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Intent-based networks for 6G: insights and challenges

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Abstract

Intent-Based Networks (IBNs), which are initially presented for introducing Artificial Intelligence (AI) into the sixth generation (6G) wireless networks, can effectively solve the challenges of traditional network in terms of efficiency, flexibility, and security. IBNs are mainly used to transform users' business intent into network configuration, operation and maintenance strategies, which are prominent for designing the AI-enabled 6G networks. In particular, to meet the massive, intelligent service demands and overcome the time-varied radio propagation, IBNs can continuously learn and adapt to the time-varying network environment based on the massive collected network data in real-time. From the aspects of both core network and radio access network, this article comprehensively surveys the architectures and key techniques of IBNs for 6G. In particular, the demonstration platforms of IBNs, such as the Apstra Operating System, Forward Networks Verification Platform, and One Convergence Service Interaction Platform, are presented. Moreover, the industrial development of IBNs is elaborated, including the emerging new products and startups to solve the problems of open data platforms, automated network operations, and preemptive network fault diagnosis. Finally, several open issues and challenges are identified as well to spur future researches.

KEYWORDS:
Intent-Based Networks (IBNs), the sixth-generation wireless networks (6G), Artificial Intelligence (AI)

1. Introduction

Radio Access Networks (RANs) are increasingly demanding the rapid acquisition, analysis, and exchange of vast amounts of data. The traditional operation and maintenance management methods have the characteristics of high labor cost, error probability, backward operation and maintenance methods, and low management efficiency. Therefore, in order to cope with the pressure of the dynamic demand, the advanced intelligent network needs to have the following characteristics: (1) Network faults can be identified in advance and optimized and repaired actively with the predictive analysis capability; (2) The declared intent of network operators can be transferred into the network layout to achieve the desired results based on the intelligent and flexible capabilities; (3) The ability of easy configuration, operation and maintenance should be fulfilled.

Due to the maturity of Network Function Virtualization (NFV) [1]and Software Defined Network (SDN) [2], IBNs do not need to directly input policy commands, but can capture the demands (intent) of constantly changing services and

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applications, transform these demands (intent) into measurable Key Performance Indicators (KPIs), and complete dynamic network orchestration. Meanwhile, the autonomous IBNs [3] can also continuously verify the matching between the actual network state and the expected network state through real-time monitoring of network KPIs and big data training, so as to adjust the network parameters to continuously provide superior QoE.

Compared with the traditional 4G and 5G, the AI-enabled IBNs designed for 6G networks are more nature and more efficient to manage in the aspect of its architecture, and its network service function is more open [4]. The combination of AI and big data technology in IBNs can improve the robustness of the network and achieve dynamic operation and maintenance. At the same time, it can optimize and configure business applications separately to improve network performance, which has a strong application prospect [5].

At present, the research on the IBNs is mainly focused on the core network. To achieve the significant improvement of 6G compared to 5G, 6G requires wireless networking of full spectrum, adapting to the whole scenario, and all aspects of the business. The IBNs should accomplish the evolution from core network to the wireless network. The main advantages include: 1) to be able to accurately identify multi-type end-user service intent in IoT scenarios, and implement multi-dimensional sensing requirements; 2) to convert users' operation, maintenance, business, user performance and other requirements into wireless network configuration, operation, and maintenance strategies, and overcome the shortcomings of traditional wireless network static solidification; 3) to reduce the operation and maintenance costs, ensure network performance and improve network robustness at the same time, through the collection of network operation and performance data, real-time perception of user experience and network performance, the use of AI, big data and other technologies for the wireless network and user performance prediction. Therefore, faced with the massive connection of 6G and higher performance requirements, the IBNs have a broad application prospect and also face challenges in architecture, key technologies, and performance demonstration.

Therefore, this survey focuses on providing a comprehensive overview of the state-of-the-art IBNs technologies and applications which satisfy the requirements of 6G wireless networks. The main contributions of this paper are:

- A comprehensive survey of IBNs deployment in 6G wireless networks is presented, involving the system architecture, key techniques, including the current research status of IBNs research program and programming framework based on network virtualization technology.
- A concise summary of the industry-based intent commercial product demonstration platforms and the related IBNs products applied in telecommunications, finance, energy, manufacturing, and other industrial fields.
- The future challenges and directions to build a more intelligent and adaptive IBN in 6G networks are presented holistically in areas of both ubiquitous and autonomous characteristics of 6G networks.

The rest of this paper is organized as follows. Section II mainly introduces IBNs deployment in 6G wireless networks. Section III describes three kinds of software of industry-based intent commercial product demonstration platform. Section IV introduces IBNs products applied in industrial fields. Future challenges and directions are highlighted in Section V, followed by a conclusion in Section VI.

2. System architecture and key technologies

As shown in Fig. 1, the typical IBNs architecture has the following elements.

- Translation and verification. The IBNs capture and translate business intent into network policies that can be automated and applied consistently across the network. The ultimate goal is for the network to continuously monitor and adjust network performance to assure the desired business outcome.
- Automatic deployment. The translated and verified policies are automatically delivered by IBNs and automatically deployed in physical and virtual network facilities through network automation or network orchestration [6].
- Network state awareness. The state of the network will change constantly. The state of the implementation may be inconsistent with the state of the verification. In order to ensure that the network can satisfy the users' intents at any time, the system needs to continuously observe and manage the network state.
- Accurate diagnosis and dynamic optimization and remediation. Based on the real-time network status, the system needs to continuously detect the consistency of the execution strategy with the original intent and take corrective action when the requisite intent is not achieved.

