# From IoT to 5G I-IoT: The Next Generation IoT-Based Intelligent Algorithms and 5G Technologies

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The authors propose a novel paradigm, 5G Intelligent Internet of Things (5G I-IoT), to process big data intelligently and optimize communication channels. They articulate the concept of the 5G I-IoT and introduce three major components of the 5G I-IoT. Then they expound the interaction among these components and introduce the key methods and techniques based on their proposed paradigm, including big data mining, deep learning, and reinforcement learning.

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## Abstract

The Internet of Things is a novel paradigm with access to wireless communication systems and artificial intelligence technologies, which is considered to be applicable to a variety of promising fields and applications. Meanwhile, the development of the fifth-generation cellular network technologies creates the possibility to deploy enormous sensors in the framework of the IoT and to process massive data, challenging the technologies of communications and data mining. In this article, we propose a novel paradigm, 5G Intelligent Internet of Things (5G I-IoT), to process big data intelligently and optimize communication channels. First, we articulate the concept of the 5G I-IoT and introduce three major components of the 5G I-IoT. Then we expound the interaction among these components and introduce the key methods and techniques based on our proposed paradigm, including big data mining, deep learning, and reinforcement learning. In addition, an experimental result evaluates the performance of 5G I-IoT, and the effective utilization of channels and QoS have been greatly improved. Finally, several application fields and open issues are discussed.

## Introduction

Over the past decade, the world has been changed by some emerging technologies such as big data, the Internet of Things (IoT) [1], and the fifth generation (5G) cellular network, helping to realize "anything, anyone, anytime, anyplace [2]" (4A).

IoT is a worldwide network based on standard communication protocols, and it applies various technologies to gather and provide observation data from the physical world [3] for IoT applications. More than 50 billion devices will be connected by 2020 as components of the IoT [4]. They will generate massive data, with the features of larger size, higher velocity, more modes, higher data quality, and heterogeneity [5]. Meanwhile, the evolution of 5G networks is becoming a major driving force for the growth of IoT. 5G is expected to have extended coverage, higher throughput, lower latency, and connection density of massive bandwidth [2], paving the way for the connection of billions of sensors over the Internet. Furthermore, some potential methods and technologies have been proposed, such as millimeter-wave (mmWave), massive multiple-input multiple-output (MIMO), and machine-to-machine (M2M) communications, so that 5G networks can be well adapted to IoT. Hence, the homogeneous and heterogeneous sensor networks [6] can connect massive sensing devices and make a great contribution to providing advanced and intelligent services for human beings.

The growing interest in the 5G-IoT and its derivative big data urges people to clearly understand its conceptual framework, potential, and challenges. Taking into account its unique characteristics, IoT data bring new challenges to both 5G and IoT, such as trust [7], security, and privacy, and they also have a direct impact on computational complexity and cost in the aspects of data storage and data processing. Meanwhile, the efficiency of transmission and the channel utilization in diverse scenarios are also challenging. Therefore, the capacities of processing big data and optimizing the transmission channel require more intelligent methods, such as machine learning and deep learning [8]. In view of those issues and requirements, we propose the 5G Intelligent Internet of Things (5G I-IoT) as an Internet-connected framework utilizing next-generation communication techniques to transmit and process data, as shown in Fig. 1.

The 5G I-IoT paradigm is the convergence of the Internet, intelligence, and things. Traditional IoT covers the Internet and things, which is a paradigm that integrates a large number of network connection entities. The combination of intelligence and things is an intelligent individual, aiming to build high functional agents or devices to realize difficult applications, such as object recognition, natural language processing (NLP), and intelligent control. Currently, machine learning and deep learning are promising methods to achieve these goals. Based on some key technologies, especially the 5G communication protocols and data exchange standards, as the intersection of the Internet and intelligence, intelligent Internet has higher communicating capability.

Finally, we focus on the concept of the 5G I-IoT, which unites the Internet, things, and intel-

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ligence, including the processing center, object processor, and sensing regions. The processing center is aimed at enabling the 5G I-IoT to deal with data through artificial intelligence (AI) methods [9]. The processing center continuously processes massive data online automatically. The object processor not only connects sensing regions and the processing center but also processes the raw data from the sensing regions and transmits them to the processing center. More importantly, the object processor can receive feedback from the processing center to take an intelligent action. The sensing regions are enormous sensors deployed to realize raw data perception.

