A Survey of Computational Intelligence for 6G: Key Technologies, Applications and Trends

Baofeng Ji, Yanan Wang, Kang Song, Chunguo Li, Hong Wen, Varun G. Menon, and Shahid Mumtaz

***Abstract*—The ongoing deployment of 5G network involves the Internet of Things (IoT) as a new technology for the development of mobile communication, where the Internet of Everything (IoE) as the expansion of IoT has catalyzed the explosion of data and can trigger new eras. However, the fundamental and key component of the IoE depends on the computational intelligence (CI), which may be utilized in the sixth generation mobile communication system (6G). The motivation of this article presents the 6G enabled network in box (NIB) architecture as a powerful integrated solution that can support comprehensive network management and operations. The 6G enabled NIB can be used as an alternative method to meet the needs of next-generation mobile networks by dynamically reconfiguring the deployment of network functions, providing a high degree of flexibility for connection services in various situations. Especially the CI technology such as evolutionary computing, neural computing and fuzzy systems utilized as a part of NIB have inherent capabilities to handle various uncertainties, which have unique advantages in processing the variability and diversity of large amounts of data. Finally, CI technology for NIB, which is widely used is also introduced such as distributed computing, fog computing, and mobile edge computing in order to achieve different levels of sustainable computing infrastructure. This article discusses the key technologies, advantages, industrial scenario applications of CI technology as NIB, typical use cases and development trends based on IoE, which provides directional guidance for the development of CI technology as NIB for 6G.**

***Index Terms*—Computational intelligence (CI), industrial Internet of Things (IoT), Internet of Everything (IoE), mobile edge computing (MEC), network in box (NIB), sixth generation mobile communication system (6G).**

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I. Introduction

TODAY'S society has entered a fairly technologically intelligent society such as smart phones, smart watches, and smart wearable devices have become popular and dominant gradually in daily lives. The Internet of Computer (IoC) has been widely used since 1991 [1], which is utilized for people's interaction for a long time. Subsequently, the mobile Internet appeared and brought about the significant convenience especially the emergence of Internet of Things (IoT) integrated physical entities with radio frequency identification, advanced sensing and so on [2], which dramatically extended the communication coverage and performance to achieve the new communication object [3].

IoT has moved toward IoE with the acceleration of the pace of intelligence, where the IoE is a completely new concept [4] and has surpassed the IoT that can be connected to the Internet to people, data, things, and network programs [5], [6]. Meanwhile, IoE is a new computational paradigm that can connect the real and virtual worlds by giving daily things to processing capabilities [7], the ultimate goal of which is to create a "better human world" and knows our preferences, desires and demands and can perform the task according to our acquirements without explicit instructions [8].

With the advent of the IoE, the amount of data will become more dramatically larger. In particular, there are abundant new applications and the requirements for transmission rate and spectrum width are becoming higher gradually. The development of 6G is to improve the shortcomings of 5G and have a higher rates and lower delays. Different from 5G, 6G may build a network that can realize air, space, ground, and sea integrated communications. Therefore, 6G technology will no longer be limited to breakthroughs in simple network capacity and transmission rate in the future. Its research and development is to narrow the digital divide and promote the IoE to be truly development and maturity. Compared with previous generations, 6G will not only improve communication capabilities, but also provide a communication infrastructure that supports various services or vertical fields. Therefore, 6G enabled CI technologies as network in box (NIB) has broad application prospects in user's personalized services as well as the IoE, Industrial Internet, smart factories, and other fields. In other words, 6G can truly realize the interconnection of all things and will be dedicated to creating a fully connected communication world that integrates ground communications, satellite communications, and marine communications [9].

Although the commercialization of 5G is still in its infancy, the research of 6G has already begun impressive and the candidate technologies such as terahertz (THz) communications, artificial intelligence (AI), computational intelligence (CI) and distributed intelligent computing all can be acted as NIB to improve the system performance considerably. It is worth noting that the CI technologies as part of NIB play a vital role in 6G. CI is a calculation model and intelligent tool with high fault tolerance, which is a new stage in the development and successor of AI. In recent years, 6G-based CI technology is developing at an astonishing speed, and its scope covers all fields of engineering technology, promoting the development of the information age. Even its application research has characteristics that exceed theoretical and methodological research. Fig. 1 shows the development process for NIB from IoC and IoT to IoE and lists the comparison and application. Fig. 2 expresses the key technologies and scenes of 6G enabled NIB based on IoE.

The contributions of this article are summarized as follows:

1) As far as we know, this is the first work that comprehensively outlines CI as a part of NIB for 6G from different aspects and perspectives. In particular, we provide a unique perspective on why CI can play an irreplaceable role as a key technology of NIB in 6G. We gave a detailed explanation on this aspect.
2) In addition, we have included the industrial application of NIB in the 6G field in the article, which makes this survey increase the practical application value and significance.
3) Finally, we use a chart to summarize and compare the various technologies involved in CI as a part of NIB for 6G and emerging key technologies have been anticipated under the development momentum of IoE.

