SCIENCE CHINA
Information Sciences

• REVIEW •
From CAS & CAE Members

December 2022, Vol. 65 221301:1–221301:13
https://doi.org/10.1007/s11432-022-3577-8

A systematic review for smart identifier networking

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Received 3 July 2022/Revised 23 August 2022/Accepted 30 August 2022/Published online 17 November 2022

Abstract The current Internet has revealed numerous shortcomings due to the limitations in its original design, and is being challenged by the user's increasingly complicated requirements for efficient data distribution. To this end, a novel network paradigm namely SINET (smart identifier networking) is proposed, aiming to shift the communication pattern of the traditional IP networks from passive best-effort packet delivery to the active on-demand adaptation of network and service resources. In this way, SINET is able to provide agile, differentiated and customizable traffic steering and performance enhancement for customers of different scenarios with various service quality guaranteed. In this paper, we are going to summarize the main design principles and associated key mechanisms of SINET, and briefly introduce its research outcomes in several typical application scenes.

Keywords identifier networking, smart collaborative networking, smart integration identifier networking, smart identifier networking, the next-generation networking

Citation Zhang H K, Feng B H, Tian A L T. A systematic review for smart identifier networking. Sci China Inf Sci, 2022, 65(12): 221301, https://doi.org/10.1007/s11432-022-3577-8

1 Introduction

The primitive design of the current Internet is now being challenged by the increasingly complicated communication requirements from various types of users, resulting in many serious drawbacks in traffic steering and service provision for the sake of unsatisfactory network flexibility, scalability, controllability, and smartness. Therefore, how to design clean-slate information networks has gained unprecedented attraction in the past decades, and plentiful major research programs have been launched around the world. For example, US-NSF (National Science Foundation) started GENI (global environment for network investigations)[1] and NeTS (networking technology and systems)[2] as early as 2005 and 2008 respectively, aiming to build a global network innovation platform and seek new paradigms and mechanisms for the future networks. Since then, a series of projects such as FIA (future Internet architecture)[3], ICE-T (US-EU Internet core & edge technologies)[4], RINGS (resilient & intelligent NextG systems)[5], and IMR (Internet measurement research: methodologies, tools, and infrastructure)[6] have been launched to accelerate the rapid developments of network innovations and practice. On the other hand, the EU initiated the FIRE project (future Internet research & experimentation) through the FP7 program in 2007 [1] to construct and validate the new Internet architectures and associated key applications. Hereafter, a number of projects have also been funded through the LEIT-ICT-Future Internet plan of the EU H2020 program, where many cutting-edge technologies such as 5G[7], cloud computing[8], and satellite communication technologies[9] are explored and studied intensively and comprehensively.

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1) GENI. https://www.nsf.gov/pubs/2006/nsf06601/nsf06601.htm.
2) NeTS. https://www.nsf.gov/pubs/2008/nsf08524/nsf08524.htm#pgm_intr_txt.
3) FIA. https://www.nsf.gov/pubs/2010/nsf10528/nsf10528.htm.
4) ICE-T. https://www.nsf.gov/pubs/2013/nsf13538/nsf13538.htm.
5) RINGS. https://www.nsf.gov/pubs/2021/nsf21581/nsf21581.htm.
6) IMR. https://https://www.nsf.gov/pubs/2022/nsf22519/nsf22519.htm.
7) Advanced 5G network infrastructure for the future Internet. https://cordis.europa.eu/programme/id/H2020_ICT-14-2014.
8) Cloud computing. https://cordis.europa.eu/programme/id/H2020_ICT-06-2016.
9) Satellite communication technologies. https://cordis.europa.eu/programme/id/H2020_SPACE-29-TEC-2020.

Therefore, studies on the next-generation information networks have been greatly promoted in recent years due to the strong support from governments and the urgent needs driven by the industry. As a result, many advanced concepts, paradigms, and technologies continuously emerged including LISN (loc/ID split networking) [2], SDN (software-defined networking) [3], IBN (intent-based networking) [4][10)], NFV (network functions virtualization) [5, 6], and DTN (digital twin networking) [7]. Specifically, LISN separates the dual roles of IP addresses and introduces a mapping mechanism to dynamically maintain their bindings for the support of user mobility management and alleviation of routing scalability in backbone networks. SDN decouples the control and forwarding plane of legacy routers and achieves flexible flow steering via the logically centralized controller for QoS (quality of service) assurance of various applications. Moreover, IBN translates and facilitates consistent configurations of business intents across the networks automatically, and ensures satisfaction of the desired intents by monitoring and adjusting network performance via the AI (artificial intelligence) techniques. NFV leverages virtualization technology to decouple network functions from their proprietary hardware, and orchestrates network services on demand based on virtual functions to improve resource utilization and user experience. In addition, DTN creates virtual twins of physical network entities and realizes co-evolution between these two spaces via necessary mappings, computing, and communications, thereby prompting network efficiency and intelligence for better service provisions.

Our team has devoted ourselves to this research area for nearly 30 years and summarized that the essential causes for the serious problems of the current Internet lie in its inherent characteristics of triple bindings in the architectural design, where user and network addressing space, resources and their serving locations, and the control and data plane of network components such as forwarding devices and service functions are tightly coupled with weak agility, elasticity, manageability and programmability. To this end, SINET (smart identifier networking), a novel network paradigm and its associated mechanism are proposed to shift the communication pattern of the traditional IP networks from passive best-effort packet delivery to the active on-demand adaptation of network and service resources, where the above bindings are simultaneously decoupled and new advanced techniques such as data analytics and machine learning are introduced for better decision making. In this way, SINET is able to provide efficient, differentiated and customizable traffic steering and performance enhancement for diversified application scenarios. In the following, we are going to present the primary design principles and key mechanism of SINET in line with its three phases of evolutionary routes, and then, briefly demonstrate its research outcomes in several typical scenes including high-speed rail networks, industrial Internet, satellite networks and IoT (Internet of Things) networks. Finally, the conclusion is given.

2 The evolution of smart identifier networking

In this section, we will present the evolutions of SINET in detail, which has three phases including the IDN (identifier networking), SCN (smart collaborative networking), and SI^2NET (smart integration identifier networking).

2.1 The identifier networking

The IDN is the initial shape of the SINET and its architectural design is depicted in Figure 1 [8]. Specifically, the IDN consists of two logical layers called NCL (network communication level) and PSL (pervasive service level), and they are further divided into the four sub-layers responsible for access control, data routing, connection management, and service advertisements, respectively. In the NCL, an AID (access identifier) is leveraged to denote the user identity while the RID (routing identifier) is used to represent the network location and routing locators for packet forwarding. Besides, the AID-RID mapping mechanism is introduced to dynamically manage their matching relationships. In this way, the user and network addressing space is decoupled in addition to the dual roles of IP addresses, which greatly improves routing stability and scalability of the backbone and facilitates mobility support for moving terminals and subnets.