In the role of connector, 5G I-IoT is a novel intelligent network based on 5G communication, which is designed to connect sensing regions (sensors) and processing center (cloud). It consists of multifarious devices and many moving server clusters. Based on the traditional IoT, the 5G I-IoT is a further research area with various advantages of 5G networks and AI algorithms.

The 5G I-IoT is intended to realize a scene where objects are seamlessly integrated into the real world and information networks to benefit a variety of applications, such as smart city, agriculture, and environment and energy [4].

In this article, we first propose the concept of the 5G I-IoT and analyze its components. Then several key methods and technologies supporting the 5G I-IoT are introduced. Meanwhile, we describe some performance metrics and illustrate preliminary performance evaluation of the 5G I-IoT. Finally, we discuss future applications and draw the open issues and challenges.

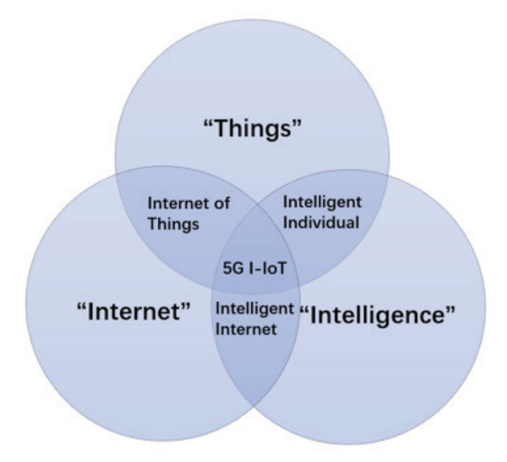

**Figure 1.** The paradigm of the 5G I-IoT.

To easily develop IoT applications under the 5G communication standard supported with little or no human intervention, a 5G I-IoT paradigm is designed with various intelligent algorithms. In the cloud, the processing center includes two components: an intelligent computing module and an execution module.

## The Architecture of the 5G I-IoT

In this section, we describe the architecture of the 5G I-IoT. As shown in Fig. 2, the 5G I-IoT paradigm is based on a general 5G cellular network. It presents the different emerging technologies, involving massive MIMO networks, dense static small cell [10] networks, and mobile small cell networks. Meanwhile, it also outlines the base stations and cloud in the 5G I-IoT architecture. In addition, we incorporate the concepts of device-to-device (D2D) [11] communication, small cell access points, and the 5G I-IoT. Furthermore, three different components of the 5G I-IoT paradigm are depicted.

### Processing Center

To easily develop IoT applications under the 5G communication standard supported with little or no human intervention, the 5G I-IoT paradigm is designed with various intelligent algorithms. In the cloud, the processing center includes two components: an intelligent computing module and an execution module. The intelligent computing module is proposed as a computing hub, consisting of multiple intelligent computing systems. To realize online learning, these systems use a deep learning algorithm, which is introduced in the next section. Each intelligent computing system is an independent intelligent processing unit, in which server clusters are included, and they are integrated through internal connection networks. The processing center performs well in computing and decision making, and it is also responsible for intelligently processing the massive data from the object processor and sending instructions to the object processor or data storage. To the best of our knowledge, no practical approaches have been proposed to build an intelligent processing center in the cloud with intelligent computing systems so far.

### Object Processor

The object processor is set up at the base station and dedicated to connecting the sensing regions and the processing center, which is to process the raw data, transmit the processed data to the processing center, and receive the feedback to make more intelligent strategies and actions. In 5G communication, massive raw data are transmitted to the base station through dense static small cell networks or mobile small cell networks at high cost. Therefore, the raw data should be preprocessed cleanly and redundantly. The involved methods and technologies of the object processor are described in detail in the following section. The object processor expects the feedback from the processing center and executes the instruction whether the channel is disconnected or not. If the channel is disconnected, the data transmission from the sensing regions is stopped, and the channel that transmits the unnecessary information is temporarily dormant. In 5G communication networks, compared to traditional direct data upload, the object processor reduces network load and channel occupancy, and brings about low energy consumption and increased data processing speed.

### Sensing Regions

The sensing regions have abundant sensors, primarily used to measure a quantity from the physical world and convert this quantity into a signal in the digital world in order to be stored or processed easily, and enormous sensors as well as diverse devices are supported by 5G networks [12]. The 5G mmWave will provide some of the emerging applications, such as D2D communication and the Internet of Vehicles (IoV). Meanwhile, these applications also emerge in the sensing regions. Explicitly, the sensing regions are to perceive the state of the world. Hence, we divide the sensing regions into two categories.