The rest of this article is organized as follows. Section II analyzes the technical advantages for CI as NIB in 6G. Section III elaborates the key technologies of CI. Section IV describes NIB for industrial applications. Section V outlines

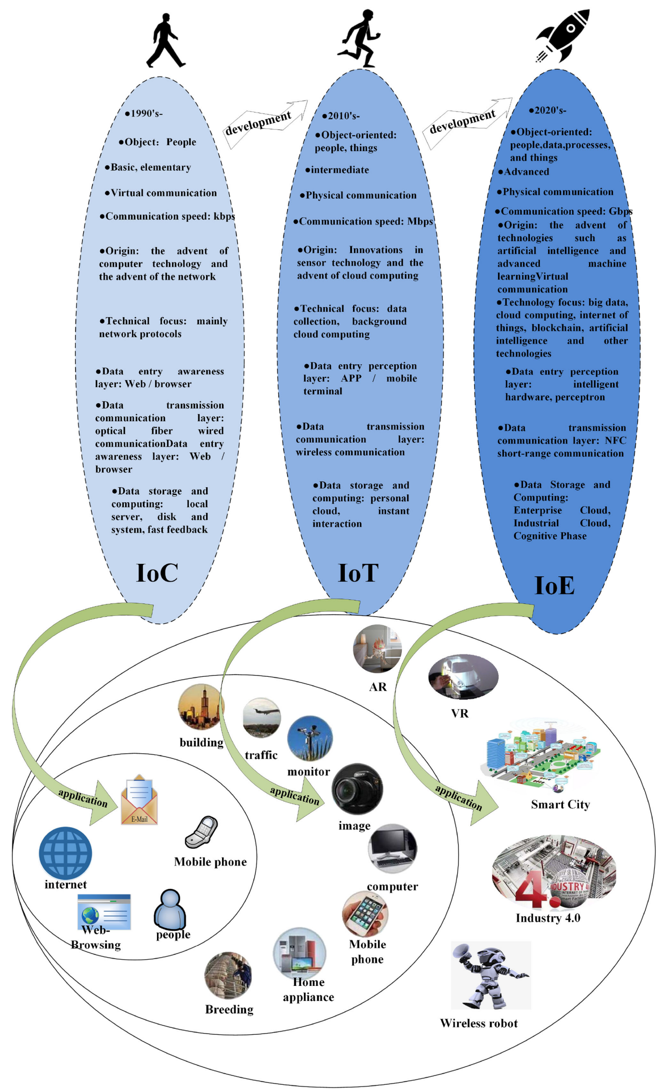

Fig. 1. Development comparison of IoC, IoT, and IoE.

the application scenarios and practical examples based on IoE. Section VI elaborates the typical use cases. Section VII raises several privacy security issues. Finally, Section VIII concludes this article.

II. Technical Advantages for CI as NIB in 6G

The communication technologies are still consumer applications from the 1G to 4G era, meanwhile, the 5G and 6G can involve the industrial applications such as industrial Internet and intelligent transportation. At present, 5G is mainly based on the early infrastructure for Industry 4.0 and the large specific application of 6G can be still opened and explored in the academic and industrial community. The most important requirements of 6G networks are the ability to handle large amounts of data and the connectivity of extremely high data rates per device; therefore, the CI technologies as NIB enabled by 6G can play a significant role in the future communication systems. Certainly, several important technologies such as the THz, AI, optical wireless

