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Development Roadmap of Polymorphic Intelligence Network Technology Toward 2035

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Abstract: The current infrastructure and technology systems of the Internet are facing major challenges in terms of intelligence, diversification, personalization, robustness, and efficiency. Thus, changing the network infrastructure and building a polymorphically definable intelligent network requires immediate attention. This work studies and determines the development trend in network technologies in China and abroad, proposes the development goal of a polymorphically definable intelligent network, and extracts a list of key cutting-edge technologies for future consideration. Based on these, a development roadmap is constructed for a polymorphically definable intelligent network in China for 2035. China should seek the research and development of key technologies, including network architecture, addressing and routing, full-dimensional definability, network intelligence, and network robust control, and guide the development of relevant industries through key contents, including core chips, products, and systems. Demonstration projects can be deployed to promote the implementation of intelligent network business, including projects concerning information infrastructure, vertical industry networks, space–earth integrated networks, and ubiquitous interconnections between humans and things. In addition, this paper proposes some suggestions on the guarantees of polymorphic definable intelligent networks in China from the perspectives of policy guarantee, scientific research platform support and joint research, international communication expansion, and human resource cultivation and employment.

Keywords: intelligence network; polymorphic; network architecture; full-dimension definable; robust control; development roadmap

1 Introduction

With the development of information and communication network technologies, the Internet has become an important infrastructure that is strongly related to national economic and social development. Furthermore, the integration of the Internet and social life is increasing on a daily basis. Users' demand for the Internet has changed from a simple end-to-end mode to the acquisition of mass content; and new modes, such as mobile Internet [1], Internet of Things (IoT) [2], and cloud computing [3], have been developed. With the continuous development of diversified terminal types and access modes [4], human–human, human–machine, machine–machine, and network–network communications have become increasingly normal [5], requiring networks to provide diverse, personalized, and efficient services for mass business [6].

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Despite the evolution of the above-mentioned requirements, the technical connotations and extensions of the existing Internet are neither abundant nor balanced. The Internet has several fundamental problems, such as rigid network structures [7], single IP bearers [8], and unpredictable threats [9–11], which render it incapable of meeting users' demand for high-quality web experience in the ubiquitous scenario. However, next-generation networks have become the focus of competition in the development of the global Internet. The United States, the European Union, and Japan have taken the lead in top-level basic research planning and industrial innovation in the field of next-generation networks. China has also clearly defined "accelerating the construction of a new-generation information infrastructure that is high-speed, mobile, secure, and ubiquitous" as an important task [12].

Currently, the focus is on promoting the incremental deployment and evolution of the Internet, fully absorbing and utilizing new ideas and methods, making fundamental changes to the Internet technology system, and building a new network architecture and technology system for 2035. Under the demand to provide users with new services, perspective, and security by 2035, as well as to support the intelligent transmission, management, operation, and maintenance of networks and enhance networks' high reliability, availability, and robustness of services, it is necessary to strengthen the innovation of network technology, promote the transformation of technology from plug-in to endogenous, adapt business requirements with a new and full-dimensional definable open architecture, integrate emerging technologies to aid network development, and build polymorphic intelligence networks with intelligent, diversified, personalized, highly robust, and high-performance features [13].

2 Global technology development

In recent years, countries worldwide have strengthened the top-level design and strategic deployment of new network technologies to take advantage of the new round of technology and industry competition.

The United States has guided the development of network technology by issuing relevant development plans or strategies. It has launched large-scale projects, such as GENI, FIND, and FIA, and the Network and Information Technology R&D Program (NITRD) in 2016 to highlight the importance of computing and infrastructure, large-scale data management and analysis, robotics and intelligent systems, cyber security and information assurance, and software design and production. On September 20, 2018, Trump released the National Network Strategy, which outlines four pillars, ten goals, and 42 priority actions of the US network to maintain leadership in the field of network architecture and technology.