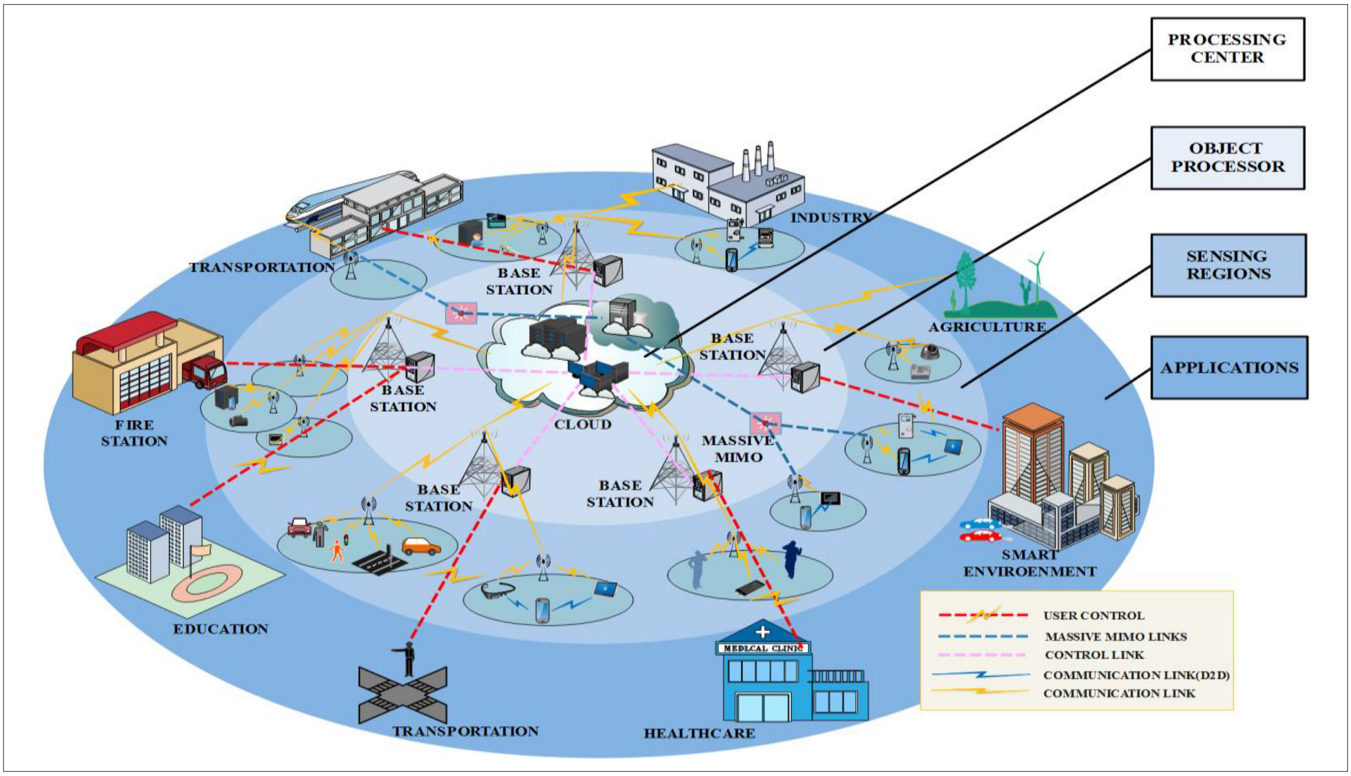


**Figure 2.** The architecture of the 5G I-IoT.

One is the mobile sensing region, which focuses on devices such as the smartphone, laptop, GPS, and car PC; the other is a fixed sensing region, which focuses on sensors such as those for weather, electrical current, and vibration. The regions enable IoT devices to interact with the physical environment and gather sensing data and transmit them to the mmWave small cell station and then to the base station for further processing in the 5G communication environment.

### Interaction among Components

In pervasive communication environments, the IoT interaction is based on the Message Queuing Telemetry Transport (MQTT) protocol [13]. The MQTT communication protocol can deliver a simultaneous message to many receivers, and its network connection is through TCP/IP. MQTT carries multiple types of data gathered from the sensing regions. Generally, MQTT has three messaging service quality types, summarized as:

- "At most once": Message release completely depends on the TCP/IP network, and messages may be lost or duplicated.
- "At least once": Ensure the arrival of the message, but the message may be duplicated.
- "Only once": Ensure that the message arrives once, but the message may be duplicated or lost.