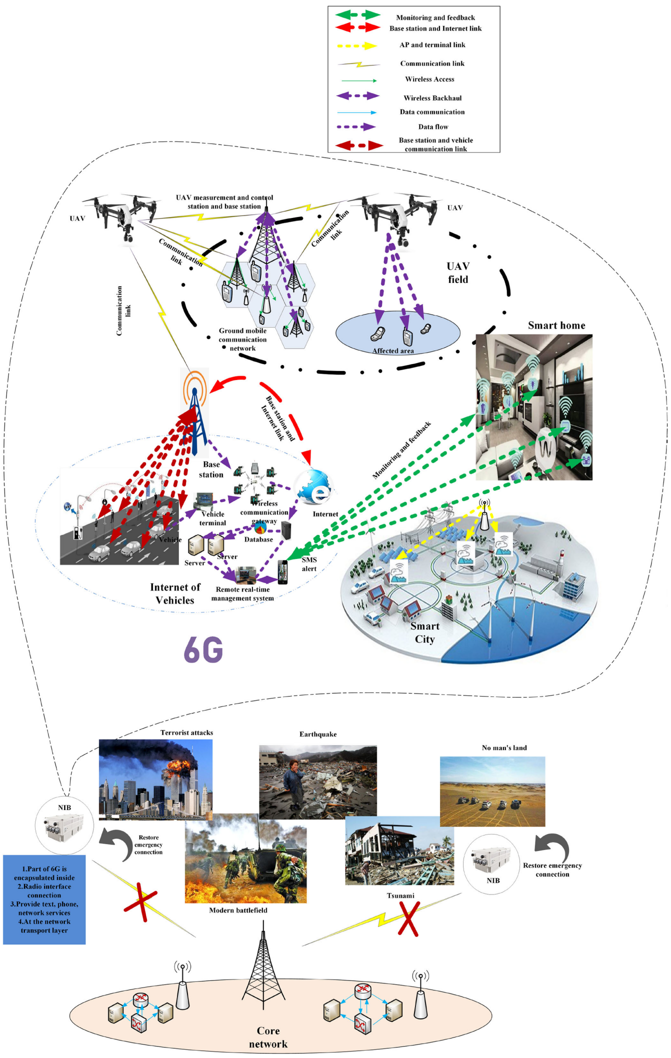

Fig. 2. Key technologies of 6G enabled CI as a part of NIB based on IoE.

communications, 3-D networks, unmanned aerial vehicles, and wireless power transmission can be also a part of the 6G system [10]–[12].

The millimeter wave band of 30G to 300 GHz has been utilized in 5G and the data speed can still provide not exceeding 100 Gbps. The THz technology adopted in 6G will be able to provide new bandwidth and allowed a large amount of data to be transmitted simultaneously. And the integration of block chain in 6G will realize the dynamic sharing of spectrum resources, the sharing of edge computing storage resources, and the sharing of distributed energy. Furthermore, the THz technology utilized in 6G network may support a variety of wireless devices to achieve real-time and remote transmission of data equivalent to the amount of human brain calculations. The THz frequency will provide a huge new bandwidth for wireless use, enabling wireless devices to remotely transmit massive amounts of computing data equivalent to the human brain in real time. For example, an unimaginable amount and type of data will be transmitted only in milliseconds. At this time, data transmission will consume less energy and the ultrahigh gain antenna will be able to be "extremely small". This will pave the way for smaller devices deployed in NIBs, including military-grade secure communication links that are very difficult to intercept or eavesdrop on. Some of the application scenarios may be familiar with 5G such as the remote control and so on, the difference of which is that the CI application in 6G can be dominant with AI instead of human. Therefore, the breakthrough of 6G cannot only provide fast network speed of all the data required for perception and control but also liberate a large number of heavy computational tasks from the human brain. Additionally, the submillimeter wave spectrum will be able to play an amazing role in existing technologies such as millimeter wave cameras used in dark environments, high-precision radar and terahertz-wave-based detectors for human security. Moreover, the base station of 6G may be able to access hundreds or even thousands of wireless connections at the same time and implement the compatible interaction with different transceivers such as drones, satellites, and so on to establish the integrated ground-air-space infrastructure [13]–[15]. Therefore, the CI as NIB utilized in 6G can be no longer a breakthrough in simple network capacity and transmission rate and it may pursue and achieve the ultimate goal of the IoE [16]–[18].

III. Key Technologies for CI in 6G

How CI technology can give full play to its technical advantages is a question worth pondering. In the 6G era, CI technology will be fully integrated into intelligent 6G network. The CI can be used to deal with the uncertainty encountered in evolutionary optimization, machine learning (ML) and data mining (DM) in the future. The CI includes neural networks, reinforcement learning (RL), evolutionary algorithms (EA), swarm intelligence (SI), fuzzy logic, artificial immune systems (AIS) and hybrid technologies such as neural fuzzy systems, fuzzy immune systems, and other types of hybrid system [19]. Therefore, this section briefly elaborates the key technologies of CI.

A. Artificial Neural Network

Artificial neural network (ANN) is a CI technology that simulates the brain processes data to deal with practical problems that need to consider multiple factors and conditions simultaneously. There are three main learning methods for artificial neuron learning.

1) Supervised learning [20].
2) Unsupervised learning.
3) Enhance learning.

B. Fuzzy Systems

Fuzzy system (FS) is a classic CI technology that uses fuzzy theory to solve problems in many fields. In contrast to certain logic, which can only have two possible values, fuzzy logic reasons approximately or to some extent indicates true or false. Additionally, fuzzy logic has been successfully used in control systems, power system control, and home appliance control.