The European Union has also launched the Future Internet and FIRE+ programs and has funded more than 400 related research projects. In addition, the European Union has released the "Horizon 2020" research plan and proposed to strengthen the innovation and application of information technology from 2014 to 2020 in which information technology investments accounted for 46% of total investments. The program focuses on next-generation computing technologies, future Internet technologies and services, content technology and information management, advanced robotics, robotic smart spaces, information and communication technologies, and key enabling technologies. In 2017, the International Telecommunication Union established the Focus Group on Network 2030 to explore new technologies for network architectures anticipated by 2030 and beyond.

Japan has launched the NWGN and JGN2+ programs and has proposed the strategy U-Japan to build a ubiquitous IoT. Recently, Japan has published the *Science and Technology Innovation Comprehensive Strategy 2016*, which focuses on the construction of ultra-smart society and the integrated deployment of artificial intelligence, equipment systems, applications research, and industrialization.

South Korea has also proposed a 10-year U-Korea strategy to identify the development of information network as a national key development strategy.

China has also focused on the field of new network technologies. In recent years, with major strategic planning programs, such as *National Informatization Development Strategy Outline*, *Innovation-Driven Development Strategy*, and *Guiding Opinions on Actively Promoting Internet Plus Action*, China has continuously improved the top-level strategies of new networks. In 2018, *The 13th Five-Year Plan for Economic and Social Development of People's Republic of China* was passed at the Fifth Plenary Session of the 18th CPC Central Committee, which clearly states the network power strategy and the Internet Plus plan. Accelerating the construction of high-speed, mobile, secure, and ubiquitous new-generation information infrastructure is an important task toward expanding the infrastructure construction space. The central government fully deploys the "Broadband China" strategy, proposes to accelerate the construction and upgrade of the network and communication infrastructure, and comprehensively promotes the integration of the three networks. In the same year, the Ministry of Science and Technology launched key projects, such as Broadband Communication and New Network, which strive to produce chips with independent

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intellectual property rights, integrated fusion networks, high-speed optical communication equipment, and future wireless mobile communications by 2022. China aims to master independent intellectual property rights, formulate industrial standards, demonstrate applications, implement a deep development strategy of military–civilian integration, and create a sound industrial synergy innovation system.

3 Technology development roadmap

Based on the requirements for the development of new network technologies, the project team has formed the overall strategic goals and phased goals of polymorphic intelligence network technology, focusing on the R&D layout, core products, industrial development, and demonstration projects. We discussed the strategic support and guarantee conditions required for the development of the polymorphic intelligence network and formed a polymorphic intelligence network development roadmap, as shown in Fig. 1.