2.1. Network architecture

To achieve the network adaptation to 6G characteristics of ubiquitous and holographic connection [5], as shown in Fig. 2, the system architecture of IBNs provides five main functional blocks: monitoring and sensing, intent translation,

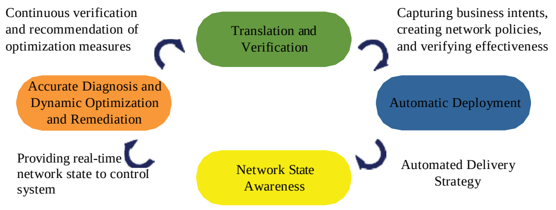

Fig. 1: System characteristics of IBNs

intelligent orchestration, automated execution, and strategy evaluation. These five functional modules constitute an intent-based management loop. Furthermore, based on network measurement data and artificial experience-based knowledge, the network capabilities including self-sensing, self-analysis, self-optimization, and self-driving can be improved.

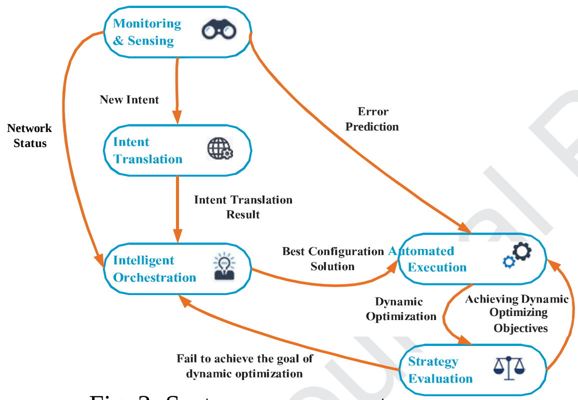

Fig. 2: System management process

The system management process is the basis of IBNs architecture. Some intent-based management functions can be implemented in the network slice element, and some functions need to be implemented in the management system. According to the deployment locations of the network management function with different intents, IBNs architecture is shown in Fig. 3.

On the basis of IBNs architecture, there are one or more centralized controllers responsible for the management of different slices of the target area, each slice running on a virtualized network infrastructure. The centralized controller has some autonomous management functions, including centralized monitoring and sensing, intent translation, and intelligent orchestration. When all kinds of data monitored by each slice are collected for analysis, the specified slice is issued to the managed one as needed. The existence of a centralized controller reduces the complexity of the slice implementation and facilitates the implementation and management of multiple intents.

At the same time, some of the self-management functions are also included in the managed slice, including distributed monitoring and sensing, automated execution, and strategy evaluation. Since each slice is closer to the network terminal and the user, the monitored raw data is less granular in time. Automated execution and strategy evaluation can be performed on a smaller time scales for more flexible dynamic tuning and real-time maintenance of intent. Moving some of the autonomous management functions from a centralized controller to a distributed slice makes the intent-based management function more efficient, improving the system performance and scalability.

2.2. *Key technologies*

In this subsection, the key techniques have been categorized corresponding to each system management process block as conversion and maintenance, network automated orchestration and management, network state awareness and fault detection, and business intent guarantee and performance self-optimization.

2.2.1. *Conversion and maintenance of business intents*

The business intent is the core driving force behind IBNs, which reflects the customers' personal needs and performance goals. The business intent specifically refers to the variety of services that the network can provide to the end-user, such as a wide area seamless coverage scenario service, that is relatively geographically dispersed and highly mobile to the user, hotspot high-capacity scenario services which face the hotspot area, including 3D stereoscopic video and augmented reality requiring higher data transmission rates, low-power large-connection scenario services for smart cities with large-scale sensor devices, and low-latency high-reliability scenarios for vertical industries such as car networking and industrial control. The capture of business intent can be accomplished through a graphical user interface or a sound sensing device using data formats such as extended markup language (xml) and Domain Specific Language (DSL). In this subsection, we review three kinds of intent translation techniques.

- ONOS intent translation process

  The SDN-based Open Network Operating System (ONOS) includes the Intent Framework component, which is designed to provide an Intent over all runtime environment and framework [7]. As a subsystem of ONOS, the Intent Framework acts as an integral part of IBNs connection. Intent Framework treats intent as policy-based directives, allowing applications to broadcast their network needs externally based on policy and management. That is, when the application declares that they need something, such as extra bandwidth or a primary channel, the controller performs the necessary configuration changes on the appropriate device, providing it with what it needs, and completing IBNs connection.