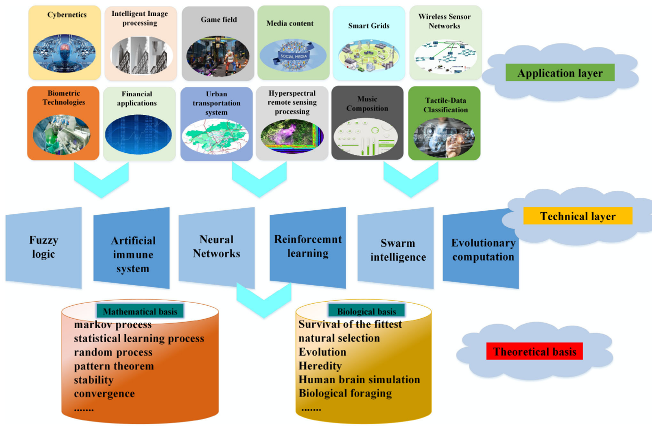

Fig. 3. CI theory, technology and application.

C. Evolutionary Computing

Evolutionary computing (EC) as a new global optimization search algorithm regardless of the function itself is continuous and general suitable for parallel processing with strong robustness for its simplicity and distinctive features such as high efficiency in the plan design control classification, clustering of time series modeling music composing and other fields has been widely applied.

D. Swarm Intelligence

SI refers to some intelligent algorithms with distributed intelligent behavior characteristics designed by birds, fish, bees, and other group behaviors [11]. The most widely accepted SI use cases are particle swarm optimization (PSO). SI algorithms have the advantages of simplicity, parallelism, and strong applicability. Therefore, it is widely used in optimization problem solving, robotics, and semiconductor manufacturing.

E. Artificial Immune System

Four decisions must be made: encoding, similarity measurement, selection and mutation in order to implement basic AIS. AIS algorithms have been successfully applied in computer security, fault detection, anomaly detection, optimization and data mining.

F. Reinforcement Learning

Traditional AI is based on ML, which is the development of technologies and algorithms that allow ML. However, the RL is a subfield of ML and is very suitable for dealing with distributed problems. It is mentioned that RL has become one of the hottest research areas in ML today with the success of Alpha Go [21].

IV. Application Scenarios of CI in 6G

In the 6G era, CI will receive widespread attention recently and becoming an important research direction of AI and computer science, which has been continuously improved with the improvement of its own performance and the expansion of its application range [22]. Fig. 3 shows the CI theory, technology, and application. The following will briefly introduce future CI applications in these areas.

A. Media Content

CI plays an important role in media content mining and processing based on big data features such as multiobjective optimization and deep learning (DL). EC such as ANN and genetic algorithm (GA) are common methods to solve complex problems. DL algorithms such as neural networks are used to detect and identify the image data.

B. Music Creation

In the field of music creation, CI technologies such as neural networks, FS and EC provide powerful tools for modeling, learning, uncertainty processing, search and optimization [23], [24]. EA is random, which makes it particularly suitable for music creation and computational creativity, while FS is suitable for music classification and analysis, using FS to design fitness functions to promote the imitation of phrase similarity between phrases. Use GA to generate melody motivation and use genetic algorithm to traverse the tree to construct the music structure. GA's chromosome notation can generate drum rhythms in a human-like rhythm accompaniment system. Neural networks are usually used to evaluate musical works or predict musical notes. Music systems developed using neural networks can generate music and assist in evolutionary creation [25].

C. Biometrics

CI is used in biometric systems and CI technologies such as neural networks, fuzzy logic, and EA have the characteristics of strong robustness and strong self-adaptability, which can be successfully applied to solve complex biometric recognition problems [26], [27]. In terms of face recognition and face monitoring, EA is a method to optimize the topology of neural networks and an effective face detection tool [28].

D. Finance

EC provides the possibility of trading strategies based on pattern recognition to profit from stock market transactions. Naturally inspired search technologies such as ANN can predict the direction of price changes, so neural networks are applied to exchange rate prediction [29]. Use fuzzy logic rules to design a specific fitness function in order to rank them as buying suggestions based on their fitness.

E. Intelligent Image Processing

CI can also be used in intelligent image processing such as image fusion. Combining fuzzy theory and neural network to process accurate information of noisy images and fuzzy information of noisy images. The combination of GA and neural network can improve the calculation efficiency to enhance the degree of automation of neural network modeling [30].

F. Wireless Sensor Network (WSN)

CI method is expected to produce a practical optimal/suboptimal solution to the distributed sensor scheduling problem in WSN [21]. For example, fuzzy logic is used to determine the number of sensors and continuous PSO algorithm is used for the distributed arrangement of sensors in marine monitoring, which not only improves the network performance but also save system cost.

G. Smart Grid

CI technology can be used in smart grids. For example, critical networks based on neural network structures can overcome time-varying delays in communication channels to improve the damping performance of the power system [31]. Using adaptive design and fuzzy logic based on PSO, energy-optimized of photovoltaic systems independent of the grid can be performed.