On the other hand, to enable efficient endpoint multi-path delivery and QoS guarantee, PSL introduces SID (service identifier) and CID (connection identifier) to uniquely denote a specific service and its established connections with customers, where SID-AID-CID(s) mappings are used to dynamically

10) Cisco intent-based networking (IBN). https://www.cisco.com/c/en/us/solutions/intent-based-networking.html.

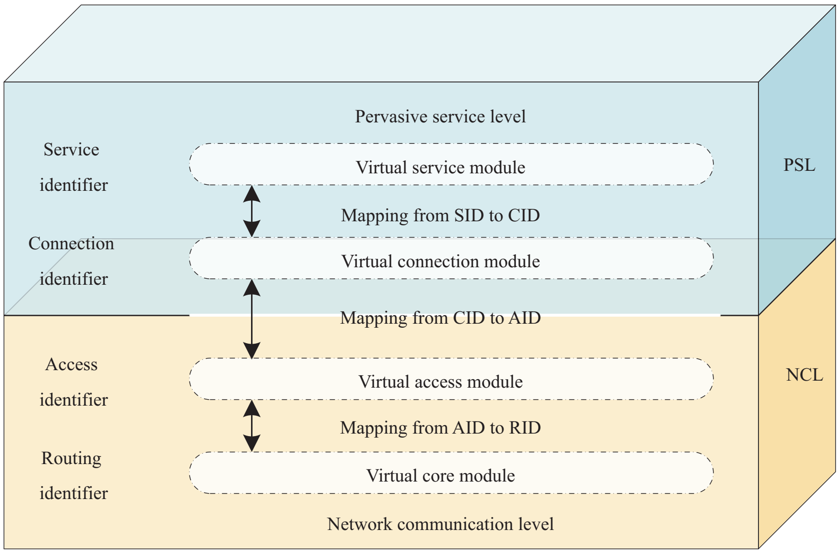

Figure 1 (Color online) The architecture design of the IDN [2, 8].

bind one or more logical data transmission channels between them. Consequently, data publishers and subscribers are able to negotiate their policies for utilization of these multiple forwarding paths, where load balancing or other preferences can be performed based on the types of flows with the purpose of better user experience and transmission efficiency.

The general working procedures of the IDN are described below. The user first issues the service descriptor to the resolution system, in order to acquire the corresponding SID and associated AID of the hosted server. Then, it delivers the request to the target node for connection establishment according to their communication requirements, and the latter in the access network will return the desired data to the subscriber via single or multiple paths based on the AID pairs indicated by each CID. Afterwards, when the access-backbone border routers receive such packets, they have to rewrite the pairs of AIDs in headers with the correct RIDs through the AID-RID mapping system, and continue to forward them across the backbone based on the destination RIDs. When the related access-backbone routers on the other side obtain these packets, they must replace the pair of RIDs with the original AIDs by means of the mapping system, and route them to the user in the access network according to the destination AIDs.

2.2 The smart collaborative networking

To improve network controllability, resource utilization and adaptation smartness, SCN [9, 10] is proposed following the IDN with a new adaptation layer added for collaborations of both service and network resources, and its architectural design is shown in Figure 2. In particular, the SCN has three logical layers called SSL (smart service layer), RAL (resource adaptation layer), and NCL (network component layer), and they are further divided by the two functional domains namely ED (entity domain) and BD (behavior domain). The ED uses SID, FID (family identifier) and NID (node identifier) to denote the identity of different services, families and components in SCN, providing a foundation to decouple the triple bindings mentioned above. Besides, the BD introduces SBD (service behavior description), FBD (family behavior description) and NBD (node behavior description) for fine-grained attribute recognition and state awareness of various resources belonging to the three layers identified by SID, FID, and NID separately.

The three layers are integrated through the associated resolution mapping mechanism, where the service requirement is firstly adapted to a network family that can satisfy the user needs based on the SBD and FBD matching in the BD. In this way, the SID can be mapped to an appropriate FID in the ED. Then, the selected network family will be deployed at the suitable physical components based on the FBD and NBD matching, and the FID will be bounded to a group of NIDs of components which need to orderly execute the required specific functions in terms of packet routing/forwarding and data processing, forming a dedicated path for the requested service with QoS guarantee.

Hence, the general working procedures of SCN are as follows. First, a provider needs to register its offered services to the mapping system identified by the related SID and SBD. Then, when a user request

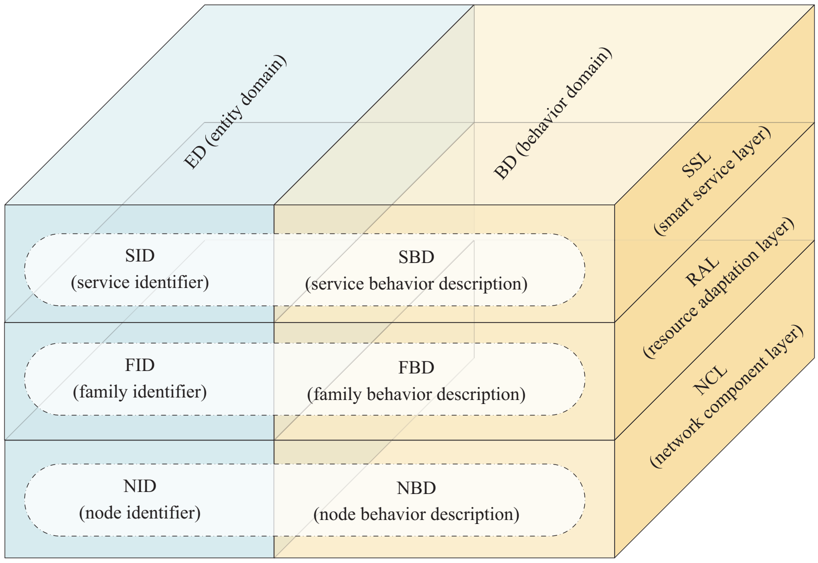

Figure 2 (Color online) The architecture design of the SCN [9].

arrives, the mapping system will extract the SID to look up the corresponding SBD of the requested service. Afterwards, it needs to match the SBD with the appropriate FBD and NBD for the effective mappings of SID-FID-NIDs, and finally distribute the necessary service policies and routes/forwarding rules to the involved entities. Consequently, SCN is able to achieve smart service provision through the dynamic awareness and on-demand adaptations of available resources in different layers, thereby significantly prompting system utilization, operation efficiency, and user experience.