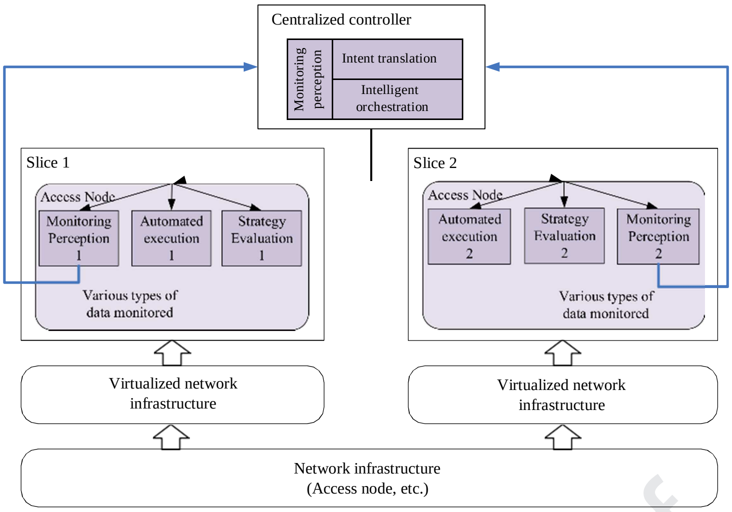

Fig. 3: System architecture

- Intent translation in NEMO project

  Unlike ONOS, which focuses on providing an intent overall runtime environment with the Intent Framework, OpenDayLight focuses on the specific interface design and implementation of the Intent Northbound Interface (NBI) [8]. Among them, the NEMO project provides an Intent model that is free of user intent by abstracting network resources and network behavior, and designs a DSL for network operation based on the model. The process through which NEMO handles the intent includes abstraction of network resources, orchestration of the intent of the user or application, and compilation of the mapping. Fig. 4 depicts the intent translation process in OpenDayLight completed by the NEMO engine.

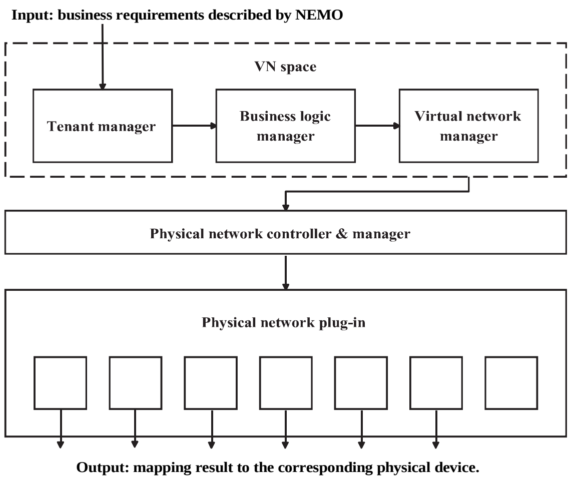

Fig. 4: NEMO engine completes intent translation in OpenDayLight [8]

- Intent translation process in NIC project

As shown in Fig. 5, the latest Network Intent Composition (NIC) architecture [9] is divided into two parts: Northside and Southside. The Northside is where the object of intent is created and manipulated, dealing with anything related to intent. To meet the users' needs, the NIC creates some auxiliary modules to receive information about the topology that the NIC will handle. The network mapping module exposes the Representational State Transfer Application Programming Interface (REST API) [10] to receive information about routers and switches that are manipulated by the NIC. The renderer API module is responsible for storing the data structures that each translator will process. the NIC will use these data structures to populate the information provided by the intent and retrieve it from the network mapping module. In the South Side, the NIC will decide which translator and which corresponding data structure should be processed so that multiple translators can work.

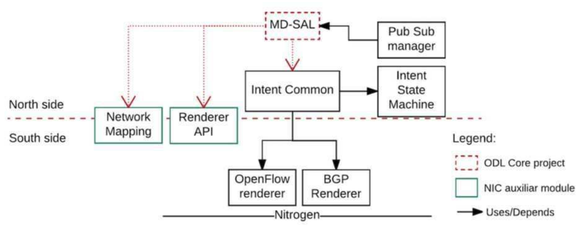

Fig. 5: NIC architecture [9]

2.2.2. *Network automated orchestration and management*

After the translation is completed and the corresponding virtual network configuration is obtained, the intelligent orchestration [11] and automated execution modules together need to complete the mapping between the virtual network and the physical network on the premise of considering the network running status. Specifically, these two modules analyze the monitored network operation data and wireless transmission data, combining pre-configured competition decision information. The result is used to judge the competitive relation between new business intent and the original intent in the network, and choose to avoid conflict or solve conflict. Ultimately, the system completes strategy formulation and cooperated optimization of intent network configuration [12].

The strategy configured for intents covers networking mode, multi-mode network resources, and physical transmission mode. Multi-mode network resources refer to wireless resources, cache resources, and computing resources. Wireless resources include time domain, frequency domain, code domain, and airspace and power domain resources. Cache resources include available storage space, file contents, and cache replacement contents. Computing resources refer to the local data processing capabilities and machine learning algorithms used by each node, as well as data computing capabilities that support machine learning.

As shown in Fig. 6, the intelligent orchestration module provides the best physical network configuration strategy with the help of AI and machine learning technologies. The implementation of business intent in wireless networks refers to the way of deployment for the access network slice.

