Postprint: Research on Next-Generation Information Technology for Sensing China

Authors: Institute of Information Engineering, Chinese Academy of Sciences

Date: 2017-02-08T00:00:00+00:00

Abstract

In 2009, the impacts of the global financial crisis became increasingly prominent. Major economies worldwide began shifting their long-term expectations for economic recovery toward reliance on scientific and technological innovation to create new economic growth points, and China also initiated the deployment and cultivation of strategic emerging industries. Against this broad domestic and international backdrop, the Party Group of the Chinese Academy of Sciences organized experts in relevant fields to conduct strategic discussions and demonstrations on the Internet of Things, sea-cloud computing, future networks, information security, and other related areas, and in 2012 launched the "New Generation Information Technology Research for 'Perceptive China'" Strategic Pilot Science and Technology Special Project (hereinafter referred to as the Information Technology Pilot Special Project), to carry out in-depth research on new generation information technology.

Full Text

Preamble

Strategic Priority Research Program (Category A) of the Chinese Academy of Sciences
ChinaXiv Partner Journal: Research on New Generation Information Technology for "Sensing China"

1. Project Background and Significance

In 2009, as the impact of the international financial crisis became prominent, major world economies began shifting their long-term recovery expectations toward reliance on technological innovation to create new economic growth points. China also initiated strategic planning to cultivate emerging industries. Against

this backdrop, the Chinese Academy of Sciences (CAS) organized strategic discussions and demonstrations among experts in relevant fields on the Internet of Things, sea-cloud computing, future networks, and information security. In 2012, CAS launched the Strategic Priority Research Program titled "Research on New Generation Information Technology for 'Sensing China' " (hereinafter referred to as the Information Technology Priority Program) to conduct in-depth research on new generation information technologies.

The program' s innovative concept of "Sea-Network-Cloud Collaboration" (hereinafter referred to as Sea-Cloud Collaboration) aims to address the challenges faced by ternary data objects (human-cyber-physical) in security, energy consumption, transmission, and processing. By achieving leapfrog innovation, it seeks to establish the technical foundation for deep integration and comprehensive utilization of information resources, physical resources, and human society, providing technical reserves and support for the formation and development of strategic emerging industries and inclusive intelligent services. This concept has gained widespread recognition in the industry and has been incorporated into relevant national major science and technology project plans, positioning it to become a banner representing China in the international IT arena. The "Sea-Cloud Computing" technology proposed by the program has also been explicitly recognized by the Internet Data Center (IDC) as one of the top ten development trends in the global high-performance computing field in 2014.

Guided by the Sea-Cloud Collaboration concept, the program has constructed a sea computing framework centered on specialized computing that elastically aggregates edge and terminal resources. It has innovatively proposed a data-driven collaborative scheduling model for sea-cloud resources, achieving breakthroughs in key technologies including specialized computing chips, deep programmable networks, and network security. The program has developed innovative architecture chips based on specialized computing and sea-cloud servers, deploying a Sea-Cloud Collaborative Information System prototype on the sea-cloud innovation environment. This system improves energy efficiency by nearly one order of magnitude compared to traditional cloud computing models and enhances local threat-to-global response efficacy by 1-2 orders of magnitude. Demonstration applications in key national regions, important fields, and typical scenarios have achieved remarkable social benefits. Notably, at the third World Internet Conference on November 16, 2016, two achievements from the program— "Cambricon 1A Deep Neural Network Processor" and "SAP Industrial 4.0 Internet Manufacturing Solution" —were selected among the 15 leading global internet scientific and technological achievements.