H. Urban Traffic Control

CI technologies such as ANN, FS, and EC algorithms have flexibility, autonomy and can overcome the nonlinearity and randomness of transportation systems, so they are suitable for dynamic urban traffic control transportation systems. Traffic event detection algorithms based on fuzzy technology can have lower false alarm rates, higher detection rates, and shorter average times in order to alleviate nonperiodic congestion of expressways [32], [33]. The PSO algorithm can handle the fuzzy rules of the signal controller and it has alleviated the pressure of urban traffic to the greatest extent and reduced the waiting time of vehicles.

I. Battery Management System

CI technology can be used in designing the charge state estimator of a battery pack. Battery state of charge (SOC) is a very important parameter in the battery management system of electric vehicles or hybrid vehicles. Based on the neural network technology in CI technology, the adaptive estimator is designed to determine the SOC of the electric vehicle battery [34]. The main framework of the estimator is a three-layer feedforward neural network with four inputs and one output. The first and third layers are pure linear functions, and the middle layer is a complex neuron network structure. The hidden neuron battery pack SOC is determined by many factors and parameters, such as the discharge current, the number of ampere hours used, the average temperature of the battery module, and the module voltage. The charging state of the battery mainly depends on the current of the battery pack. In addition, the SOC estimator using the improved PSO algorithm is not only simple in structure, but also has high calculation efficiency.

J. Gaming

AI and CI algorithms are widely present in games, such as ML, RL, and GA iteration. The intelligent path search algorithm in the game mainly includes a star algorithm and GA, which is a heuristic function path calculation search algorithm. The process of path finding can be greatly reduced by designing a reasonable heuristic function in the algorithm and is widely used in game path finding [35], [36].The use of CI technology provides an interesting alternative to scripts in most games. For example, an evolved neural network can be used to control agent behavior instead of programming it.

K. Hyper-Spectral Remote Sensing Processing

CI theory and its algorithms have also been successfully applied in the field of hyper-spectral remote sensing processing, that is, the dimension reduction and classification of hyper-spectral remote sensing images [37], which effectively solves the problems that traditional algorithms cannot solve and has good development prospects. Generally speaking, the accuracy is guaranteed by using neural networks and transparency is achieved by using fuzzy sets.

L. Other Applications

EA has many applications in real-world parameter optimization, which is one of the most advanced methods to solve complex optimization problems today and is often used in industries such as automotive and aerospace [38], [39]. Neural network technology has the ability to continuously learn during operation in the field of automatic control [40], [41], so it can be used to detect and identify system failures and help store information for decision making. Additionally, in academia or industry, big data analysis (BDA) is becoming more and more popular and there are a large number of practical applications in IoE such as business intelligence, environmental science, and cyber security. The algorithms used in the different application areas abovementioned can be compared as shown in Fig. 4.

V. 6G-Enabled NIB for Industrial Applications

With the rapid development of wireless transmission technology in 5G and the upcoming 6G communication system, 6G-enabled NIB has been extensively studied in academia and industry. Since one of the key features of the new generation of mobile networks is the ability to meet the needs of different vertical directions, NIB is an alternative method that can meet the needs of the next generation of mobile networks. NIB is a multigeneration 2G/3G/4G/5G/6G integrated and rapidly deployed hardware and software solution, which is a powerful and portable software and hardware integration box that integrates a core network, remote radio head and baseband unit (BBU). At the same time, NIB represents a portable and portable physical device that is flexible and can move freely or according to actual needs. The device can be used to provide connections between a group of disconnected and possibly mobile devices, and allow services such as text messages, phone calls, and Internet connections to be transferred between each other's devices. NIB equipment encapsulates part of the entire 5G or 6G mobile network, and two NIBs are connected through a standard radio interface, that is, each NIB treats the other as a preexisting legacy infrastructure component, or connects through a dedicated interface, generally providing short-term communication services. Recently, the industry has promoted the development of emergency and tactical networks, with the main purpose of increasing practicality, integrating solutions into the smallest possible physical devices. NIB also