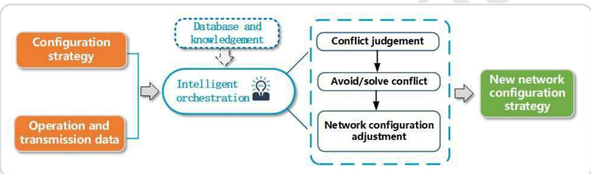

Fig. 6: Schematic diagram of network automation arrangement and management module

A typical process includes the following: first, in Congress component, in order to realize the rapid and automatic deployment of IT services and complete the dynamic management of infrastructure, VMware proposes Policy as a Service to utilize the cloud to realize the provision of diverse services; second, in the open and extensible Cisco DNA architecture [13] proposed by Cisco (whose details will be further discussed in Section 3), the system completes the task of automatic provisioning and network deployment. When a new device is added to the network, the Cisco DNA Center assigns a policy based on its identity, simplifying the setup of the remote controller. In addition, the SDN-based IBNs [8] can easily realize the automatic delivery of network policies by utilizing the separation characteristics of its control plane and data plane. Cisco SD-Access utilizes software-defined access technology, and completes policy-based automation from the edge to the cloud.

As can be seen from the above, the automated orchestration and management of the network is usually based on a specified strategy. The generation of the policy can be pushed to the system in advance, or dynamically generated by using big data and AI technology based on information collected from various infrastructures. The former is developed offline to reduce the complexity of policy generation, while the latter can automate the process of strategy formulation, installation and configuration, self-optimization, and fault detection in network lifecycle management, making the network a system that can control and operate automatically.

2.2.3. *Network state awareness and fault detection*

The primary task of periodically maintaining IBNs is to complete the perception of new business intents. The process of sensing needs to be completed based on the monitored wireless transmission data combined with network operation and maintenance data. This task is accomplished to trigger the intent translation function and the periodic functions driven by intent in the network.

As shown in Fig. 7, the monitoring and sensing module is mainly used to identify and predict whether there are new problems such as network congestion in the network. In addition to completing the diagnosis and identification of new business intents, it can also maintain existing intents based on network monitoring. Big data analysis predicts the trends of network changes, realizes network fault prediction, and performs autonomous optimization of foreseeable network faults through dynamic tuning and intelligent orchestration in automated execution.

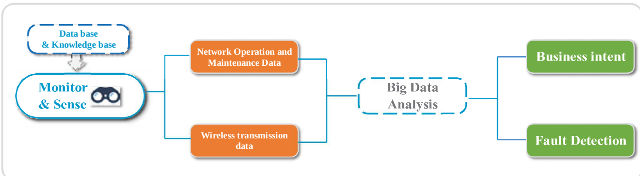

Fig. 7: Schematic diagram of the monitoring and sensing module

Autonomous network has three vital features: early prediction of failures, and the monitoring of new business intents. Typical architectures like DNA architecture proposed by Cisco [13], and Intent Northbound Interface (Intent NBI) [4] presented by Open Networking Foundation (ONF) accomplish the network state awareness and fault detection function. The autonomous IBNs system needs to obtain multi-dimensional data from the network, such as wireless network operation and maintenance data, wireless transmission data, and terminal measurement data through information sensing or big data probes methods. The network operation and maintenance data can be used to judge the generation of new service intents; the wireless transmission data and the terminal measurement data can be used to evaluate the real-time performance of the current network configuration policy, that is, to compare the consistency between the network execution strategy effect and the intent desired effect.

2.2.4. Business intent guarantee and performance self-optimization

Business intent guarantee and performance self-optimization is another key technology that is used in IBNs system architecture. In 6G AI-based wireless networks, the key challenge of business intent protection is the adaptive adjustment of time-varying wireless networks [15] parameters. Utilizing the technology of big data training and AI, the strategy evaluation module in Fig. 2 can be driven by infinite intent, which can guarantee the protection of business intent and optimize the adjustment of network performance. Based on centralized or distributed big data collection in the network, IBNs can extract the temporal and spatial characteristics of the data by using AI technology according to the terminal measurement data and the wireless transmission data monitored in real-time [16]. The module analyzes the data monitored by the network, and evaluates the network performance status of the current network that is performing the configuration policy. Then it compares the outcomes with the preset intent performance indicator threshold of the intent translation output to determine whether the current network performance satisfies the intent requirement. If so, the existing network policy should be maintained, including parameter configuration and dynamic tuning. However, if not, the procedure should first roll back to the intelligent orchestration module, and then combine the current network configuration plan and the historical configurations feedback of the service level and resource utilization efficiency, coming up with a better configuration adjustment strategy. The new strategy will achieve the highest resource utilization efficiency and the best service level. Finally, the current network is re-configured to promote adaptive intelligent optimization of the wireless access network. The policy evaluation module includes a centralized evaluation module responsible for global network performance evaluation and a distributed evaluation sub-module responsible for evaluating each intent execution performance in the network. The centralized evaluation module can be located in the wireless network control, and the distributed evaluation sub-module can be located in the access network node with local data processing capabilities.

2.3. Research programs and programming frameworks

This subsection presents an overview of the research status of IBNs research programs. The IBNs can promote the evolution of the 4G/5G network to the whole life cycle automation by mastering its own holographic state and constructing and operating a network architecture with closed-loop control functions according to business intents. The research on IBNs in the academic community mostly focuses on emerging technologies such as virtualized networks and SDN.

2.3.1. Distributed overlay virtual ethernet network

Reference [17] proposed an IBNs virtualization solution for Distributed Overlay Virtual Ethernet network (DOVE). By abstracting IBNs management, building a network virtualization architecture, loosely coupling the physical and virtual infrastructures, and operating independently of each other, multiple independent tenant service requests can be simultaneously satisfied in one network.