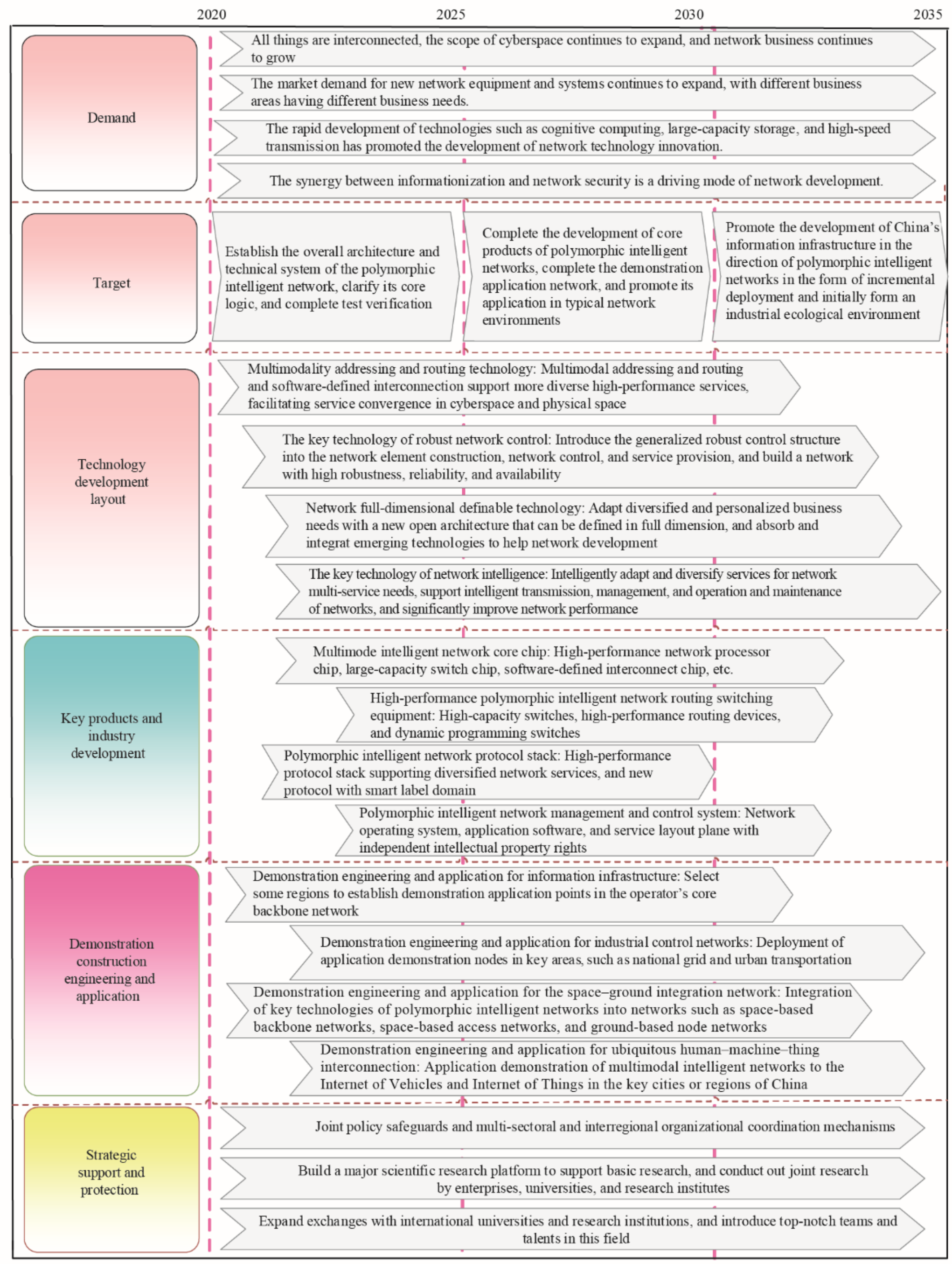

Fig. 1. Development roadmap of polymorphic intelligence network technology.

3.1 Development needs and goals

In recent years, Internet applications have expanded rapidly, and the problem of making full use of the network has been solved. However, in the face of the demand for specialized services carried by the deep integration of the Internet and the economy, the development of the connotation of Internet technology has not fully supported the expansion of extended network applications. This has restricted its support for economic and social developments on a broader and deeper level. The main development needs are summarized as follows:

(1) The network space has been continuously enriched and expanded. The demand for IoT has surged. Large convergence, large connections, big data, and new intelligence have gradually penetrated all aspects of information networks. The new network needs to meet the diversified needs of the IoT and provide efficient processing services for massive data.

(2) The market demand for new network equipment and systems continues to expand in the industrial, electronics, automotive, and medical sectors. Vertical industry requires new networks to support specialized and customized services.

(3) The emergence and development of new technologies, such as cognitive computing, large-capacity storage, and high-speed transmission, have significantly improved the resources and capabilities of network platforms and promoted the development of network technology innovation, which helps to make full use of network resources and provide better web experience for users.

(4) The paired development model of informatization and network security requires the new network to consider the service quality and security of the network in the process of technological innovation and evolution, and the endogenous security mechanisms can help provide highly reliable network services.