In the proposed 5G I-IoT, the data message is transmitted to the object processor, then to the processing center for further processing. The MQTT communication protocol is used to interact with the three components. More specifically, the messaging service quality of the MQTT will be optimized, since the object processor can receive and process data, then transmit data to the processing center. Thus, the loss and duplication of data information will be reduced, which enhances efficient resource usage.

In the following section, the key methods and technologies used in the three components mentioned above are introduced.

## Methods and Technologies of the 5G I-IoT

In this section, some novel methods and technologies, like big data mining, deep learning, and reinforcement learning, are involved in solving the key problems, helping to fulfill the 5G I-IoT system automatically and intelligently. The combination of AI and 5G technologies applied in IoT can achieve the 4A target.

As mentioned above, big data mining is widely applied in sensing regions and the object processor, and deep learning technology is used in the object processor, while reinforcement learning is involved in both the object processor and processing center.

### Big Data Mining

Compared to traditional data, the big data generated in 5G I-IoT are of various types in which more real-time analysis is required. The 5G I-IoT data mining system contains three agents, namely data collection, transmission, and pre-processing. As illustrated in Fig. 3, the sensing regions are used to accomplish data collection, and then transmit raw data.

On one hand, the fixed sensing regions deploy sensors at some specified locations to collect sensing data in 5G I-IoT according to application requirements. Then the small cell station will disseminate 5G network management and collect commanded messages to all the sensor nodes.

Based on this indicated information, the sensing data are collected at different sensor nodes and transmitted to a base station for further processing. On the other hand, the mobile sensing regions also collect data from various internet applications.

In terms of noise, redundancy, and consistency, data from fixed sensing regions and mobile sensing regions may have different levels of quality. Transmitting, storing, and analyzing raw data would cost more. Therefore, preprocessing raw data is required in the object processor. Generally, the preprocessing methods include integration, cleansing, and redundancy. Data integration combines data from different sources by two main methods, namely data warehousing and data federation. Data cleansing aims to modify or delete incomplete, unreasonable, and inaccurate data. Data redundancy is a method that deletes some redundant data by redundant detection and data compression. The data preprocessing methods are to provide unified data with higher quality conducive to the processing center.

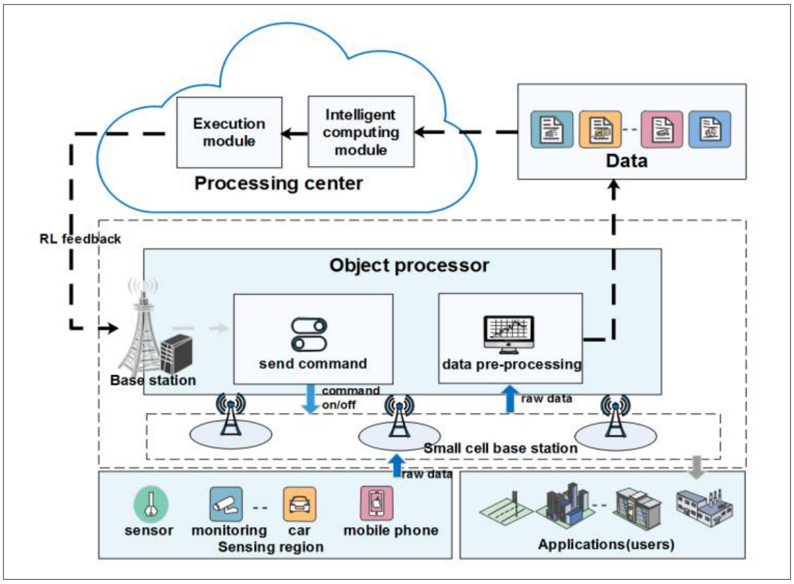


Figure 3. The object processor of the 5G I-IoT.

### Deep Learning

Deep learning is a branch of machine learning based on learning data representations with various architectures, such as deep neural networks, and deep belief networks as well as recurrent neural networks. Deep learning has been applied to many fields and produces better results, comparable to human experts. Generally, deep learning is considered as a vital step toward true AI. With the development of the IoT under the 5G standards, a lot of data streams are generated in the sensing regions and uploaded to the cloud for analysis. Effective ways of combining big data mining and deep learning can provide better services for IoT, so the 5G I-IoT holds the promise of improving people's lives via both intelligence and automation by adopting deep learning algorithms.