Article	Application scenario	Typical algorithm used	Innovation	Result
[23]-[25]	Music creation	Evolutionary algorithms and neural networks	Using neural networks to predict notes, fuzzy systems can be used to deal with emotions and music types in works	Music systems developed using neural networks can generate music and assist evolutionary composition. Fuzzy system suitable for music classification and analysis
[26]-[27]	Biometrics	Evolutionary computing and neural network technology	Feature extraction technology based on CI and feature matching technology based on CI	Using evolutionary computing and neural network technology to successfully apply biometric data representation and dimensionality reduction
[28]	Fingerprint image	Neural network, fuzzy technology	A novel singularity point selection method for innovative fingerprint images based on CI technology	Fingerprint images were captured based on touch and non-touch fingerprint recognition technology
[29]	Financial	Evolutionary computing, fuzzy systems	The fuzzy logic rule base is used to represent trading rules, and the artificial evolution process is adopted to enable the system to learn to form good rules under dynamic market conditions	Searching for the best fuzzy trading rules, creating a highly adaptive and dynamic rule base system
[30]	Intelligent image processing	Fuzzy logic	Use fuzzy if-then rules to input the approximated segmentation into the fusion system	Get the fused approximation and get the fused image
[21]	Wireless sensor network	Swarm intelligence	An optimization algorithm for node localization based on swarm intelligence algorithm is proposed	The optimization model was solved, and the exact location of the nodes was obtained
[31]	Smart grid	Particle Swarm Optimization and Genetic Algorithm	An optimal wide area monitoring system based on RBF neural network is proposed, and its parameters are optimized by particle swarm optimization	Ability to identify input-output dynamics of nonlinear power systems
[32]-[33]	Urban traffic signal control	Fuzzy systems, neural networks, evolutionary computing, and swarm intelligence	A traffic event detection algorithm based on fuzzy technology is proposed, and a complex multi-objective problem is solved using particle swarm optimization technology	Helped to quickly find the cause and impact of non-recurring traffic congestion, make timely decisions, coordinate traffic signal control, route guidance, etc. to minimize its impact
[34]	Battery management System	Particle swarm optimization algorithm, neural network technology	Neural network technology for adaptive estimator design, using improved particle swarm optimization algorithm to train neural network	The improved particle swarm optimizer has higher training efficiency, small error in charge state estimation, high calculation efficiency, and can be applied to most low-cost microprocessors in real time.
[37]	Hyperspectral remote sensing processing	Fuzzy neural network, fuzzy set, genetic algorithm, neural network	Proposed the use of fuzzy set granularity of information processing, neural networks and fuzzy theory combined	Neural network is used to ensure accuracy, genetic algorithm optimization algorithm is used to determine the size of the neural network, and fuzzy sets are used to achieve transparency

Fig. 4. Comparison of various application scenarios.

has other features such as self-organizing functions and special services provider. Furthermore, the flexibility required for next-generation mobile networks can be achieved by including the principles of the NIB in these networks, so it can be the cornerstone of a flexible and adaptable network.

Therefore, the NIB provides services through a wireless connection and an important industrial use case for NIB is restoring basic connections in an emergency. For the case of communication infrastructure damaged and services interrupted, NIB can restore the basic communication services in the affected area in the fastest and easiest way and can quickly deploy a ready-to-use network made up of equipment that requires only minimal setup requirements. In addition, NIB is an attractive solution for handling suddenly increased traffic loads. Several NIBs can be used to offload some mobile-initiated traffic when the peak period of network usage suddenly occurs in the industry. The technology currently used in the NIB solution is mobile technology especially the combination of 6G and Wi-Fi. NIB can also be combined with microwave, Ethernet or fiber optics, Wi-Fi, telemedicine and downloading 3-D maps of buildings to improve the system and enhance the user experience in industrial applications.

NIB can also act as a traditional network and can be deployed stably to implement the wide coverage [17], [18]. NIB can provide connectivity as a stand-alone solution as well as signal connection lost. It is suitable for commercial, private, government, and military scenarios with its small, compact, and portable features. Other advantages include:

1) Independent, secure.
2) Supports up to millions of users.
3) No need for existing infrastructure.
4) Operate as a secure standalone or integrated.
5) Integrate 4G LTE functions into existing networks.
6) Can operate in any LTE band (3GPP or unlicensed).
7) Scalable to meet customer needs.
8) Suitable for air, ground, sea, disassembly and network mobile operations.

The core of the idea of combining 6G technology with NIB is to install all software and hardware modules required by the mobile network into one or several physical devices. The NIB can be deployed in a wide range of situations including extreme disasters, special rescue missions, emergency management, armed forces, peacekeeping missions and transit mobile communications networks. This node component of the radio access network (RAN) in NIB provides a seamless LTE network solution. In addition to being lighter in weight, these enhanced integration technologies translate into better quality of service and higher bit rates for packet data-intensive applications. NIB provides a rapidly deployable, high-speed 6G LTE communications network to support operations of defense, public safety and security forces. It can integrate mobile environment installations of land, air, sea, pedestrian, and unmanned systems to provide mesh communication, thereby expand system coverage. As an independent network, NIB can provide network coverage in rural and remote areas without any existing infrastructure.

VI. Typical use Cases Based on IoE in 6G

In order to realize the vision of "smart connection" in the 6G era, the 6G network will be presented as a "distributed intelligent computing" network architecture. Meanwhile CI technology is also widely used in IoE applications such as fog computing, edge computing, and cloud computing to enable different levels of sustainable computing infrastructure. It can perform large-scale calculations through distributed computing resources, which enable it to solve problems that require processing very large data sets. Fig. 5 shows a simple comparison of them.