Traditional network virtualization-based solutions [18] focus on designing the functional requirements of a network virtualization platform and providing traditional network management and device provisioning at the virtualization level. In this mode, the lifecycle management of the endpoint requires multiple management points to be updated at the same time. When the management point cannot respond to changes in the underlying configuration details in time, it will cause network failure. Therefore, to meet the network services requirements of multiple tenants in a network environment, it is necessary to set a declarative expression for network management, allowing it to express the network functions required by the tenants, rather than being limited to the configuration and control of the infrastructure. This network virtualization solution consists of two essential components, as shown in Fig. 8, one for specifying network functions, an architecture-based abstraction representation, and the other for an efficient and scalable virtualization platform. The abstract network management functionality translates intents into a proprietary language for specific infrastructure configurations. In addition, the network virtualization platform relies on several independent and isolated virtual networks that belong to multiple tenants, so that tenants can define and manage their own networks independently of other tenants.

2.3.2. Open software-defined framework

In order to achieve the goal of intent-based design, Ref. [19] proposed an SDN-based network programming framework, namely, the Open Software Defined Framework (OSDF). The OSDF provides an advanced Application Programming Interface (API) that application administrators and network administrators can use to express applications and network requirements across multiple network domains. As shown in Fig. 9, the OSDF also provides a set of advanced network operation services for handling public network configuration, monitoring, and Quality of Service (QoS) provisioning. In addition, the OSDF is

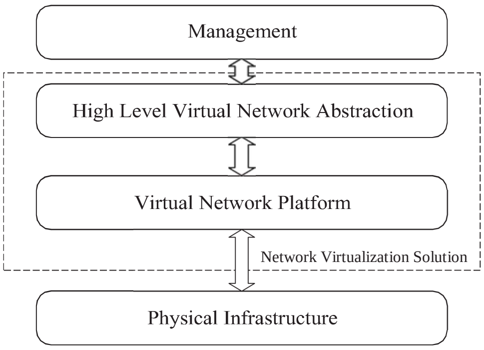

Fig. 8: Network virtualization architecture [17]

equipped with a policy conflict management module to help network administrators detect and resolve policy conflicts.

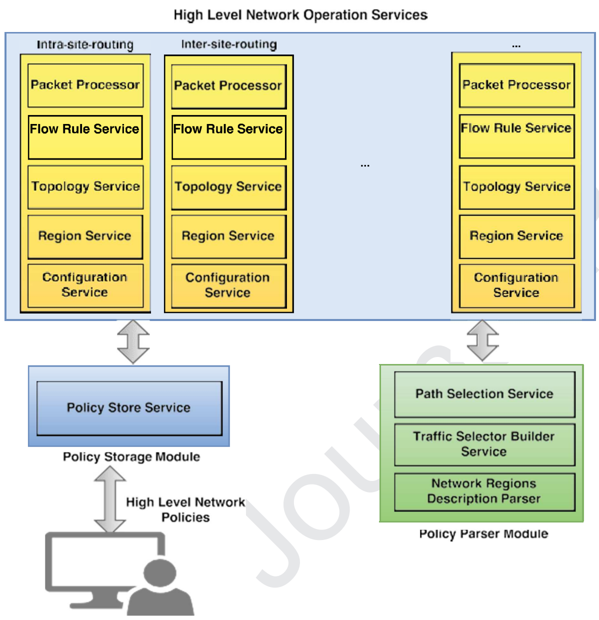

Fig. 9: OSDF framework [19]

Based on the open API of the ONOS, [19] presented the modules such as policy storage, policy analysis, and policy conflict detection in the OSDF framework described above on the SDN test platform, and implemented a typical model using OSDF.

2.3.3. *Over the top IBNs framework*

In [20], the author proposed an OTT (Over the Top) IBNs framework for 5G network slicing, as shown in Fig. 10. The proposed IBNs framework provides a simple service platform for users and operators. The framework speeds up the placement and configuration of service requests. It provides system feedback for network services and guarantees their reliability. The concept of an intent is extended to cover application slice setup requests for providing services to the public (e.g., MBB and IoT). The modules of the OTT IBNs platform is located on the Cloud-Over-the-Top Application Platform (COASP).

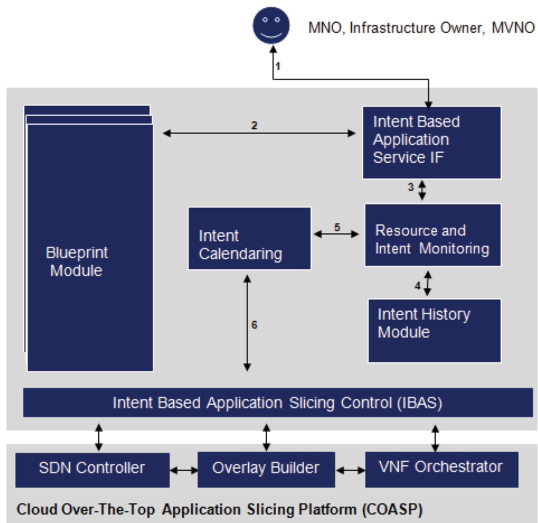

Fig. 10: OTT IBN framework [20]

Discussion: The above introduces the programs that the academic community has proposed to apply to the concept of virtual network intent and the software framework for the establishment of IBNs. It can be seen that the implementation of IBNs is closely related to the SDN and the virtualized network technologies. However, the construction of IBNs should be built on the existing network architecture to avoid blindly increasing the complexity of network changes and performance instability caused by emerging technologies. Therefore, to build an intent-driven network in a wireless network, appropriate evolution should be made in conjunction with the network control management technologies and functions that the existing network structure can provide.