As shown in Fig. 4, we set the processing center in the cloud, including the intelligent computing module and execution module, to process data automatically with intelligent algorithms. Also, deep learning algorithms are applied to design the intelligent computing module.

We design various intelligent computing systems, such as a vehicle detection system, a vehicle identification system, a pedestrian detection system, a pedestrian posture recognition system, and an anomaly detection system. They adopt deep learning algorithms and become the foundations of the intelligent computing module. Each intelligent computing system is a separate system to process different data, and moreover, the data information can be shared among systems.

The intelligent computing systems handle various types of data in real time, making the prediction and decision tasks, and upload the processing results to the execution module before sending them to users or being stored locally or in the cloud.

### Reinforcement Learning

Reinforcement learning provides a representation of the states in an environment by taking actions and receiving rewards. One of the features of reinforcement learning is learning the optimal strategy by exploring unknown environments. From this perspective, three components are required with careful treatment, namely agents, rewards, and policies. Details of these components are presented as follows.

In 5G I-IoT, an agent is defined as the set of object processor and processing center. Its input is the data from the sensing regions, while its output is a command that controls the channel's states of activity from the execution module. Each command corresponds with a reward generated in the big data environments. It may stand for objective quantities like channel occupancy or subjective ones like the quality of experience (QoE) of users.

A policy has been designed in the processing center, providing control commands. Under the processing center, one of the key concerns is efficient judgment. Therewith, the policy is introduced in detail.

First, we set a certain probability coefficient indicating the importance of each intelligent computing system in the execution module according to different application scenarios. Second, the probability coefficients are initialized randomly, and the data are processed by the intelligent computing system, and the processing results are multiplied by their corresponding probability coefficients. Then the operation result is compared to some threshold or criterion produced in the execution module. If the result exceeds the threshold, the execution module will send a command to the processor in the base station aimed at closing the data transmission channel and preventing the uploading of unnecessary information.

In the process, the reinforcement learning method helps to accelerate the execution module's automatic learning of the probability coefficients and thresholds for different application scenarios online. Moreover, each intelligent computing system can also learn automatically in different application scenarios to obtain computing results with higher accuracy. According to different scenarios, online learning methods lead to automatic and intelligent progress compared to setting the threshold manually.

The 5G I-IoT is envisioned to address some issues, such as enormous data processing and communication channel congestion. With the combination of 5G technologies and AI algorithms, the visions of the 5G I-IoT are processing big data intelligently, improving the effective utilization of channels and optimizing communication channels.