A. Mobile Edge Computing

The idea of deploying services on NIB is consistent with MEC, a technology that pushes services to the edge of the network to reduce traffic from the core network. At the same time, MEC can be defined as the implementation of edge computing, bringing computing and storage capabilities to the edge of the network within the RAN to reduce latency [42]–[45]. For example, first, MEC can support vertical segmentation services and provide emerging big data services such as video analysis to authorized third parties. Second, the MEC platform can be located at an aggregation point such as a BBU in a cloud operation deployment or it can be directly located in a mobile backhaul such as a small unit gateway. Third, for video streaming media services, MEC with edge architecture uses video analysis and video management applications to apply intelligent video acceleration solutions. Fourth, use the network as a supported

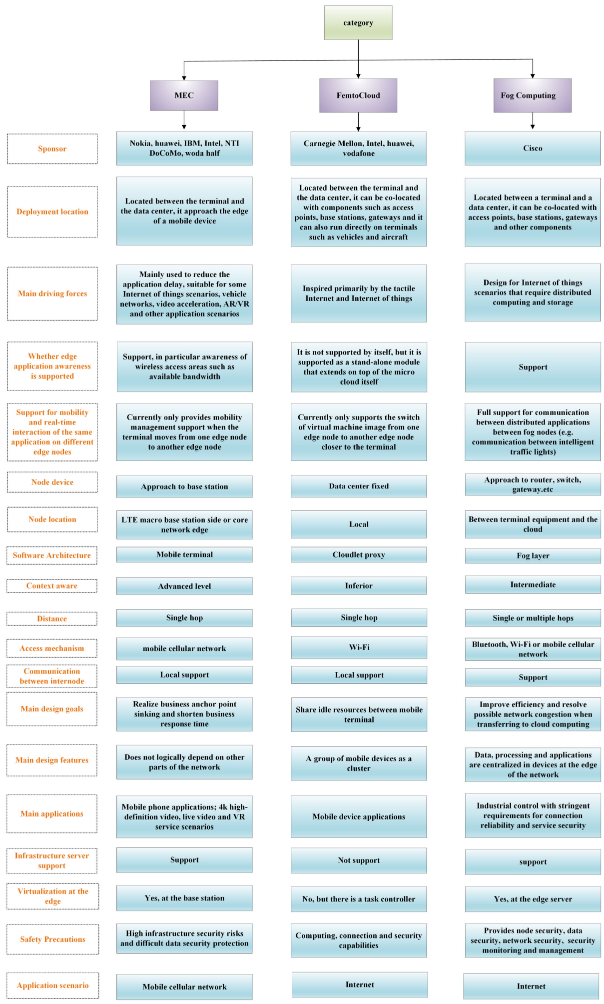

Fig. 5. Comparison of MEC, FemtoCloud, and fog computing.

adaptive streaming media application to encapsulate multimedia content in the MEC to improve the quality of experience. Finally, use the edge as a cache to store media content and increase the life of mobile devices by forcing computational offloading [46]–[47]. In the 6G era, MEC can be widely used in various fields such as transportation systems, intelligent driving, real-time haptic control, and augmented reality.

B. Fog Computing

Fog computing, also known as fog networking, is a distributed computing infrastructure based on fog computing nodes placed on any architectural point between the terminal device and the cloud [45]. The advantages of fog computing are: first, it provides storage near the edge, which reduces the traffic load. Second, reduced data movement across the network and improved security and scalability to a certain extent. Third, reduced network bandwidth and reduced the possibility of data being attacked during transmission [48], [49]. Fog computing plays a role in advertising, entertainment and BDA as well as IoT, connected vehicles, wireless sensor and actuator networks, and cyber-physical systems [34].

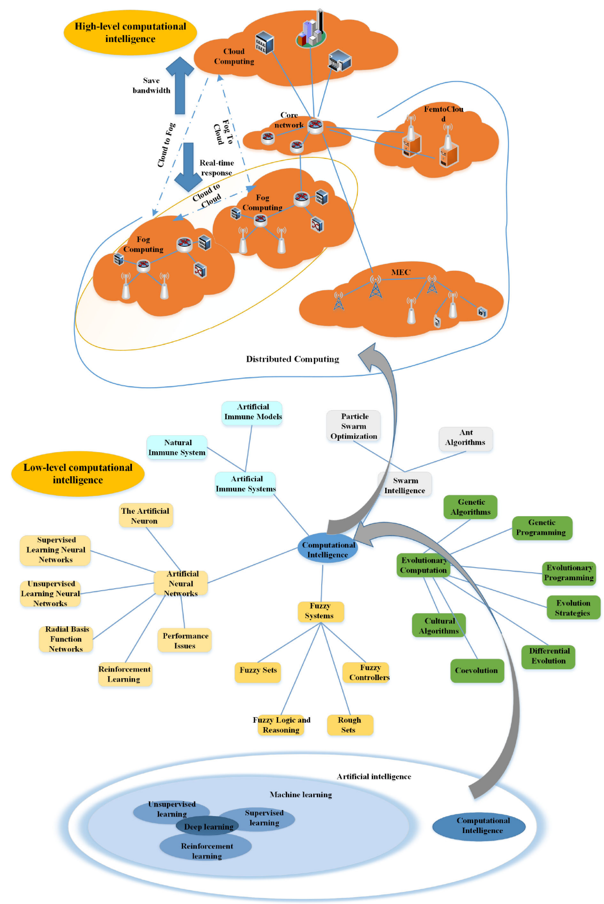

Fig. 6. Relationship for various technologies.