Based on the above-mentioned analysis, polymorphic intelligence network technology focuses on the fundamental problems of the rigid network structure, single IP bearer, and unpredictable unknown threats. It attempts to establish a new network architecture and a relevant technical system that can be incrementally deployed, form a series of domestic or international standard specifications and patent groups, and to provide a set of internationally influential Chinese Program powers to build a new network infrastructure that is smart, efficient, secure, and credible. Polymorphic intelligence networks strive to lead the breakthrough development of China’s new network architecture and core technologies, help incubate enterprises with international competitiveness, and establish research platforms and teams covering cutting-edge theory, engineering technology, system testing, and industrial applications, thereby providing the corresponding core technology and capacity for strengthening the competitiveness of China’s network industry.

Considering factors such as the potential of new network technology, the scale of network construction, and the potential for cost reduction, and combined with the development needs of national network technologies, the phased objectives and space–time layout of polymorphic intelligence network development are as follows:

(1) 2020–2025: Establish the overall architecture of polymorphic intelligence networks and clarify its core operating logic, develop a principle verification system, establish a technical system of polymorphic intelligence networks, and form an evaluation mechanism and standard specifications. Initially, polymorphic intelligence network technology and industrial ecology will cover scientific research, technological development, equipment manufacturing, and network operations.

(2) 2025–2030: Complete the development of the core chip/equipment/system of polymorphic intelligence networks, complete the construction of the test network, demonstrate the application of the network, complete the industrial layout of core components and equipment/system, and promote application in typical network environments.

(3) 2030–2035: In the form of incremental deployment, we will promote the development of China’s information infrastructure toward polymorphic intelligence networks, and gradually deploy applications in infrastructure core networks, data center networks, industry networks, and other typical application environments. We attempt to form synergistic technology and an environment of industrial development; thus, polymorphic intelligence networks and products begin to benefit people and livelihoods, resulting in significant economic and social benefits.

3.2 Key technology R&D layout

3.2.1 Independent innovation of polymorphic intelligence networks architecture

To achieve the development needs of information networks, such as intelligence, diversification, personalization, high robustness, and high efficiency, we must completely break the rigid framework of traditional networks and

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build a full-dimension definable open network architecture by deepening the definition of network function from the top to bottom, recognizing and refining the basic elements of network functions based on the concept of all-around deconstruction and full-factor openness. Based on the concept of network virtual function services, we should pool network resources and improve the efficiency and flexibility of service deployment, thus further promoting resource utilization. We should also adopt new technologies to aid network development, embed endogenous security and artificial intelligence into the polymorphic intelligent network system, and create a comprehensive and robust architecture system. Based on open integration, a polymorphic intelligent network system with the core concepts of full-dimensional definable polymorphic addressing and routing, network intelligence, and endogenous security structure should be constructed. The development requirements of a future network business must be met through network structure self-organization and service self-adaptation. Such requirements include high efficiency, intelligence, high reliability, low latency, and endogenous security. In this way, it is ensured that the network is open and scalable and has incremental deployment, heterogeneous integration, and other capabilities to support the demand for network reconstruction and rapid deployment of new services, providing ongoing evolution impetus for the development of new networks.

3.2.2 Polymorphic addressing and routing technology

For polymorphic heterogeneous identity addressing and routing technology, we research polymorphic heterogeneous identity addressing and routing technologies that support IP, geospatial, content, identity, etc., and support its compatibility with existing network addresses, research the polymorphic addressing and the interworking of inter-route technology, which supports intelligent switching between addressing routing modes for end-to-end transmission requirements of users. We also investigate unified look-up table and forwarding technology supporting multiple modal addressing, which supports the extension of addressing modes and definability, and research technology of wide-area networks that supports real-time state awareness, program control, and terminal access identity management. Further, we study the polymorphic protocol definition and adaptation technology based on a full-dimensional definable platform, which supports software-defined protocol stack structure and dynamic adaptation to achieve cross-platform support of polymorphic protocol stack. For the service transmission requirements of users, we study the intelligent coordination mechanism of polymorphic addressing routing and select the optimal routing mode for transmission automatically by the network.

