and uncertainty of users and services, movement of users' locations, sudden increase in service volume, and other factors make multidimensional network resources and the network state dynamic. Therefore, it is essential to study deterministic network technologies to ensure network determinism and improve network resource utilization and service quality.

Deterministic network technologies can be divided into three categories according to the protocol level (Fig. 7). (1) The physical layer adopts flexible Ethernet (FlexE) technology, which adds a FlexE layer in the middle between the Ethernet data link and physical layer to decouple the service rate and physical channel rate. Physical layer and data link layer collaborative scheduling guarantee the network delay based on time-slot switching, which is mainly used in 5G bearer network scenarios. (2) The data link layer adopts a time-sensitive network (TSN) standard, which is primarily used in factory intranet/in-vehicle network scenarios. It contains three main aspects. First, it has high requirements for time synchronization. All the devices in the network need to achieve accurate time synchronization to negotiate time boundaries. Second, it uses scheduling and traffic shaping technology to efficiently schedule and integrate traffic classes with different bandwidths and end-to-end delay requirements. Third, it uses multiple paths to achieve troubleshooting, prevent hardware or network failures, and support communication path selection, reservation, and fault tolerance. (3) The network layer adopts deterministic network (DetNet) technology, which provides a deterministic delay and jitter based on statistical multiplexing and supports centralized control, explicit routing, jitter reduction, congestion protection, and multipath routing.

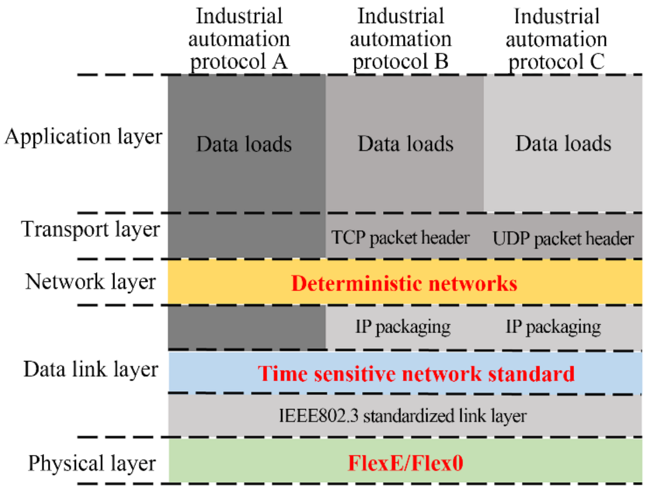

Fig. 7. Schematic of deterministic network technology architecture.

Note: TCP refers to transmission control protocol; UDP refers to user datagram protocol.

4.1.2 Segment routing technology

Segment routing (SR) is a representative technology for SDN in backbone networks, with the advantage of backbone-level scalability. It can solve the challenges of making existing IP networks flexible and controllable, as well as providing multiprotocol label switching, which telecom operators fully recognize. SR technology seeks a balance between distributed intelligence and centralized optimization. It can enhance packet forwarding, supporting the network in transmitting unicast packets through specific forwarding paths (instead of the shortest path forwarding algorithm usually used for packets).

SR is a paradigm of source routing mechanisms in which a node can usually be either a router or switch. A trusted server or virtual forwarder running a management program operates on packets using an ordered list of instructions (called segment labels). Segment labels are local and global labels that represent the topology or type of instruction. In addition, SR makes it possible to specify paths for data forwarding, thus masking information from intermediate nodes and formulating each message in the ingress node regarding the state of each information flow. To align with modern IP networks, SR applies protocols that support equivalent routing, which means that data forwarding can use all the possible paths in the network.

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4.1.3 Cloud-computing and cloud–network convergence technology

Network and communication technologies are highly responsive and agile in supporting rapidly changing business needs. Cloud computing provides customers with lower latency, higher bandwidth, and lower-cost service experiences through an end-to-end holistic solution that quickly responds to user requests and improves service quality [13]. This enables telecom operators to respond to user demands, provide high-quality services, and promote the deep integration of telecom operators' networks and enterprise businesses. Cloud computing platforms provide a novel consumption model in which enterprises can procure computing resources on demand and delegate infrastructure management to cloud service providers.

Cloud–network convergence refers to the unified definition and orchestration of network and cloud resources, supporting agile resource awareness, reasonable quality assurance, elastic planning, and the management of the entire network. This can provide more convenient and flexible connectivity. Through virtualization and integrated technical architecture convergence, resources are reasonably encapsulated and uniformly orchestrated to build a solid foundation for an information infrastructure that is simple, open, concurrent, and intelligent. From a macro perspective, cloud–network convergence is a profound form of change in a novel information infrastructure, connoting the comprehensive integration and in-depth innovation of cloud and network technologies and production organization methods to guarantee the digital transformation of society [14].