2.3 The smart integration identifier networking

In order to efficiently integrate various types of networks and make full use of their rich resources, SI^{2}NET is further proposed [11] and its framework is shown in Figure 3. Specifically, it firstly partitions the current Internet into two spaces namely SS (service space) and NS (network space), and then, introduces the KS (knowledge space) as the central hub of horizontal resolution and vertical adaptation between them, so that different levels of resources can be coordinated and scheduled uniformly.

Besides, the SS and NS are further divided into the CP (control plane) consisted of SCOs (service control objects) and NCOs (network control objects), and the OP (operation plane) composed of SOOs (service operation objects) and NOOs (network operation objects). The CP objects of the SS and NS are leveraged to monitor and control the OP objects, and deliver necessary service policies and configuration instructions to the latter. Meanwhile, the OP objects need to perform specified actions to the receiving packets according to the assigned policies and instructions such as data forwarding, content caching, and header/payload inspections. Note that SOOs and NOOs include not only physical objects such as servers, routers, and switches, but also any virtual objects running on containers or virtual machines that are able to perform dedicated service and network functions. On the other hand, the KS is made by a logically-centralized NKD (network knowledge database) and an IA&NSO (intent analysis & network service orchestrator). They are used to realize unified identification, attribute recognition and state awareness of different resources in SI^{2}NET, and analyze the intent of user requests for orchestrations of specific services that meet their demands to the underlying networks with the help of optimization methods, data analytics techniques, and machine learning approaches.

Therefore, the general working procedures of SI^{2}NET are as below. When receiving user requests, the IA&NSO firstly determines which types of network services can satisfy their requirements. After that, it will query the NKD to obtain the identifiers, attributes and running status of the involved CP and OP objects, and schedule a specific network service for these users via the horizontal resolution mechanism. Then, the IA&NSO will generate associated configurations and instructions via the CP objects to deploy the required network services based on the vertical adaptation mechanism. Finally, the user flow is redirected to the entry of the network service for data forwarding and processing. In addition, the NKD in the KS needs to collect state information of all resources in the CP and OP via triggered and periodic

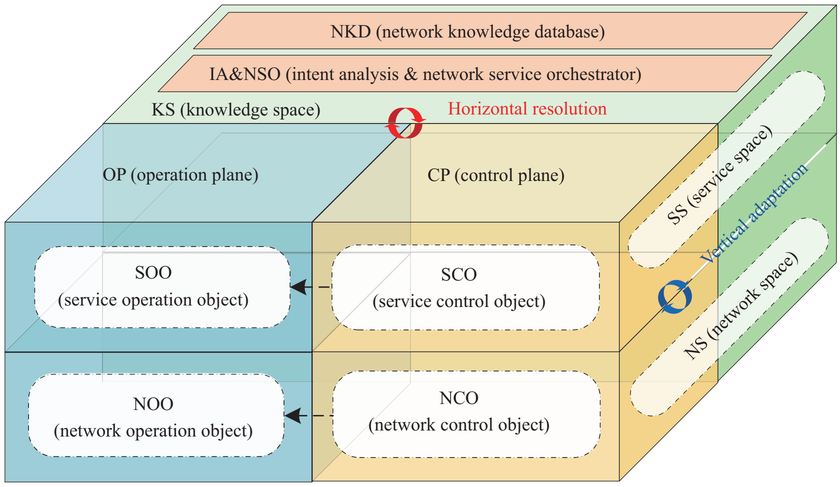

Figure 3 (Color online) The architecture design of SI^{2}NET.

interaction means, providing the basis for IA&NSO to perform better decision making.

In addition, SINET can be deployed in an incremental way where most of the legacy devices are still used without any upgrades. For example, to support deployment of IDN, only ingress and egress nodes of a network are required to add several new functionalities such as mapping management and packet encapsulations/de-encapsulations, along with a distributed mapping system introduced separately at the control plane. As for the SCN and SI^{2}NET, it can directly work over the SDN/NFV-enabled networks but need to add a few new control and management entities, which are in charge of traffic steering and service provision based on machine-learning algorithms and multi-domain collaboration mechanism [12].

3 The applications of smart identifier networking

In this section, we will demonstrate representative research outcomes of SINET in several typical application scenes including high-speed rail networks, industrial Internet, satellite networks, and IoT networks.

3.1 High-speed rail networks

The high-speed movements of trains result in frequent handovers to their accessing networks, and how to fully perceive effective link states and formulate mobile switching strategies is crucial for their reliable communication and data transmission. Due to its advantages in mobility support and flexible collaboration of multi-dimensional resources, SINET can offer a unified framework for high-speed railway networks to achieve secure user access and customized traffic delivery.

Specifically, a SINET-based vehicle cloud computing paradigm namely SVCC-HSR is proposed in [13], aiming to address the security and transmission issues in high-speed railway networks. As depicted in Figure 4, SVCC-HSR has three layers, namely the C-HSR, C-Edge and C-Remote. The C-HSR is required to perform status collection and data analysis while C-Remote needs to cope with the authentication for access devices, management of identifier binding relationship, and centralized data storage and computing management. Besides, C-Edge is served as proxies for the C-Remote/C-Edge to process data locally for better operation efficiency. SVCC-HSR also enables fast handoff authentication, hierarchical data encryption, group compression and multi-path transmission with associated mechanism, and the purpose is to remarkably improve the throughput of large-volume data delivery with necessary confidentiality.

As for the performance optimization, many schemes and algorithms have been raised to achieve efficient authentication, reliable transmission, and multi-path traffic steering in high-speed railway networks [14–16]. For example, in [14], a prediction approach for link quality is proposed based on the collected real-world dataset of high-speed railway networks, where the observed two-time-scale variation characteristics of link states are used for assurance of reliable data transmissions. In [15], a multi-path cooperative transmission algorithm is proposed to aggregate available bandwidth of both homogeneous and heterogeneous access networks. Moreover, in [16], an efficient network selection scheme is proposed