2. Program Progress

2.1 Breakthroughs in High-Energy-Efficiency Chip Technology

In neural computing, the program proposed the world' s fastest reconfigurable processor architecture for deep learning chips, achieving a 1,000-fold improve-

ment in performance-to-power ratio compared to mainstream CPU-based artificial neural network algorithms and opening a new direction for programmable custom circuits internationally. *MIT Technology Review* identified the reconfigurable processor as "the chip that the AI field has been waiting for." The world's first deep learning reconfigurable processor, "Cambricon 1," won the Best Paper Award at the 2014 International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS' 14), marking Asia's first Best Paper Award at a top-tier computer hardware conference. *Communications of the ACM* selected it as one of the 20 research highlights in computing for 2014. Building on this technology, related achievements were selected among the 15 leading global internet scientific and technological achievements at the 2016 third World Internet Conference. The world's first multi-core deep learning processor, "Cambricon 2," received the Best Paper Award at the International Symposium on Microarchitecture, while the world's first general-purpose neural network instruction set, "Computer Language," achieved the top review score at the 2016 International Symposium on Computer Architecture, with one-sixth of the conference papers citing reconfigurable processor achievements.

In algebraic computing, the program proposed the proprietary AppA ISArcTM instruction set architecture and made over 140 innovations and inventions in microprocessor architecture. It solved the high-frequency design challenges for 512-bit ultra-wide bus cores. The MaPU 1.0 chip, manufactured using 40nm process technology, achieved a clock frequency of 1.2 GHz with peak computing capability of 192 GFLOPS@64 and peak processing capability of 500 GFLOPS@64/1 TFLOPS@32. Its kernel performance-to-power ratio reaches 36 GFLOPS@32bit/W when executing typical algorithms, representing world-leading levels. The "Black Hole 1.0" supercomputing system based on MaPU 1.0 has completed debugging and will enter trial use at the China Academy of Engineering Physics, State Grid, and the "Tianlai" experimental system of the National Astronomical Observatories. The MaPU HPP1.0 design verification has been basically completed and will adopt 16nm manufacturing process with a clock frequency of 1.4 GHz, peak computing capability of 3.225 TFLOPS@64/6.5 TFLOPS@32, and peak processing capability of 4.65 TFLOPS@64/9.32 TFLOPS@32. Its kernel performance-to-power ratio approaches 100 GFLOPS@64/W, more than one order of magnitude higher than international mainstream microprocessors and reaching absolutely world-leading levels. The "Black Hole 2.0" supercomputing system based on MaPU HPP1.0 will achieve an overall system performance-to-power ratio of 30 GFLOPS/W, nearly one order of magnitude higher than mainstream international/domestic supercomputing systems.

2.2 Deep Programmable Network Technology Leading Network System ITization

The program developed an advanced network programming model and Protocol-Oblivious Forwarding (POF) extended instruction set, enabling unified net-

work programming of control and data planes using C language. It broke through novel network forwarding technologies such as in-network storage and synchronous transmission to provide efficient forwarding layer support for applications. The program developed key equipment and systems including POF advanced programming environments, controllers, software/hardware switches, and wireless switches. Through strategic cooperation with Huawei, it constructed a POF technology ecosystem and implemented the OpenPOF open-source project, co-leading the standardization open-source project PIF with the U.S. P4 project to seize the initiative in developing next-generation network foundational technology standards.

The program established the world' s first wide-area network testbed supporting POF technology—FuNET—covering nearly 30 nodes across 15 cities in China, the United States, Russia, and Australia. It achieved interconnection with U.S. GENI, becoming China' s test network for China-U.S. industrial internet cooperation. The testbed supports 128 concurrent traffic loads and no fewer than 1,024 virtual component concurrent measurements, enabling relatively independent iterative upgrades of integrated systems and supporting the aggregation and integration of innovative resources and cross-regional, cross-disciplinary online collaborative R&D testing. The program proposed an information-centric 5G new network architecture based on deep programmable networks and developed the world's first verification system integrating 5G and information-centric networks, implementing video application scenarios with mobile information requesters, providers, and both simultaneously.