Cloud network slicing technology is an end-to-end infrastructure consisting of computing, networks, and storage resources. It has good application potential for the distribution and isolation of cloud and network resources for cloud–network convergence. Network slicing refers to dividing a physical network into multiple logically independent virtual networks, independently set according to different service requirements (such as latency, bandwidth, security, and reliability) to flexibly adapt to different network application scenarios. Based on network slicing, cloud network slicing combines the network characteristics required by various services, real-time network demands generated by other traffic flows, and dynamic changes in cloud resources. Thus, cloud and network resources can be managed, scheduled, and optimized in a collaborative and integrated manner to achieve the end-to-end unification and isolated reservation of cloud network resources, automated establishment and optimization of cloud network connections, and automated provisioning of cloud network service capabilities.

The specific implementations of cloud network slicing technology are divided into resource-unified scheduling, cloud network awareness, and adaptive adjustment. Resource orchestration unifies cloud network resources for abstraction management and capability encapsulation, abstracting simplified logical network devices and virtual network services from a complex physical network. Cloud network sensing adopts the diverse collection methods of heterogeneous resources to realize the real-time acquisition of cloud network services and network quality, which requires adaptive adjustments and further automates cloud network service adjustments, optimization, and scheduling.

4.2 Measures for developing key technologies

4.2.1 Strengthening the guiding role of science and technology special projects

The rapid development of novel network architectures must be combined with major national research projects. Regarding industrial construction, (1) we should implement core industrial technology research, form a future network industry ecosystem with a flexible configuration and robust scalability, and strive to build a novel model for future network research and development that integrates chips, equipment, network architecture, core technologies, test facilities, and application demonstration. (2) Scientific research projects should be highly integrated with infrastructure construction needs, and the output results of major science and technology projects should first be applied to urban network communication construction. We should introduce SDN technology to the backbone network. A transformation should be carried out in the core layer of the metropolitan area network to optimize traffic, and a unified intelligent control system and capability platform should be built. (3) We should accelerate the development of the new-generation Internet-based IPv6; reasonably increase the transformation and upgrading of networks, terminals, and software systems; promote the smooth evolution and large-scale commercialization of IPv6; exert the demonstration effect of intelligent city construction; improve the penetration rate of IPv6 users and network access coverage; and strive to maintain the leading international level of information and communication network infrastructure.

Regarding science and technology innovation, we should (1) enhance major original innovation and core technology, collaborate to promote original innovation and re-innovation, implement action plans for the transformation of scientific and technological achievements, and continuously promote the industrialization of high-tech achievements. (2) We should also actively promote the training and selection of information and communication technology talents, accelerate the construction of a globally competitive information and communication industry talent system, encourage industry–academia–research docking, promote the establishment of a multiparty joint training mechanism, significantly improve the ability of independent innovation, and accelerate the transformation of scientific and technological achievements.

While building a novel network architecture, we should first focus on upgrading satellite communication, fiber optic communication, SDN, AI, and other network and communication-related technologies, driving industrial development with technology breakthroughs, and supporting the rapid transformation of network structures. Second, we should empower existing network facilities and evolve and upgrade from simple link-based to intelligent and controllable networks. These will lay a solid foundation for the construction of the consumer Internet, industrial Internet, IoT, 5G/6th generation mobile communication (6G), military–civilian function combined network, satellite Internet, and other industries, and promote the integration of network architecture evolution and network technology innovation.

Considering the practical development of China’s novel network architecture, the development needs can be combined with critical scientific research projects to build a localized network test platform for the verification of network technology. In addition, the exchange and cooperation between enterprises and technical research departments should be strengthened to provide sufficient primary conditions for transforming scientific research results and verifying application demonstrations.

4.2.2 Promoting the demonstration and validation of applications

The landing point for science and technology innovation is industrial development. The R&D and innovation of future network architectures are key components to enhance the regional technology level and core competitiveness, and a significant driving force to support the development of the digital economy and information society, which can strengthen the national economy and social security level. Developing the sensing network infrastructure industry, along with verifications and demonstrations based on cutting-edge communication technologies, would be conducive to forming technological and industrial highlands, establishing novel advantages in international competition, and enhancing the long-term momentum of innovation.

In the construction of the consumer Internet, as the future network technology represented by SDN matures, novel network architectures are deployed on a large scale in commercial networks based on small-scale testing and validation. Through the SDN/NFV/cloud and other network technologies, an operationally integrated network with global on-demand resource scheduling and fully available network capabilities can be built.