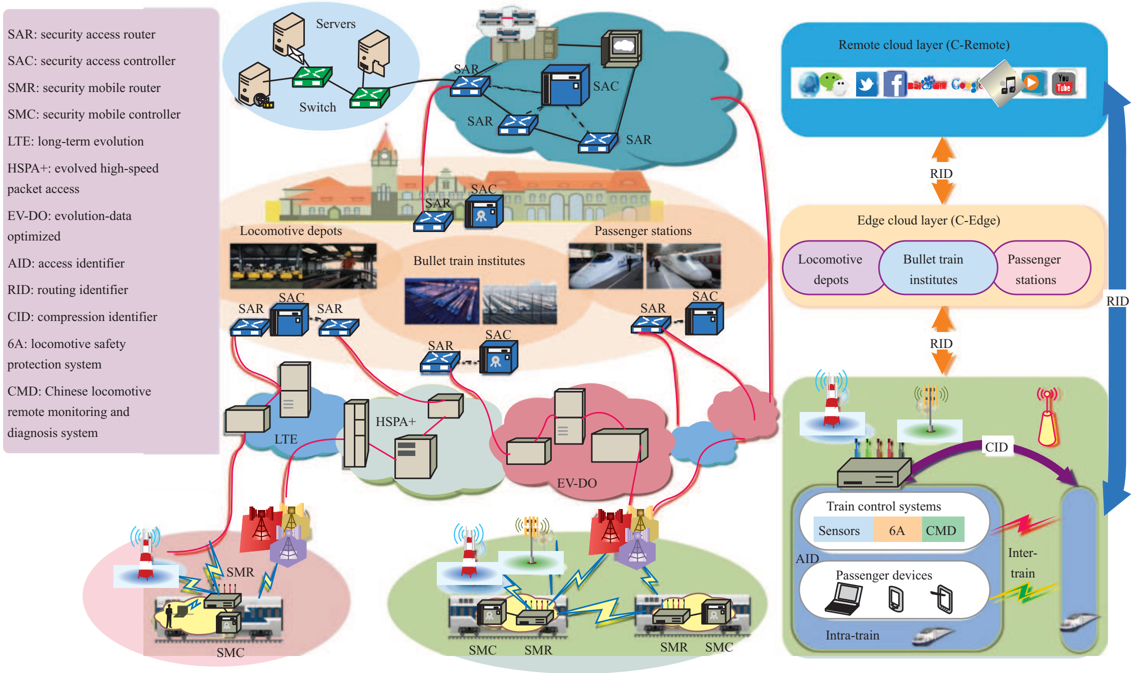

Figure 4 (Color online) The cloud-based computing paradigm for smart high-speed railway networks [13].

for high-speed railway networks where fuzzy logic is leveraged to cope with uncertainty of link quality of wireless networks and the utility functions are used to select the best candidate for QoS guarantee.

3.2 Industrial Internet

Industrial Internet has strict requirements in terms of latency, jitter, packet loss and transmission rate, and it is important to coordinate spectrum and computing resources of each device to maximize system utilization. SINET is able to efficiently support unified control and management for limited network resources of the industrial Internet due to its decoupling of the triple bindings, which greatly facilitates flow delivery with different communication demands.

With respect to the network framework, a three-tier orchestration system is proposed in [17] to efficiently collaborate multi-dimensional resources for the industrial Internet. As shown in Figure 5, the cloud tier provides powerful computation and storage capacity to train different neural network models for support of various smart services. The edge tier dynamically collects the network state and executes complicated tasks by the cooperation of local nodes. The end tier collects data generated by heterogeneous industrial IoT devices in real time, and connects to the Internet through industrial gateways. In addition, a dynamic resource adaptation method is raised to improve efficiency of resource management.

Besides, industrial Internet focuses more on the QoS guarantee to comprehensively prompt system utilization and ensure strict industrial indicators including security, latency and packet loss [18–22]. For instance, the authors in [18] proposed a dedicated data-link implementation for multi-hop industrial deterministic applications, where centralized control and TDMA (time division multiple address) mechanism are leveraged to provide strict real-time and high reliability for end-to-end data transmission by means of the IEEE 802.11 protocol. A load balancing algorithm is also proposed in [19] using the game theory method for real-time control systems based on WLAN (wireless local area networks). On the other hand, to address the security issues in the industrial Internet, a multi-agent resource dynamic adaptation algorithm is proposed in [20] to improve training efficiency and privacy protections in nodes. In [21], an emergency-triggered priority access control mechanism is proposed to ensure real-time transmission of emergency information via the synchronous wired polling and wireless time-slotted TDMA techniques. Moreover, a self-attention based deep learning service model is proposed in [22] to effectively support real-time and smart data analysis and provide decision making and failure prediction services for reliable and safe operation of industrial systems.

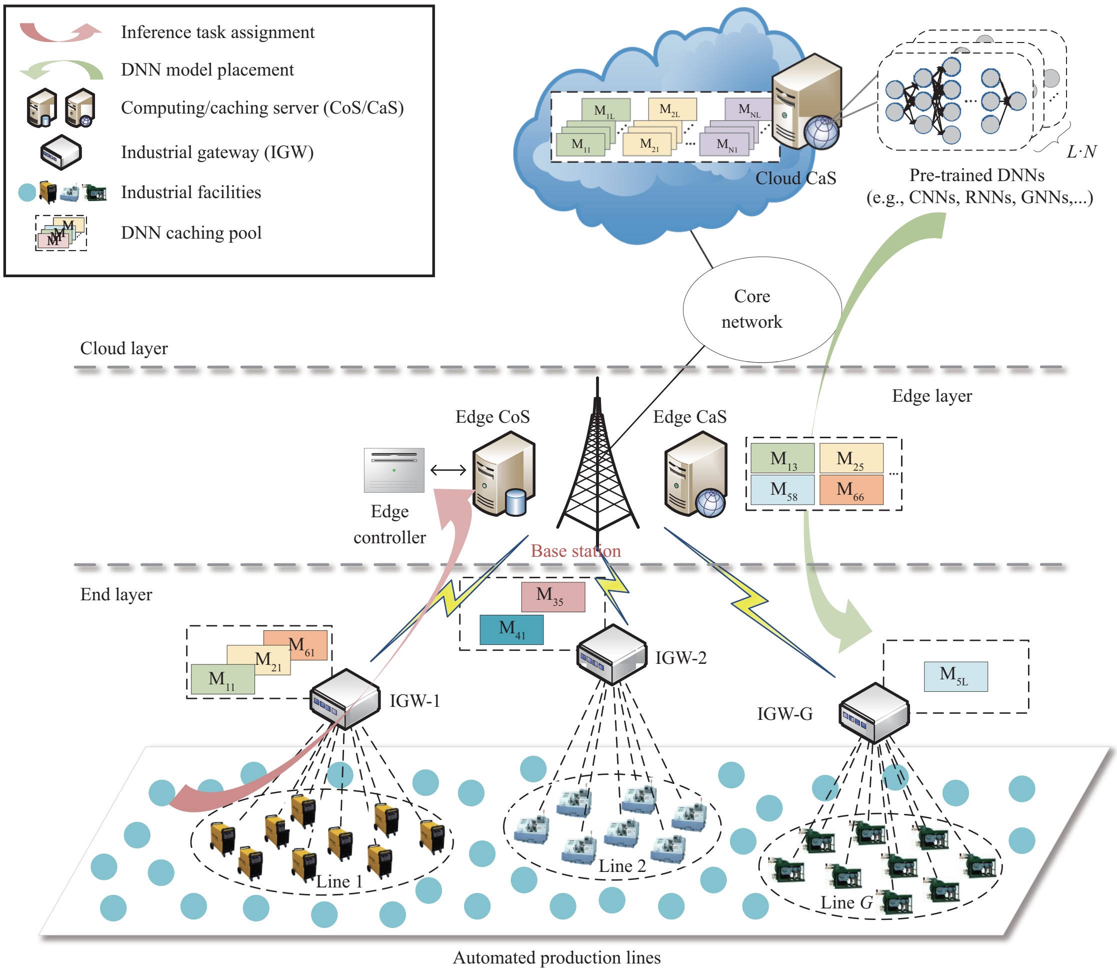

Figure 5 (Color online) The three-tier orchestration system for the industrial Internet [17].