3. Industry-based intent commercial product demonstration platform

In this section, we present several typical industry-based intent commercial product demonstration platforms, including the Apstra operating system, forward networks verification platform, and one convergence service interaction platform.

3.1. *Apstra operating system*

The Apstra Operating System (AOS)[3] is a vendor-independent data center network distributed operating system that enables business agility, significantly improves operational efficiency and reduces downtime. the AOS automates the entire lifecycle of network infrastructure and services. Starting with the customers stated intent, the AOS automates the

[3]https://go.apstra.com/white-paper-architecture-overview

process of designing and deploying network configurations and ensures that the network is always providing real-time telemetry and analysis capabilities that are continuously validated. As shown in Fig. 11, the AOS includes five main elements, namely intent, reference design, services, systems, and resources.

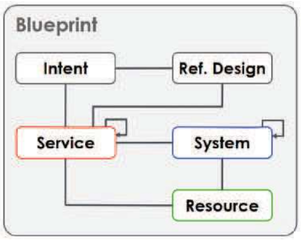

Fig. 11: AOS blueprint

3.2. *Forward networks verification platform*

The forward networks verification platform[4] can help network operators to search in complex networks, quickly debug problems, verify the correctness of large-scale verification strategies, and make changes to production equipment by creating an actual network model in the software.

Forward networks represent the users' network intent as a set of policy statements and requirements, which are then verified by the networks' software model. Forward Networks map policies and intents to device configurations and relies on software models to test performance in specific scenarios or to check real-time data, eliminating potential errors and reducing network risk. Forward Enterprise software provides a unique network modeling tool that uses mathematical verification techniques to predict network behavior and provides the network with three key functions: search, verification, and prediction.

3.3. *One convergence service interaction platform*

The one convergence service interaction platform offers one convergence Network Service Delivery (NSD) solution, which provides Layer 3 to Layer 7 network service orchestration, lifecycle management, and service assurance for OpenStack Neutron, Cisco ACI (which will be discussed in the next section), and other SDN controllers or architectures. The solution for this service platform includes the following features:

- Network service orchestration and lifecycle management, including common methods for configuring and orchestrating heterogeneous services and seamless support for VM;
- Providing a wealth of network services, including multi-vendor and open-source network services, firewalls, VPNs, load balancers;
- Supporting Tap, L2 and L3 insertion modes;
- Supporting operator visibility and service assurance analysis;
- Flexible deployment model, including OpenStack Group-based models and OpenStack Neutron APIs.

4. Industrial products of IBNs

Since the concept of intent was put forward, a series of new products and startups have emerged in the industry to solve the problems of open data platforms, autonomous network operations, and preemptive network fault diagnosis required to build IBNs. This section presents IBNs products applied in industry fields.

4.1. *Cisco's application-centric infrastructure and DNA solutions*

Cisco's Application-Centric Infrastructure (ACI) defines applications as a set of policies that enable Cisco's new data center SDN solution on the network, making it easier for customers to adopt and improve IBNs in the data center. By abstracting the application as a policy group on ACI, one can eliminate the complexity of network settings and quickly deploy the network that best fits your application. Through linkage with various server virtualization infrastructures, the automation of network deployment can be greatly improved, and the automation of intent-based policies in the network can be facilitated. With the ACI architecture, customers can build a cloudy network with a consistent policy model to seamlessly deploy and migrate applications across geographies. And cisco has "DNA" solutions for enterprise networking. DNA center, aimed at one of the most important modules of IBN - "assurance". Cisco hopes to use the concept of "intent" to solve the problems of network operation and management, so that networkers can no longer bear the blame. The operation and maintenance personnel need to know what the problem is, and how to fix it quickly. In the traditional network scenario (even with SDN), the operation and maintenance personnel still need to make a painstaking investigation. The launch of cisco DNA center is to provide a global view of the network for the majority of network operation and maintenance personnel, so that the entire network is visible and can directly respond to and transform the "management intent". The traditional network management software mainly relies on Simple Network Management Protocol (SNMP) for device monitoring, which is inefficient, with limited information and heavy equipment burden. The Cisco DNA center, on the other hand,

[4]https://www.forwardnetworks.com/network-automation-software/

uses a lot of telemetry methods to gather global information, thus to accomplish scenario correlations by AI and machine learning ways. This is the key element that enables IBN. With the help of the DNA center, operations and maintenance personnel can realize full network visualization, and can predict trends, assess impacts, and proactively respond to pre-solve problems, so as to make automatic remediation of network failures possible.

4.2. *Spruce network DeepFlow products*

DeepFlow is an integrated network traffic collection and analysis platform launched by spruce network. The DeepFlow product is mainly divided into three parts: (1) virtual switch traffic collection software; (2) DeepFlow network data analysis software; (3) DeepFlow platform controller software.