C. FemtoCloud

The basic idea of FemtoCloud is to be controlled by a controller to achieve the function of the cluster [43]. The advantages of FemtoCloud are: better scalability and less dependent on infrastructure. Specifically, FemtoCloud performs various tasks that reach the control device through computing services. The Femtocloud client service running on mobile devices can estimate the computing power from various mobile devices and use it with user input to determine the computing power available for sharing. Then, the Femtocloud client service shares the available information with the control device. The control device is responsible for estimating the user's existence time and configuring the participating mobile devices to provide computing as a service cloud. However, the security of FemtoCloud may become a challenge in such application environments because of the high variability and the dynamics and instability of mobile devices. Fig. 6 shows the relationship between the various technologies.

D. Edge Cloud

Edge cloud is also a typical IoE application, which is an important area for future innovation and has many IoT application potentials. The advantages of edge cloud are: most of the data can be processed through edge cloud or edge computing and reduce the amount of data sent to remote data centers [50], [51]. The application areas of edge cloud include smart home, smart cities, smart health, AR or VR, and machine-to-machine communication [48]. In addition, edge cloud has an absolute advantage in highly accurate 3-D indoor positioning and it saves latency and bandwidth after adopting edge cloud in terms of scalable and flexible video surveillance [52], [53].

VII. IoE in 6G Privacy Issues and Development Trends

A. IoE Security

New demand of IoE emerges gradually with the rapid popularity of IoE worldwide. After integrating IoT technologies such as smart objects, BDA and communication capabilities, and the biggest problem is how to ensure security in such a large-scale scenario. The beautiful vision of 6G makes people look forward to it. But to realize these beautiful visions, we will have to face many technical needs and challenges. The huge traffic and data explosion make it more difficult to identify potential security risks in the 6G era [54]. Since the data generated by smart objects and users of the IoT can be obtained on the network, so there are three key issues for IoT devices and services to be considered: data confidentiality, privacy, and trust [55]–[58].The goals of network security are: protect IoT devices and services that are accessed from inside and outside the device without authorization. Protect services, hardware resources, information and data in conversion and storage.

B. Cybersecurity Issues in Specific Areas

Additionally, network security issues in specific areas also deserve attention with the start of the 5G era and the arrival of the 6G era ten years later. IoE brings changes in the urban infrastructure and makes smart cities possible. The city's pipeline network, electricity, energy, transportation, and other infrastructures have countless sensors and cameras for monitoring and they will be intelligently controlled through the network. However, it also exposes risks to the hacker's vision, once criminals have the viewing authority of the camera, they illegally obtain the information they want through the camera such as a banknote transporter. Cyber security technology which is based on the key core technology of the IoE is the same as AI, big data, and internet of vehicle. Moreover, cyber security is no longer just information security.

C. Outlook

The emerging key technologies accelerate the iterative update of the IoE, which is relying on big data resources to reshape application scenarios such as transportation, medical care, and social governance which change all aspects of urban life [59]. 5G, 6G, IoE, distributed AI and other technologies will be deeply combined with the acceleration of the pace of IoE intelligence in the future. The rise of a variety of intelligent new technologies and mature commercialization are crucial to the development of the IoT toward the era of the IoE such as AI, blockchain, cloud computing, big data, smart home, edge computing, IoT, 5G, 6G and so on [60]–[62]. In the future, the intelligent technology combined with IoE will continue to heat up our smart lives and we can more easily manage data and control our equipment in more directions.

VIII. Conclusion

With the development of wireless technology, 5G would not be able to fully meet the growing demand for wireless communications in 2030. Therefore, 6G would need to be rolled out. The 6G was still in the research stage. The application of 6G technology and NIB in industry would be a new research area. In addition, 6G with CI technology could help us process a large amount of data in the IoE field. This article analyzed 6G technical advantages, described 6G enabled NIB for industrial applications, introduced the basis of CI key technologies thoroughly and summarized relevant application of CI in different scenarios based on IoE, which could use IoE-based distributed computation such as MEC and fog computing for typical use cases. As one of the research directions of 6G technology, distributed intelligent computing had laid a certain foundation for the development of communication technology. Additionally, several privacy issues and challenges were also elaborated in this article.

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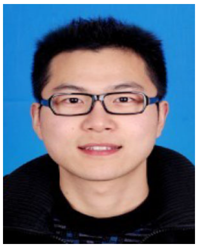

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