3.3 Satellite networks

The satellite-ground integrated networks have been considered as a crucial direction of the future Internet, but it is still facing many challenges particularly in heterogeneous network convergence and efficient differentiate routing. The SINET is able to achieve better network integration and traffic steering for the sake of its architectural flexibility and system controllability.

Specifically, an elastic framework to integrate satellite and terrestrial networks is proposed in [23, 24], where the identity and location of both networks and terminals are decoupled for better support of user mobility management, routing scalability alleviation and heterogeneous network convergence. Figure 6 shows an illustration of the corresponding communication process. Suppose that EP1 has obtained the SID of the desired content along with the related EID of the EP2 via the resolution system. Then, it will send a request to the EP2 based on the user identity. Afterwards, the ARs and BRs will encapsulate the packets with appropriate local locators with the help of the hierarchical Loc-ID mapping system when entering a new network domain till the destination node. The purpose behind is to separate the inter- and intra-domain routing into the control and data plane, respectively, so that the heterogeneity of different types of networks can be hidden to the outside without the need to perform complex protocol translation. Moreover, each network domain is able to apply its suitable routing protocol based on its characteristics, which greatly facilitates the heterogeneous satellite network to integrate with the terrestrial networks. Note that each satellite is required to cache necessary mapping entries locally for addressing of accessing endpoints and neighbor networks based on the tailored and optimized mobility management schemes [25], in order to sharply reduce their interactions with the ground mapping system. Furthermore, to achieve efficient customizable data forwarding in space, a flexible differentiated routing architecture displayed in Figure 7 is proposed in [26], which synthesizes the topology snapshot and centralized routing for building

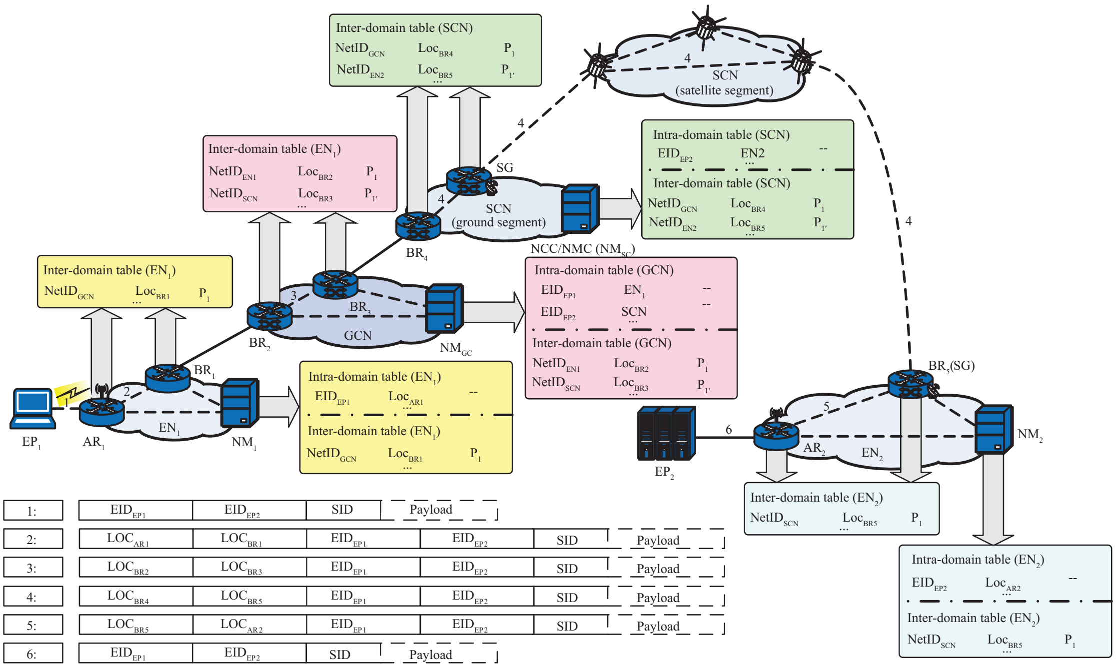

Figure 6 (Color online) The communication process in SINET-SGIN [23].