3.2.3 Full-dimensional definable network technology

Polymorphic intelligence networks require research regarding the coordination mechanism of dual-mode data-layer circuit/packet-switching technology to support the automatic adaptation of services, thus providing users with more choices and better experiences. The collaboration architecture of IP network and optical network based on resource pooling and fine grit needs to be studied to build a multi-mechanism collaborative solution. A software and hardware collaborative data-layer processing architecture as well as a language and front-end cross-compilation mechanisms should be developed to achieve high-performance data processing. Wired/wireless and dynamic/static multimodal channel-access techniques are studied to support coverage scenarios in space, in the sky, on the ground, and at sea. The key processing modules of the data layer need to be researched, such as software definition package parsing and the structure/algorithm of and software definition adaptation actions, forming the IP core. The software definition interconnection protocol, exchange structure, and packet processing technology should be researched, and the data-layer abstract processing model for protocol-independent forwarding should be researched and expanded to optimize the flow of software-defined packet processing logic. Network software-defined measurement sensing technology is studied to provide fine-grained and customizable refined network awareness capabilities and to support polymorphic intelligence networks with smart platforms.

3.2.4 Key technique of network intelligence

Network intelligence mechanisms must be researched based on artificial intelligence, big data analysis, etc., to support sensing–decision–adaptation integrated design, intelligent sensing, independent decision-making, and automatic execution of the network. Driven by the consistency of improvements in service quality, global coordination control technology must be investigated based on user experience. Service-bearer technology for business intelligence adaptation and the design of efficient and reliable intelligent transmission optimization mechanisms should be studied to realize fast fitting of network resources. A network model needs to be established with strong time–space scale characteristics, and a mathematical fitting method from complex scenarios to the network model should be researched to support resource intelligent adaptation based on scenario fitting. Depth-perception technology, such as business distribution and network resources, must be studied to determine the neighborhood inheritance mechanism of the network scenario view, thus realizing a unified description system of high-level perceptual semantics. The intelligent optimization technology of network transmission should be studied to realize structural congestion avoidance for the whole network and globally coordinated control of network resources based on user experience.

3.2.5 Key technique of network robust control

In view of uncertain disturbance factors, such as random failure of network nodes or links and vulnerability of network element systems, polymorphic intelligence networks require a generalized robust control mechanism, formal description method, and evaluation method. Mechanisms such as dynamic structure, heterogeneity, and redundancy must be introduced at the network architecture level, and robust network architecture based on closed-loop negative feedback control must be investigated. Dynamic, random, and heterogeneous methods of network elements, such as network address, topology, and routing should be studied. Based on the uncertainties of robust control structures, key technologies such as dynamic random scheduling, dissimilarity design, and output vector strategy decisions should be investigated. The corresponding systems should be developed in a typical network equipment environment to determine the effective configuration and implementation of robust control mechanisms in the data, platform, network, and operating environments. A new robust network with high reliability and availability can be constructed.

3.3 Core products and industry development

We will develop core chips/products/systems of polymorphic intelligence networks, guide relevant industries to develop rapidly and strengthen their competitiveness, help incubate innovative enterprises with international competitiveness, and form industry application platforms and teams, including frontier theory, engineering technology, and system testing.

3.3.1 Core chips of polymorphic intelligence networks

Polymorphic intelligence networks will be used for the development of key chips for router/switch systems with full-dimensional network data planes, as well as for the development of high-performance network processor chips and high-speed non-blocking high-capacity switch chips. These networks will also be used to develop chip intelligent cache algorithms to improve chip cache utilization and reduce power consumption, in the research and implementation of the core chip's large-capacity flow table data structure and high-efficiency search algorithms, enabling network devices to support large-scale flow table rule sets at lower costs, and to improve network device packet processing capabilities.