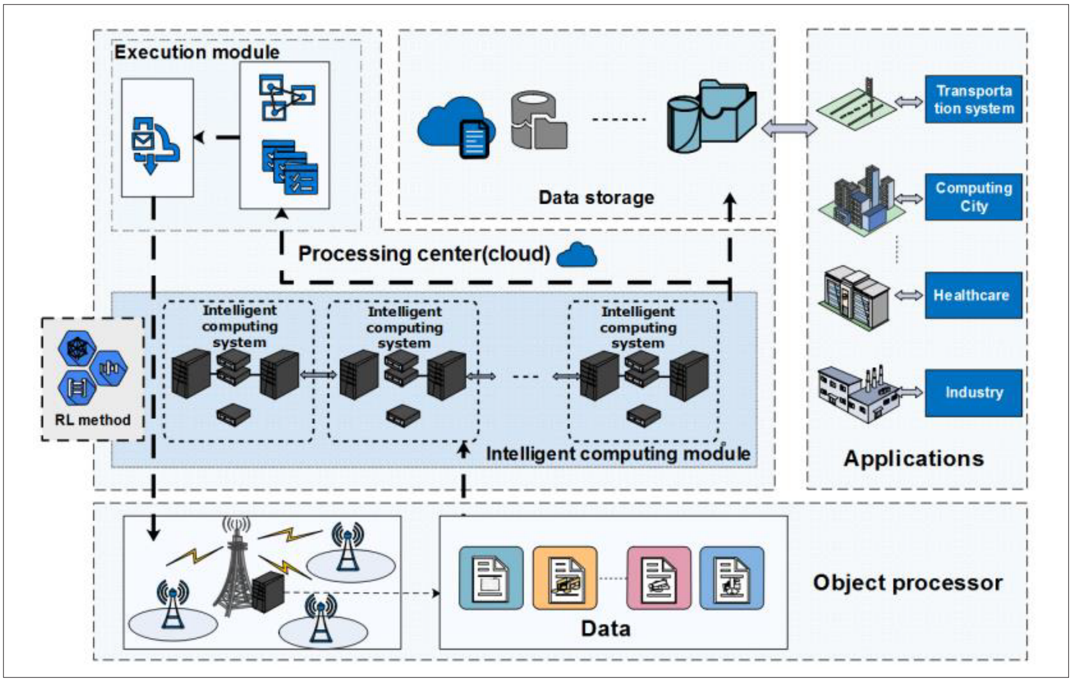


Figure 4. The processing center of the 5G I-IoT.

To sum up, in the 5G I-IoT paradigm, the sensors collect and transmit data to the base station for processing by the object processor, which adopts big data mining. Subsequently, the data is addressed in the processing center with deep leaning, and reinforcement learning is adopted to optimize the entire system online. From the perspective of 5G, the methods and technologies we propose make a great contribution to optimizing the communication networks. Usually, the base station completes the resource allocation, and massive data is waiting to be uploaded. With the increase of the data being transmitted to the processing center, the network load and time consumption of data transmission will be worse. The processing center can intelligently handle the data and give the feedback to the object processor, which executes a command to inactivate the channel temporarily so that more useful data can be received in a shorter time slot, and with lower channel occupancy and energy consumption. The pressure of allocating resources and upload latency are reduced in the base station.

## Performance Evaluation and Key Indices

The 5G I-IoT aims to achieve intelligent processing of big data and optimization of communication channels. Generally, an integrated and fair assessment of 5G communication networks should take more performance metrics into account, including latency (L), spectrum efficiency (SE), energy efficiency (EE), data rates (DR), reliability (R), QoS, load (Lo), implementation complexity, and more [14]. However, due to diversity and complexity, the assessment of communication networks has usually only considered one or two key performance metrics. To assess the effectiveness of the 5G I-IoT, we propose an evaluation indicator and provide a simulation experiment. The evaluation indicator is the effective utilization of channels (EUOC), which is different from the above indicators but related to them.

In Fig. 5, we show the curve of the EUOC in the 5G-IoT and 5G I-IoT. In the experiment, we set up $m$ groups of different service data while assuming $n$ groups of valid services data. The effective utilization rate of the indicator channel is $n/m$. The blue line in the figure is simulated by our method, and the red line is simulated by the traditional method. Obviously, our proposed method is more effective. Moreover, the algorithms of the 5G I-IoT also affect the improvement of some key indicators in 5G network transmission.

In Table 1, we enumerate the performance metrics from three different types of IoT paradigms and analyze whether their performance improves. Compared to 4G-IoT and 5G-IoT, we conclude that the performance of EE, QoS, and EOUC in 5G I-IoT is improved.

The 5G I-IoT is envisioned to address some issues such as enormous data processing and communication channel congestion. With the combination of 5G technologies and AI algorithms, the visions of the 5G I-IoT are processing big data intelligently, improving the effective utilization of channels, and optimizing communication channels.

## Applications and Open Issues

In this section, we provide some specific applications and open issues that are worthy of study in the future.

### Exploring the Applications

As known, traditional IoT has a very wide range of applications, and the proposed 5G I-IoT can not only support these applications, but also make traditional IoT intelligent and automatic. A few possible applications have been provided as follows.

**Intelligent Transportation:** As a part of the big data, data from transportation systems (TS) is becoming pervasive. Reliability and intelligence help to improve TS, reducing road congestion, and fuel and economic losses. With the upcoming

5G era, massive sensors and monitoring devices will be deployed on vehicles, trains, roads, and railways. The methods of deep learning and reinforcement learning are used to analyze the data gathered by the sensors and monitoring devices, which detect pedestrians, traffic sign obstacles, abnormal situation detections, and so on. Then according to the feedback from reinforcement learning, we can predict traffic congestion, weather conditions, and abnormal situations, and provide user traffic information on all roads. Furthermore, the methods of the 5G I-IoT are applied to increasing trafficable scenarios like self-driving and terrorist resistance.