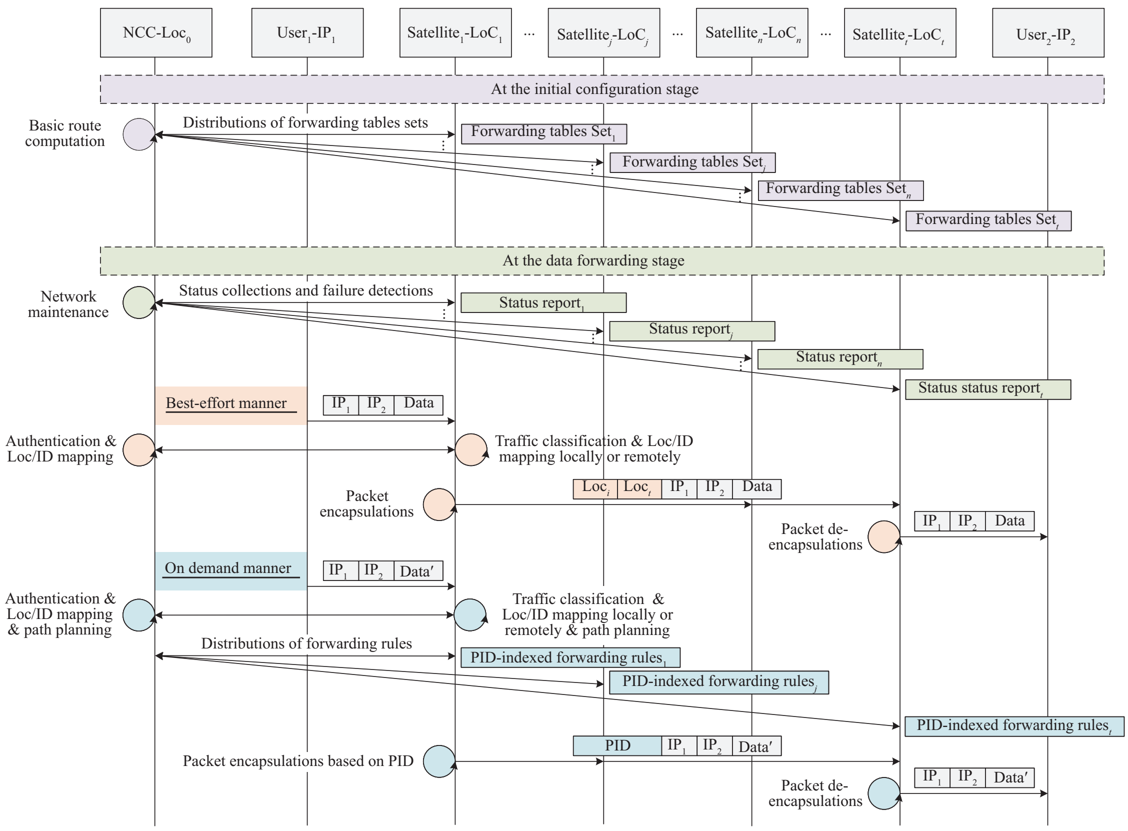

Figure 7 (Color online) A schematic diagram of the hybrid data forwarding schemes in SINET-SGIN [26].

a robust signaling control channel between the satellites and terrestrial control center, in addition to a hybrid forwarding approach for support of both best-effort and on-demand data delivery to meet user diverse communication requirements with the limited and time-varying transmission resources.

Besides, due to the high-dynamic characteristics and limited on-board processing capacity of the satellite networks, how to optimize topology planning, routing efficiency, and performance enhancement has been widely discussed [27–31]. For example, an efficient link allocation algorithm for multi-layer satellite networks is proposed in [27] to remarkably simplify the topology dynamics, and another solution in [28] considers queue length, traffic volume and the number of connected nodes of the high-layer relay nodes for efficient inter-layer link allocations, aiming to sharply reduce the link switching and avoid unnecessary congestions. Besides, a QoS-oriented satellite routing algorithm is proposed in [29] to allocate link bandwidth based on user priorities, and a group-based network recovery scheme is proposed in [30] where the remaining key challenges are also discussed in detail. On the other hand, an SFC (service function chaining) deployment framework and associated mapping algorithm are proposed in [31], where virtualized value-added services such as traffic analysis and data caching are deployed at the terrestrial segment of satellite networks nearby users, in order for improvements of system utility and quality of experience.

3.4 IoT networks

The access of massive heterogeneous IoT devices enables various new Internet applications, however, it also brings a number of technical challenges in terms of access control, resource allocation, performance enhancement, and attack detection. In fact, SINET is able to offer identity-based entity management and efficient task scheduling, which greatly prompts cybersecurity and QoS guarantee of IoT networks.

In particular, a fine-grained authentication framework is proposed in [32], with the purpose of efficient access control for different types of IoT devices with better network security. To evaluate computation offloading policies for IoT devices in SINET, a multi-queue-based theoretical model is proposed in [33] to derive the analytic solutions of related task average response latency and energy consumption. Besides, an efficient cache consistency management approach is proposed in [34] to eliminate outdated IoT data buffered by distributed in-network storage without heavy signaling costs introduced. A collaborative caching approach based on the deep reinforcement learning is also proposed in [35] to improve hit ratio of edge networks accessed by IoT devices, where edge servers make caching decisions locally and update the related parameters to the central node for the subsequent optimizations from the global view. Moreover, a federated DRL-based cooperative caching approach is proposed in [36], which aims to further improve edge caching efficiency with lower computation complexity and communication costs for model training and parameter exchanges, through the well-designed small state and action space of the proposed algorithm. To deal with the packet disordering and retransmission problems in IoT networks, a multipath forwarding mechanism is proposed in [37] to improve the throughput and reliability of data distribution via adaptive adjustment of flow scheduling policies based on awareness of network congestions. In [38], an IoT cooperative paradigm is raised to offer fault diagnosis and forecast for high-speed moving vehicles which efficiently integrates energy harvesting and AI to lower energy costs, volume of data exchanges, and processing time of involved sensors. In [39], an RL-based (reinforcement learning) SFC deployment algorithm is proposed for suitable decomposition of involved network functions to related overlay networks, with the purpose of better resource utilization and user experience. To maximize the utilization of system resources, an adaptive deep Q-learning based SFC mapping approach is proposed in [40], where two simple heuristic algorithms are provided as candidate actions to alleviate the computation complexity of model training. Additionally, to strengthen network security at edges for resource-limited IoT devices, an efficient framework to integrate SFC with ML (machine learning) is proposed in [41], in addition to a CNN-based (convolutional neural networks) anomaly traffic detection algorithm that can recognize attack flows quickly with high accuracy. In [42], a P4-based network immune scheme is proposed to resist eavesdropping attacks for IoT devices, where packet load and headers are encrypted separately and are sent via multiple paths in a disordered manner.

In summary, SINET offers a novel and fundamental network paradigm that decouples the triple bindings of the current Internet, which significantly improves its agility, scalability, and intelligence to name, control, and coordinate available resources uniformly and efficiently. In this way, SINET can construct different types of network services on demand according to the application scenarios, addressing their urgent communication needs in data delivery and content distribution.

4 Conclusion

This paper first briefly summarizes the development trend of the current information networks, and then introduces the design principles and associated key mechanism of SINET in line with its three phases of the evolutionary routes namely IDN, SCN, and SI^2NET. Finally, the typical application scenarios of the SINET are illustrated in detail including the high-speed railway networks, industrial Internet, satellite networks, and IoT networks. SINET can effectively overcome the serious drawbacks of the Internet due to its decoupling of triple bindings, and is able to provide fine-grained and customizable communication services for various types of users on demand for the sake of its inherent network flexibility, controllability and smartness, offering a novel and potential solution for the technical progress of the future networks.

Acknowledgements This work was supported in part by National Key Research and Development Program of China (Grant No. 2019YFB1802503) and Fundamental Research Funds for the Central Universities (Grant Nos. 2021PT202, 2020JBM013).