4.3. *Juniper contrail security software*

Junipers Contrail Security software is a member of the Juniper Contrail product line, which allows users to protect applications running in any virtual environment. It is an open, distributed cloud security solution. Contrail Security provides dynamic and scalable network virtualization for enterprise and SaaS (Software as a Service) cloud providers with distributed, intent-driven security solutions that enable the network to redirect suspicious traffic based on the intent of the application owner or network administrator. The solution seamlessly protects applications between the cloud and the public cloud infrastructure and proactively initiate remediation to reduce network operational risks.

4.4. *Huawei cloud fabric solution*

Huawei intent-driven Cloud Fabric solution enables IBNs automated configuration, predictive analysis, and continuous verification optimization. It aims to build a cloud data center network with intelligent operation and maintenance, large bandwidth, low latency and zero packet loss for customers. This solution facilitates flexible scaling of data centers and implements unified management of public clouds and private clouds, reducing construction and operation costs. This solution is already widely deployed in Internet companies and large enterprises.

4.5. *Discussion*

The main features of the products of the four companies mentioned above are summarized in TABLE 1. It can be seen that most of the products for IBNs are converted from network abstraction to network strategy, automatic operation of the strategy, and fault perception prediction. The realization of the policy-issuing of intents through SDN, combined with big data analysis and AI technology to predict potential network problems has become a key link in IBNs.

5. Challenges and future research direction

Ubiquitousness and autonomy are two characteristics of 6G [5]. On the one hand, 6G will break through the application scope of traditional wireless communication and evolve into a basic Internet supporting the operation of the whole society and all sectors/industries. Based on 5G space-air-ground networks, 6G will further integrate space-air-ground-sea networks to provide full coverage and unlimited wireless connection. On the other hand, AI is one of the most popular topics at present, and AI technology is being explored in almost every field. The combination of 6G wireless networks and AI makes AI better serve the future network in improving network intelligence and reducing operation and maintenance costs. In this section, challenges of IBNs implementation in 6G will be discussed from the perspective of the aforementioned two 6G characteristics, and future research direction will be spurred as well.

Firstly, with the evolution of network standards and frequency bands, the mobile network presents diversification and isomerization, and the complexity and cost of network operation and maintenance increase accordingly. Existing commercial wireless networks have many configurable parameters. In the face of the communication of high-dimensional space-air-ground-sea networks and the rapidly changing business needs, the traditional IBNs operation and maintenance mode lacks the agile operation system and its maintenance cannot keep pace with the high-speed scenarios of 6G networks. Relying on a few external security mechanisms, it is difficult to support the highly uncertain development of future intelligent business, so a more flexible and concise intelligent IBN is urgently needed.

Aside from the overall architecture of IBNs mentioned in this paper, the deployment of the IBN controller and data processing in both 6G Core Network(CN) and RAN should be precisely arranged. As shown in Fig. 12, THE IBN controller could in turn or partly be responsible for the functions of wireless intent processing cycle, including the intent translation, conflict resolution, network layout optimization, network configuration, activation, and strategy optimization; and complete the acquisition of operational and wireless transmission data, and terminal measurement report of the access network in the network layer and access layer. The IBN controller, which occupies most computing resources, can be located in a centralized cloud, a base station controller, or a macro station with network management capabilities. In the base station (Fog-Remote Radio Unit, F-RRU) and terminal equipment (Fog-User Equipment, F-UE) with edge computing and management functions, the distributed data collection and processing and network resource optimization are carried out to realize the efficient operation of network management strategy.

Secondly, although the AI technology develops very

Table 1: Overview of the development of IBNs industry products

Product name	Category	Application scenario	Main technology used	Characteristics
Cisco ACI	Network infrastructure SDN solution	Enterprise network, hybrid cloud, data center	Software defined access; Network virtualization technology; Big data analysis	• Centralized, application-based policy automation implementation, cross-domain management and troubleshooting of network services; • Hardware visibility, fault prediction and repair; • Based on VM, seamless implementation across management programs and data centers.
Spruce Network DeepFlow	Virtual network traffic collection and analysis software platform	Private cloud, industry cloud, hybrid cloud	Software defined access; Virtual traffic collection technology; Big data analysis	• Associate the cloud platform to realize virtual network traffic analysis and collection; • Full-scale storage of traffic, back-tracking network status at any time; • Programmable alarms to quickly guide troubleshooting.
Huawei Cloud Fabric	Cloud data center network	Cloud network integration scenario, network virtualization scenario	Cloud network collaboration based on SDN; Big data analysis; AI	• Intent-driven network automation; • AI-based operation and maintenance, predictive analysis and anomaly detection; • Based on ONOS platform and open API architecture, support expansion and resource sharing of multiple cloud platforms.
Juniper Contrail Security Softwar e	Cloud security software	Application running environment, such as public cloud, private cloud, server, etc.	Application traffic detection; Machine learning	• Support the definition of simple terminology as an intent to simplify policy creation; • Unified control and management commands to ensure security services across a cloudy environment; • Provide application traffic visibility for detecting anomalies and taking corrective actions.