3.3.2 High-performance polymorphic intelligent network routing and switching equipment

Polymorphic intelligence networks will be used for the development of a large-capacity non-blocking Ethernet switch to build a polymorphic intelligent network router device supporting the demand for high-capacity data forwarding with cluster expansion capability in the future network. We investigate a new type of routing device with unified addressing that supports extended and defined polymorphic routing addressing modes, and we will develop a highly dynamic programming switch that supports network virtualization services. The processing logic of the switch can be dynamically programmed to support multiple different service processing simultaneously. The switch can be used to possess independent control, forwarding, and monitoring planes to improve the robustness of the network.

3.3.3 Polymorphic intelligent network protocol stack

Polymorphic intelligence networks will be used to develop high-performance polymorphic protocol stacks suitable for diversified network services, support personalized customization of network services, and consider the flexibility and efficiency of protocol processing. These networks will also be used to develop protocol standards for multi-protocol coexistence, support cross-platform and cross-media data routing and forwarding and support the rapid transformation of polymorphic protocols. Furthermore, we will use these networks to develop new protocols with smart identification domains and support data intelligent routing and network intelligent operation or maintenance; develop a high-performance network protocol stack based on general-purpose computing platforms that support packet cross-core processing, network processing performance with CPU multi-core parallel expansion,

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multi-network services, full compatibility with traditional network services and improve network throughput, thereby significantly reducing network processing delay.

3.3.4 Polymorphic intelligent network management control system

Polymorphic intelligent networks will also be used for developing management and control systems and to support unified management, intelligent scheduling, and data analysis of the entire network. They will be used to support traditional device control functions to be compatible with the framework of current mainstream network operating systems and adapt to the future technological evolution of the control plane. Polymorphic intelligent networks will also be used to develop diversified and intelligent middleware and application software in operating systems, support resource abstraction and automatic operation and maintenance management, support distributed generation and consistency maintenance of network views, support technologies such as network fault and collision detection, and form a technical environment for the further development of polymorphic intelligent networks. Resource management will also be investigated for orchestration planes to support flexible scheduling, joint optimization, and integrated management of computing, storage, transmission, and other resources.

3.4 Demonstration project construction and application

Polymorphic intelligent network technology will be used to actively promote the transformation and upgrade of traditional industries, integrate thousands of applications and services into people’s lives, serve economic development, accelerate the ecologicalization of business, intelligent networks, and intelligent operations, and create intelligent connections, such as IoT and Internet finance. Based on this, polymorphic intelligent networks can be utilized for the deployment of application demonstration projects in the following four typical areas to promote applications in a typical business, supporting economic and social development.

3.4.1 Demonstration engineering and application for information infrastructure/operator networks

In the core backbone network of the operator, we will select a part of the region to establish an application demonstration network, conduct research on the implementation of the polymorphic intelligent networks, verify the support capability for traditional network services, support the rapid upgrade and expansion of the network, and deploy new services that are diversified and personalized. Subsequently, we will begin testing the new services, support the deployment of new services and multi-service integration, select typical case scenarios, perform network intelligent operation and maintenance, user mobility, network robust control, network virtualization management, virtualization application, and demonstrations, such as provisioning and rapid customization of large customer services across domains and cross-layer services to support intelligent management and polymorphic operation of the network.

3.4.2 Demonstration engineering and applications for vertical industry networks

Application demonstration nodes can be deployed in key vertical industry networks, such as state grids, urban transportation, and industrial interconnects, to conduct research and testing for their highly robust and diverse needs and verify the compatibility of polymorphic intelligent networks with multi-protocol access and the capability of multimodal addressing and routing of custom protocols. We will verify the resistance of polymorphic intelligent networks to random disturbances and uncertainty attacks in special industry scenarios. To meet the needs of the business, a full-dimensional definable platform of polymorphic intelligent networks will be applied to support flexible and efficient adaptation to different scenarios.