References

1 Tselentis G, Domingue J, Galis A, et al. Towards the Future Internet: A European Research Perspective. Amsterdam: IOS Press, 2009
2 Feng B, Zhang H, Zhou H, et al. Locator/identifier split networking: a promising future Internet architecture. IEEE Commun Surv Tut, 2017, 19: 2927–2948
3 Khorsandroo S, Sánchez A G, Tosun A S, et al. Hybrid SDN evolution: a comprehensive survey of the state-of-the-art. Comput Networks, 2021, 192: 107981
4 Li G, Xu G, Sangaiah A K, et al. EdgeLaaS: edge learning as a service for knowledge-centric connected healthcare. IEEE Network, 2019, 33: 37–43
5 Schardong F, Nunes I, Schaeffer-Filho A. NFV resource allocation: a systematic review and taxonomy of VNF forwarding graph embedding. Comput Networks, 2021, 185: 107726
6 Wang X, Xing H, Zhan D, et al. A two-stage approach for multicast-oriented virtual network function placement. Appl Soft Computing, 2021, 112: 107798
7 Wu Y, Zhang K, Zhang Y. Digital twin networks: a survey. IEEE Internet Things J, 2021, 8: 13789–13804
8 Zhang H, Su W. Fundamental research on the architecture of new network—universal network and pervasive services (in Chinese). Acta Electron Sin, 2007, 35: 593–598
9 Zhang H, Luo H. Fundamental research on theories of smart and cooperative networks (in Chinese). Acta Electron Sin, 2013, 41: 1249–1254
10 Zhang H, Quan W, Chao H C, et al. Smart identifier network: a collaborative architecture for the future Internet. IEEE Network, 2016, 30: 46–51
11 Zhang H, Feng B, Quan W. Fundamental research on smart integration identifier networking (in Chinese). Acta Electron Sin, 2019, 47: 977–982
12 Li G, Zhou H, Feng B, et al. Context-aware service function chaining and its cost-effective orchestration in multi-domain networks. IEEE Access, 2018, 6: 34976–34991
13 Dong P, Zheng T, Du X, et al. SVCC-HSR: providing secure vehicular cloud computing for intelligent high-speed rail. IEEE Network, 2018, 32: 64–71
14 Zhang H, Quan W, Song J, et al. Link state prediction-based reliable transmission for high-speed railway networks. IEEE Trans Veh Technol, 2016, 65: 9617–9629
15 Zhang Y, Dong P, Yu S, et al. An adaptive multipath algorithm to overcome the unpredictability of heterogeneous wireless networks for high-speed railway. IEEE Trans Veh Technol, 2018, 67: 11332–11344
16 Yan X, Dong P, Zheng T, et al. Fuzzy multi-attribute utility based network selection approach for high-speed railway scenario. In: Proceedings of IEEE Global Communications Conference (GLOBECOM), 2017. 1–6
17 Zhang W, Yang D, Peng H X, et al. Deep reinforcement learning based resource management for DNN inference in industrial IoT. IEEE Trans Veh Technol, 2021, 70: 7605–7618
18 Cheng Y, Yang D, Zhou H. Det-WiFi: a multihop TDMA MAC implementation for industrial deterministic applications based on commodity 802.11 hardware. In: Proceedings of Wireless Communications and Mobile Computing, 2017
19 Cheng Y, Yang D, Zhou H. Det-LB: a load balancing approach in 802.11 wireless networks for industrial soft real-time applications. IEEE Access, 2018, 6: 32054–32063
20 Zhang W, Yang D, Wu W, et al. Optimizing federated learning in distributed industrial IoT: a multi-agent approach. IEEE J Sel Areas Commun, 2021, 39: 3688–3703
21 Yang D, Ma J, Xu Y, et al. Safe-WirelessHART: a novel framework enabling safety-critical applications over industrial WSNs. IEEE Trans Ind Inf, 2018, 14: 3513–3523
22 Zhang W, Yang D, Xu Y, et al. DeepHealth: a self-attention based method for instant intelligent predictive maintenance in industrial Internet of Things. IEEE Trans Ind Inf, 2020, 17: 5461–5473
23 Feng B, Zhou H, Zhang H, et al. HetNet: a flexible architecture for heterogeneous satellite-terrestrial networks. IEEE Network, 2017, 31: 86–92
24 Feng B, Zhou H, Li G, et al. SAT-GRD: an ID/Loc split network architecture interconnecting satellite and ground networks. In: Proceedings of IEEE International Conference on Communications (ICC), 2016. 1–6
25 Feng B, Zhou H, Xu Q. Mobility support in named data networking: a survey. J Wireless Com Network, 2016, 2016: 220
26 Feng B, Huang Y, Tian A, et al. DR-SDSN: an elastic differentiated routing framework for software-defined satellite networks. IEEE Wireless Commun, 2022. doi: 10.1109/MWC.011.2100578
27 Huang Y, Feng B, Dong P, et al. A multi-objective based inter-layer link allocation scheme for MEO/LEO satellite networks. In: Proceedings of IEEE Wireless Communications and Networking Conference (WCNC), 2022. 1301–1306
28 Shi W, Gao D, Zhou H, et al. Traffic aware inter-layer contact selection for multi-layer satellite terrestrial network. In: Proceedings of IEEE Global Communications Conference (GLOBECOM), 2017. 1–7
29 Li T, Zhou H, Luo H, et al. SERvICE: a software defined framework for integrated space-terrestrial satellite communication. IEEE Trans Mobile Comput, 2018, 17: 703–716

30 Feng B, Cui Z, Huang Y, et al. Elastic resilience for software-defined satellite networking: challenges, solutions, and open issues. IT Prof, 2020, 22: 39–45
31 Feng B, Li G, Li G, et al. Enabling efficient service function chains at terrestrial-satellite hybrid cloud networks. IEEE Network, 2019, 33: 94–99
32 Ai Z, Liu Y, Chang L, et al. A smart collaborative authentication framework for multi-dimensional fine-grained control. IEEE Access, 2020, 8: 8101–8113
33 Zhang Y, Feng B, Quan W, et al. Theoretical analysis on edge computation offloading policies for IoT devices. IEEE Internet Things J, 2019, 6: 4228–4241
34 Feng B, Tian A, Yu S, et al. Efficient cache consistency management for transient IoT data in content-centric networking. IEEE Internet Things J, 2022, 9: 12931–12944
35 Zhang Y, Feng B, Quan W, et al. Cooperative edge caching: a multi-agent deep learning based approach. IEEE Access, 2020, 8: 133212–133224
36 Tian A, Feng B, Zhou H, et al. Efficient federated DRL-based cooperative caching for mobile edge networks. IEEE Trans Netw Serv Manage, 2022. doi: 10.1109/TNSM.2022.3198074
37 Shi J, Quan W, Gao D, et al. Flowlet-based stateful multipath forwarding in heterogeneous Internet of Things. IEEE Access, 2020, 8: 74875–74886
38 Yang D, Cui E, Wang H, et al. EH-Edge—an energy harvesting-driven edge IoT platform for online failure prediction of rail transit vehicles: a case study of a cloud, edge, and end device collaborative computing paradigm. IEEE Veh Technol Mag, 2021, 16: 95–103
39 Li G, Zhou H, Feng B, et al. Efficient provision of service function chains in overlay networks using reinforcement learning. IEEE Trans Cloud Comput, 2022, 10: 383–395
40 Li G, Feng B, Zhou H, et al. Adaptive service function chaining mappings in 5G using deep Q-learning. Comput Commun, 2020, 152: 305–315
41 Feng B, Zhou H, Li G, et al. Enabling machine learning with service function chaining for security enhancement at 5G edges. IEEE Network, 2021, 35: 196–201
42 Liu G, Quan W, Cheng N, et al. Softwarized IoT network immunity against eavesdropping with programmable data planes. IEEE Internet Things J, 2021, 8: 6578–6590