The WIA-FA protocol developed by the program became the world' s first wireless technology standard for factory high-speed automatic control applications. Mr. Rudy, Secretary of IEC TC65, commented that "WIA-FA is a pioneer in factory automation technology upgrades and will play an important role." The program also initiated and promoted the establishment of the Edge Computing Industry Alliance. In this field, the program has already received one second prize of the National Technical Invention Award and one second prize of the National Science and Technology Progress Award, with related achievements selected among the 15 leading global internet scientific and technological achievements at the 2016 third World Internet Conference.

2.3 Preliminary Formation of Integrated Security Technology System for Sea-Network-Cloud Collaborative Protection and Supervision

For Sea-Cloud Collaborative Information Systems, the program constructed an integrated security technology system for Sea-Network-Cloud collaborative protection and supervision. It systematically deployed security control and protection at the sea end, network, and cloud end, enabling high-speed security processing at the sea end and deep intelligent analysis in the cloud. Through systematic Sea-Network-Cloud collaborative mechanisms, it substantially reduces data transmission volume between sea and cloud, enhancing local threat-to-global response efficacy by 1-2 orders of magnitude.

The threat response speed at the sea end has increased by 1-2 orders of magnitude. The dedicated signature verification device achieves signature speeds exceeding 1.5 million times/second and verification rates exceeding 670,000 times/second—50 times faster than existing equipment. The program broke through homologous software application analysis technology, achieving second-level detection capability for billion-function-level and trillion-instruction-level code segments, increasing detection speed by two orders of magnitude. It discovered, for the first time internationally, software vulnerability types such as Hanging Attribute Reference, identifying over a thousand unknown vulnerabilities. These achievements were reported by dozens of foreign media outlets including *Wired* and are now used by more than 90 organizations worldwide. The program increased rule-based content identification scale from 100,000 to 10 million and improved the matching speed of its regular expression matching engine by 1-2 orders of magnitude compared to representative engines such as PCRE, Microsoft GRETA, Google RE2, and C++ Boost regex, leading the second-place competitor by more than four times in national regular expression matching technology competitions.

Network transmission volume has been reduced by two orders of magnitude. Lightweight computing 前移 (migration) to the sea end can reduce data transmitted back to the cloud from 2.5 billion entries to approximately 20 million entries —a two-order-of-magnitude reduction. The network transmission lightweight encryption algorithm RECTANGLE developed by the program achieves four times better comprehensive performance than existing international standards. Vincent Rijmen, designer of the Advanced Encryption Standard, commented that it features "simple design, in-depth security analysis, and excellent hardware and software implementation performance." The program's overall technical solution has been transformed into national proposals for the "Intelligent Manufacturing Major Project" and core technical content for the industrial IoT architecture of the "Industrial Internet of Things Industry Alliance."

2.4 Providing Systematic Solutions for Key National Regions and Important Fields

In the field of border defense and control, the program developed a perception system featuring high bandwidth, low power consumption, and low latency, achieving interactive video, voice, and data transmission. The system currently operates stably in harsh natural border environments, transforming traditional duty patterns of border defense forces and realizing the transition from "human defense" to "technical defense," thereby strongly supporting national border and coastal defense sovereignty and security.

2.5 Supporting Integrated Development of Key Industries and Leading Business Model Innovation

Addressing national practical needs for the integration and interaction of information technology and the physical world in industrial fields, the program

proposed an autonomous reconfigurable industrial control system architecture. In the field of dedicated communications, it proposed a Sea-Cloud Collaborative secure mobile communication architecture and developed a Sea-Cloud Collaborative secure mobile communication system that comprehensively enhances mobile communication protection capabilities for terminals, communication networks, applications, and the cloud. The system provides secure communication functions for sensitive information and personal privacy, with the Guangdong Provincial Government currently funding a ten-thousand-unit scale application demonstration.

In the field of Sea-Cloud Collaborative big data analysis, media deep understanding technology based on Sea-Cloud Collaboration dynamically migrates computing between sea end and cloud, reducing cloud computing load by at least 30% and decreasing data transmission between different data landing points by more than three orders of magnitude. The Sea-Cloud Collaborative audio-video fusion solution achieves over 99% precision in discovering known audio-video clips of interest at 3,000× real-time speed, and over 90% precision with no less than 80% recall for unknown clips at over 100× real-time speed—doubling precision and quadrupling speed compared to existing solutions, positioning it to become the next-generation national information content security audio-video technology solution.