In the industrial Internet, SDN, edge computing, network AI, and other technical architectures are used to solve network challenges and meet the needs of the industrial Internet in terms of low latency, deterministic latency, network security, network service customization, and a trillion connections.

Based on the previously proposed concept and practices for a “Smart China,” the IoT can be actively applied to the construction of smart cities, intelligent transportation, and in other scenarios, the new-generation information technology such as big data and cloud computing can be adopted, and a large number of sensors distributed in urban areas can be connected to provide intelligent sensing and intelligent analysis capabilities. Combined with efficient data transmission, the collaborative operation of “things” without human intervention is being realized, establishing a basis for reliable data accumulation and predictive sensing and analysis.

In 5G/6G construction, while deploying the large-scale 5G infrastructure, the integration of 6G with AI and machine learning should be explored to achieve intelligent sensing, positioning, resource allocation, intelligent interface switching, and other capabilities. Validations and demonstrations should be performed in the fields of spatial communication, intelligent interaction, holography, haptic Internet, emotional and tactile communication, virtual assistants, multi-sensory mixed reality, inter-machine collaboration, body domain networks, and fully automated traffic.

In satellite networks, space-based and terrestrial networks will be integrated to realize the efficient transmission and sharing of information among various types of users and application systems on land, on the sea, in the air, and in near-Earth space, providing an essential platform for future multi-system and multi-information integration and collaboration in the field of network communications. Moreover, it is important to promote the development of critical technologies and industries in many directions, including information electronics, satellite communications, and 5G, as well as forming a large-scale industrial chain and developing novel industries.

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5 Suggestions for the development of novel network architecture in China

5.1 Strengthening the integrated implementation of policies, laws, and regulation

The government's role in guiding and regulating macro-industrial development requires sound policy and legal systems. Establishing a novel network architecture technology industry requires policy support and legal protection in the market, financing, talent allocation, the implementation of significant projects, and other related aspects. It is recommended that the management and coordination of essential issues, policies, and projects be strengthened to develop future communication networks and industries and promote sound development for industrial applications with management innovation. It is essential to use all kinds of media resources for the widespread dissemination of scientific information and to enhance the public's scientific understanding of the future development of information and communication networks. We should regularly discern and evaluate the information industry's development trend and technical progress and provide scientific assessments for the future development layout of Internet technology and the information and communication fields.

5.2 Cultivating a healthy development ecology for the novel network architecture industry

It is recommended to highlight the critical roles of the network foundation, core platform, data elements, and security; support the development of novel models of novel network architectures; enhance the innovation activity of enterprises; grow the scale of the industry; balance the industrial ecology; integrate the consensus of various industries; and build a solid foundation for the high-quality development of the novel network architecture industry. The industry should foster a series of independently operated enterprise-level platforms, build Internet industrial platform testing systems and public service systems, and reasonably guide the business of industrial enterprises into the "cloud." Enterprises should actively take advantage of the future network and communication industry to demonstrate the industry's quality development with focused and scientific development strategies. The government should expand market opening and gradually form a benign ecological environment conducive to developing networks, platforms, applications, novel business models, and other clusters.

5.3 Promoting industry–academia–research in-depth cooperation and combined development of civil and military functions

Relying on the respective advantageous resources of telecom operators, equipment manufacturers, Internet companies, research institutes, and universities, a future network education platform should be built to popularize knowledge in the field of future networks and improve the innovation ability of society as a whole. We should focus on the technology and knowledge concentration characteristics of research institutes and universities, strengthen the positioning of the main body of enterprise innovation, promote industry–academia–research in-depth cooperation, and jointly carry out special research in the field of information and communication technology. Finally, we should strengthen the research and development of network security technology and the application of technical means and breakthroughs in network security technology bottlenecks, accelerate the transformation of results, implement key technology industrialization, and support the deepening of the development of information and communication technology in the direction of combining military and civilian functions.

5.4 Building comprehensive and innovative talent and research teams

A global vision should be established, and high-level talent should be introduced. Focusing on the construction of a highland for industry–talent integration in economic and technological development zones at all levels, we should promote investment and give high-end support to high-end professionals of novel networks. Meanwhile, we should rely on a national talent program to enrich the talent reserve and optimize the echelon structure, and build a talent introduction network using both rigid and flexible methods. We should support high-end talent based on the novel network industry development needs through innovation and entrepreneurship, improving and optimizing the talent incentive mechanism, and reasonably adjusting scientific and technological personnel equity and dividend incentive approaches. The construction of novel network research teams should be strengthened, giving full play to the role of scientific research institutes and universities in cultivating talent, and building the highlands of scientific research in the fields of future networks and communications.

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