3.4.3 Demonstration engineering and application for the space–ground integrated network

In response to national strategic needs, polymorphic intelligent network technology will be integrated into space-based backbone networks, space-based access networks, ground-based node networks, etc., and interconnected with demonstration networks for information infrastructure to build a full-coverage, wide-access, user-customized, and highly robust space–ground integrated network demonstration project. It mainly conducts demonstration research on wide/baseband multimode access, private protocol conversion, multiclass intelligent user management, and high-speed data forwarding, and supports highly reliable continuous communication in a wide space–time range.

3.4.4 Demonstration engineering and application for ubiquitous interconnection of human and physical objects

Application demonstration projects for the interconnection of human and machines, such as the Internet of Vehicles and IoT in key cities or regions in China, will be deployed to further stimulate the innovation vitality of new fields and drive the rapid growth of new technologies and the social economy. The project team will conduct research and experiments on key technologies, such as multi-protocol self-organizing networks and data-distributed collaboration, and integrate intelligent genes of polymorphic intelligent networks into the ubiquitous Internet to support intelligent management and automatic adaptation requirements of nodes and networks. Simultaneously, in this application demonstration, we will verify the ability of polymorphic intelligent networks to support new network technologies and network services, and further explore technological innovations.

3.5 Strategic support and guarantee

Combined with the development of new network technology, the following points are needed to provide strategic support and guarantee because China's basic frontier technology is weak, the international influence of standard norms is small, and the structure of production, education, and research is scattered and immature.

3.5.1 Active and stable policy safeguards, multi-sectoral and interregional organization coordination mechanisms

According to *Several Opinions of the CPC Central Committee and the State Council on Deepening the Reform of Institutional Mechanisms and Accelerating the Implementation of Innovation-Driven Development Strategies*, the decisive role of the market should be exploited in resource allocation with the government fully playing its role. An interdepartmental and interregional organization and coordination mechanism should be established, led by the Ministry of Science and Technology and coordinated by the Ministry of Finance, Ministry of Industry and Information Technology, Ministry of Education, Chinese Academy of Sciences, Chinese Academy of Engineering, State-Owned Assets Supervision and Administration Commission, and other relevant departments. Relevant research and development through ministries and provinces should be actively promoted, scientific decisions should be made, and regulatory management should be conducted.

3.5.2 Build a major scientific research platform to support basic research, and organize and conduct joint research on production, education, and research

We will organically integrate domestic and superior foreign scientific and technological resources, strengthen open cooperation, coordinate and deploy networks, build a major scientific research platform for multidisciplinary talents in the field of new-type networks, establish a scientific organization form that concentrates on major issues, commit to solving major strategic needs of the country in this field, address major scientific and technological problems in the industry, and handle major bottlenecks in the industry. Further, we will explore the original innovation of the frontier foundation to provide important support for the development of scientific research results of independent innovation in the country and national defense construction.

3.5.3 Expand exchanges with international universities and research institutions, and introduce top-notch teams and talents in this field

We should actively expand exchanges and cooperation with international universities and research institutions, quickly absorb and transform advanced foreign achievements, break down barriers to technologies and systems, and gradually narrow the technology gap with advanced countries and regions. Meanwhile, we should attend to the construction of a talent team and form a long-term effective talent introduction and training mechanism.

4 Conclusion

The basic concept of our proposed new network technology innovation is to take the open architecture, software-defined networking and network function virtualization technology as the foundation and the development of AI as an opportunity, support the reshaping of baseline technology, create an evolutionary development model of incremental deployment, and build new polymorphic intelligence networks for 2035. The goal of polymorphic intelligence networks is to promote China's communication network technology to the level of leadership and to make China's communications industry more powerful. In response to the development needs of information networks and combined with research trends in China and abroad, this paper studies and determines the development trend of China's new network technology and formulates a roadmap for the development of polymorphic intelligence network technology for the reference of network scientists.

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