3. Originality

Addressing the four major challenges facing information technology development —security, energy consumption, transmission, and processing—the program pioneered the concept of utilizing distributed computing capabilities at client sides to provide personalized, on-site sea services. It constructed a new generation information service system through the Sea-Cloud Collaboration model. "Sea-Network-Cloud Collaboration" builds a new computing structure by aggregating edge and terminal resources, forming a two-stage three-body distributed computing system with cloud computing that effectively reduces network transmission load and improves the efficacy and security effectiveness of ternary fusion information processing. Theoretical calculations show that the Sea-Cloud Collaborative Information System can improve overall ternary fusion information processing efficacy by one order of magnitude compared to traditional "end-pipe-cloud" computing models.

4. Significance of the Program for Industry

As industry informatization deepens, the situation where key technologies and products are controlled by others becomes more severe—an unavoidable challenge for China' s information construction. Without autonomous control, there can be no security. Grounded in national needs, the Information Technology Priority Program has conducted bold innovation and exploration at the core chip, network equipment, and system application levels. Related achievements have

been widely applied with remarkable results, with some already entering commercial operation, providing positive support and impetus for the development of related industries and the autonomous, controllable, and secure development of China' s information construction.

5. Recommendations for Future Deployment

In terms of industrial promotion, we recommend increasing support for autonomous controllable complete machine integration or industrial ecosystems. The government should send positive market signals, comprehensively guarantee autonomous technology equipment in party, government, and military markets, enhance market confidence among software and hardware enterprises, cultivate user trust and usage habits in autonomous technology equipment, and fully leverage China' s market advantages to form a virtuous development mechanism where enterprises and markets mutually reinforce each other.

In information technology talent cultivation, we should break traditional employment models and rigid constraints according to field and industry characteristics and needs, innovate talent evaluation mechanisms, use actual academic and research capabilities as measurement criteria, and gather talents worldwide for utilization.

6. Summary

The Information Technology Priority Program has conducted extensive innovation and application in chips, future networks, intelligent manufacturing, cybersecurity, and other fields. Related achievements have been demonstrated in key national industries, regions, and fields with remarkable results. Looking forward, the program will persist in innovation, address national strategic needs, and based on Phase I research achievements and collaborative teams, conduct in-depth research and overcome difficulties to provide scientific and technological support for China' s cyber power strategy. We recommend accelerating the demonstration and launch of Phase II based on the solid foundation of Phase I implementation.

Centered on the development trend of human-cyber-physical ternary fusion in information technology, the program effectively addresses the four major challenges of "security, energy consumption, transmission, and processing." Based on the Sea-Cloud Collaboration innovation concept, it achieves original and leapfrog innovation in core devices, basic software, computing systems, future networks, and security architecture, creating and developing a new generation information technology system for "Sensing China." The program has achieved a batch of internationally leading original technical results, conducted application demonstrations in key national regions and fields, and provided strong support for the autonomous, controllable, and secure development of the information industry and deep integration of informatization and industrialization.

Yin Hao, Academician of the Chinese Academy of Sciences. He has long been engaged in research on communication network and information system theories, methods, and technologies, undertaking multiple major national scientific research and engineering projects. He has received one first prize and two second prizes of the National Science and Technology Progress Award, six first prizes and five second prizes of the Military Science and Technology Progress Award. He is a national-level candidate of the "Hundred, Thousand, and Ten Thousand Talents Project" in the new century, enjoys special government allowances, and has received the Outstanding Scientific and Technical Talent Award of the entire military. In October 2011, then Chairman of the Central Military Commission Hu Jintao signed an order to award first-class merit to four individuals, including Yin Hao, for their outstanding contributions in scientific research.

Note: Figure translations are in progress. See original paper for figures.