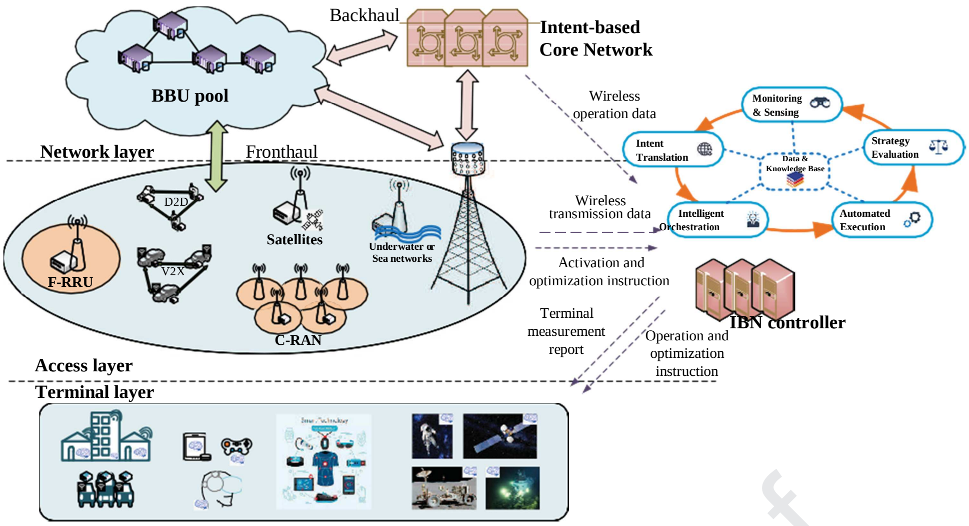

Fig. 12: An example of intent-based 6G network architecture

fast, and in many scenarios has demonstrated its strong ability [21], its application in the commutation system is still at the exploration stage. The research on the integration of AI and wireless communications technology has just started in recent years. At present, the combination of AI and wireless communication only remains in the optimization of 5G system architecture. AI technology needs a longer-term research process before it really gets mature to achieve a novel AI-driven network architecture. Researchers have been trying to apply AI technology to the traditional IBNs architecture. The studies based on the SDN core network have shown positive features including business self-sensing network, self-configuring network operations, and performance self-optimization of network. However, the current study of IBNs only focused on the core network, and intent-driven wireless networks need further exploration. Although the flexibility in the initial design of IBNs architecture is considered, it is still based on the traditional 5G network architecture and does not take into account the characteristics of the AI technology, which is the dominant part. 6G is expected to make use of the smart connection to change the traditional network architecture, so that the wireless network can provide sufficient flexibility and extensibility for diversified business types and application scenarios, and realize good interaction between the wireless network and user requirements, so as to innovate network operation and maintenance mode and realize efficient reconfigurable flexible networking.

The AI-enabled IBNs should have a very strong ability to deal with complex problems and serve for different high-quality services for diverse application scenarios. The complexity and high artificial dependence of the RAN in the future require IBNs to be able to translate users' operational performance and other requirements into the wireless network configuration, operation and maintenance policies, and realize end-to-end self-configuration of RANs. Besides, real-time user experience and network performance can be perceived by collecting network measurement data, and predictive analysis and intelligent optimization can be carried out by using AI, big data and other technologies to ensure network performance while reducing operation and maintenance expenditures and improving network robustness. The introduction of AI-based IBN into the 6G network architecture requires solving the problems of data collection, model training, algorithm selection, and the evolution of the current network architecture. In terms of data collection (AI data), it is necessary to specify the types of data to be obtained and the ways to obtain data for the realization of each function of the IBNs. [22] proposed an energy-efficient interference control scheme for the ultra-dense small cell systems, in which a BS optimizes the transmit power without knowing the channel states of the neighboring cells and suppresses the inter-cell interference in ultra-dense small cell systems. It is a promising way to construct an autonomous self-organized network [23] by statistically analyzing big data as [22] simplified and improving the cellular communication efficiency. In the aspect of model training (AI computing power), it is necessary to deploy AI model training equipment that supports computing and storing at the appropriate protocol layer in combination with network architecture, and allocate network computing resources and trained models reasonably. In terms of algorithm selection (AI algorithm), the appropriate AI algorithm with high operation efficiency and high operation accuracy should be selected according to the functional requirements and the operational capability supported by the network.

To sum up, IBNs for 6G are evolved from the wireless access network and intent network with the functions of real-time measurement data collection, network edge computing power and the support of AI algorithms, which adapt to different network configuration methods and physical layer transmission technology to meet the networking needs in the era of 6G Internet of things, such as massive connection, ultra-low delay, and super-large bandwidth. Based on real-time wireless transmission data, IBNs using big data and AI technology can identify network faults in advance, and carry out active strategy optimization and fault remediation. Although there are challenges in many aspects, the research on the combination of IBNs with 6G technologies and scenarios, such as THz, visible light or space-air-ground-sea integrated communication and AI-based wireless networks, will probably become a key factor in network automation and intelligence.

6. Conclusions

This article provides a comprehensive survey of the recent advances of IBNs for 6G. We surveyed the corresponding system architectures and categorized the key techniques for IBNs. The research status of IBNs and programming framework based on network virtualization technology has also been summarized. We discuss three demonstration platforms that help the network plan, design, and implement/operate the network to increase network availability and flexibility. In addition, we also present an overview of the development of IBNs industrial products. However, although the agility, robustness, and security IBNs bring to the core network, more research on AI-enabled IBNs adapted to 6G network requirements needs to be done in the future to improve the flexibility and intelligence in autonomous network operations.

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Dear Madam/Sir,

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Best Regards,

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