Profile of Hongke ZHANG

Prof. Hongke ZHANG received his M.S. and Ph.D. degrees in electrical and communication systems from the University of Electronic Science and Technology of China, Chengdu, China, in 1988 and 1992, respectively. He is currently a professor at the School of Electronic and Information Engineering, Beijing Jiaotong University, and the director of the National Engineering Research Center for Advanced Network Technologies (formerly known as the National Engineering Lab on Next Generation Internet Technologies). He is also with the Department of New Networks, Peng Cheng Laboratory, Shenzhen, China. Prof. Zhang is a fellow of IEEE for contributions to high-speed railway communications, and was elected as a member of the Chinese Academy of Engineering (CAE) in 2021. His team was named National Huang Danian-style Teacher Team in Institutions of Higher Learning by the Ministry of Education in 2018.

Prof. Zhang has devoted himself to the study of next-generation network technologies for nearly thirty years, and resulted in many research outputs in both academics and industry. He is the initiator and promoter of the SINET (smart identifier networking) technical system, a novel network paradigm that aims to address the serious drawbacks of the current Internet in mobility support, routing scalability, transmission efficiency, and QoS (quality of service) guarantee. Based on his years of research and practice in the field, Prof. Zhang has attributed the essential cause for the intractable problems of the Internet to its inherent characteristics of triple bindings in the original design, where addressing and routing are tightly coupled in TCP/IP networks for both end systems and service resources, in addition to the coupling of the control and data plane of network components when forwarding packets and processing data. To this end, he re-designed the network architecture from the perspective of naming space and functional partitioning, and proposed the associated multi-dimensional identifier-based parsing and mapping mechanism, in order to fully decouple the intrinsic multiple bindings aforementioned and further shift the communication pattern of the Internet from best-effort packet delivery to the on-demand adaptation of service provision and network resources, matching diversified user requirements for various applicable scenarios.

Prof. Zhang has also prompted the standardization process of SINET and directed its engineering applications in different industrial-specific networks such as the HSR (high-speed railway) networks and industrial Internet, enabling reliable and high-throughput data transmission services for their distinct communication demands. For instance, it is challenging to provide efficient data sharing services along HSR lines due to the unsatisfactory link quality and limited network resources. To solve this problem, Prof. Zhang proposed a SINET-based cooperative transmission mechanism that can leverage multiple available mobile telecommunication networks for bandwidth aggregation, and perform data delivery efficiently in a multipath way with necessary traffic scheduling and shaping, significantly improving the communication throughput of HSR. Correspondingly, the developed SINET-based routing devices and control systems have been applied to HSR trains and dedicated vehicles for high-bandwidth and emergency communications.

Prof. Zhang is the chief scientist of two National Basic Research Programs of China (973 Program), and has authored over a hundred publications as well as 6 monographs for SINET and IP network techniques. He has served on the editorial boards of several distinguished journals in the area of communication and computer networks such as IEEE Internet of Things Journal and IEEE Transactions on Network and Service Management, and as a chair or technical program committee member for many domestic and international conferences where he has also given a number of keynote speeches about research progress and outcomes of SINET. Besides, Prof. Zhang made outstanding contributions to 4 IEEE standards, 4 ISO/IEC standards, and 1 RFC on the basis of the SINET key techniques. He is the holder of more than 100 patents, where over 50 ones have been licensed or transferred to the industrial companies such as ZTE Corporation, a global leading integrated communication information solution provider, and China High-Speed Railway Technology Co., Ltd., which principally engage in the operation and maintenance of rail transit. Prof. Zhang has won two National Technology Invention Awards of China (2nd Grade) in 2014 and 2017 respectively, and 4 other provincial and ministerial-level science and technology awards for his impressive achievements in network communication technologies.

Selected publications

- Zhang H, Su W. Mobile Internet Technology. Beijing: Posts & Telecom Press, 2010.
- Zhang H, Su W, Quan W. Smart Collaborative Identifier Network: A Promising Design for Future Internet. Heidelberg: Springer, 2016.
- Zhang H, Wang H, Su W. Architecture and Key Technologies of Identifier Network. Beijing: Posts & Telecom Press, 2020.
- Zhang H, Su W. Fundamental research on the architecture of new network-universal network and pervasive services. Acta Electron Sin, 2007, 35: 593–598.
- Zhang H, Luo H. Fundamental research on theories of smart and cooperative networks. Acta Electron Sin, 2013, 41: 1249–1254.
- Zhang H, Dong P, Quan W, et al. Promoting efficient communications for high-speed railway using smart collaborative networking. IEEE Wireless Commun, 2015, 22: 92–97.

• Zhang H, Quan W, Chao H C, et al. Smart identifier network: a collaborative architecture for the future Internet. IEEE Network, 2016, 30: 46–51.

• Zhang H, Luo H, Chao H C. Dealing with mobility-caused outdated mappings in networks with identifier/locator separation. IEEE Trans Emerging Topics Comput, 2016, 4: 199–213.

• Zhang H, Quan W, Song J, et al. Link state prediction-based reliable transmission for high-speed railway networks. IEEE Trans Vehicular Tech, 2016, 65: 9617–9629.

• Zhang H, Dong P, Yu S, et al. A scalable and smart hierarchical wireless communication architecture based on network/user separation. IEEE Wireless Commun, 2017, 24: 18–24.

• Zhang H, Cheng Y, Yang D, et al. State of the art of industrial network technologies: a review and outlook. Chin J Internet Things, 2017, 1: 13–20.

• Zhang H, Feng B, Quan W. Fundamental research on smart integration identifier networking. Acta Electron Sin, 2019, 47: 977–982.

• Gao S, Zhang H, Das S K. Efficient data collection in wireless sensor networks with path-constrained mobile sinks. IEEE Trans Mobile Comput, 2011, 10: 592–608.

• Luo H, Zhang H, Qiao C. Optimal cache timeout for identifier-to-locator mappings with handovers. IEEE Trans Network Service Manage, 2013, 10: 204–217.

• Feng B, Zhang H, Zhou H, et al. Locator/identifier split networking: a promising future Internet architecture. IEEE Commun Surv Tut, 2017, 19: 2927–2948.