**Intelligent Healthcare:** The 5G I-IoT will improve the quality of human life by executing some tasks intelligently and automatically. Therefore, once we apply the 5G I-IoT to healthcare, a great improvement will be achieved. The physiological characteristics of the patient can be monitored in real time, and the data can be collected to be processed. The processing center can analyze the data of patients' real-time status by intelligent algorithms, including deep-learning-based facial recognition, gesture recognition, target tracking, and some other technologies. Once abnormalities happen, the processing center will trigger the alarm automatically to call nurses and doctors for help or realize remote treatment, which is a great advantage of the 5G I-IoT.

**Intelligent Agriculture:** It is a basic requirement of sustainable development to increase the production of healthy food grains and prevent the loss of crops. In the 5G I-IoT, the data in sensing regions are collected by unmanned aerial vehicles (UAVs) and various sensing devices, and are processed and analyzed intelligently by intelligent algorithms in the processing center, including image matching based on deep learning, texture recognition, plant disease recognition, crop detection and classification, and so on. The analyzed result is used to judge whether the growth of crops is healthy or not, which is automatically transmitted to the GPS vehicles so that they can intelligently fertilize and irrigate the crops.

The 5G I-IoT proposed in this article is a universal framework. In addition to the fields mentioned above, the 5G I-IoT can also be applied to logistics, smart environment, and smart home, which requires more modular algorithms in the computing center.

## Open Issues and Challenges

Although some similar topics of the intelligent IoT have been widely discussed, there are still many issues and challenges. In this section, we describe some challenges and issues in detail.

**Open Research Challenges:** In order to ensure the adoption of 5G I-IoT, the challenges involving the aspects of security, privacy, and trust management should be considered and overcome. Reliable big data fusion and mining are expected in 5G I-IoT with many devices and sensors generating enormous data volume [15], so trust management is important. It should be pointed out that devices and sensors are usually used without supervision and hence are unprotected. In addition, most transmitting data communication is wireless from sensing regions to the base station, which is also easy to eavesdrop. The 5G I-IoT is a human-centered network service, and it is important to preserve the security and privacy of individuals.

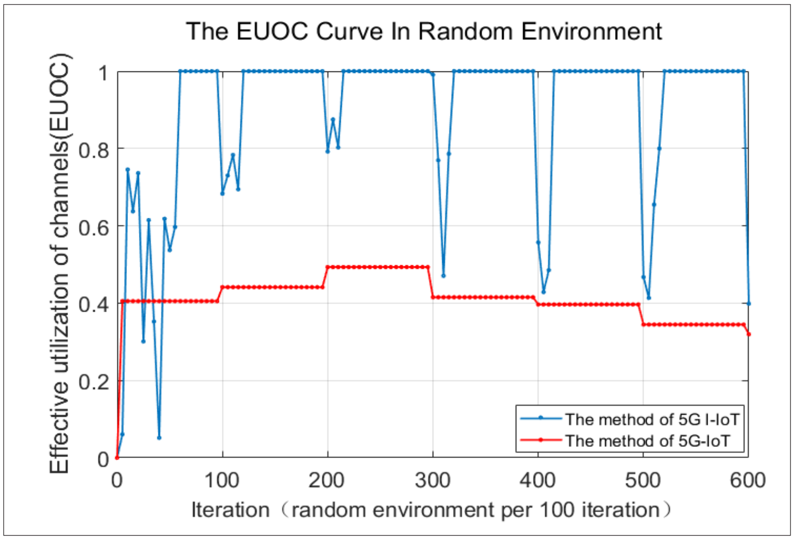


Figure 5. The EUOC curve in a random environment. Every 100 iterations give a random environment, which is a new group of service data.

| | 4G IoT | 5G IoT [14] | 5G I-IoT |
|---|---|---|---|
| L | +– | – | – |
| R | +– | + | + |
| Lo | +– | – | – |
| SE | +– | + | + |
| EE | +– | + | ++ |
| QoS | +– | + | ++ |
| DR | +– | + | + |
| **EUOC** | +– | + | ++ |

Table 1. The performance metrics.

**Future Research Directions:** We summarize the future research directions in two aspects: information fusion and deep reinforcement learning. The sensing regions generate enormous homogeneous and heterogeneous data, which is of a single data source and single modality. To make full use of data resources and mine the most valuable information, and obtain high-quality and expandable data, multi-modal information fusion technology should be considered in the object processor to accomplish the feature extraction and fusion.

Besides, deep reinforcement learning should be considered for application in the 5G I-IoT. It is a new method to incorporate deep learning and reinforcement learning that enables the processing center to learn useful information quickly and send the feedback to the object processor automatically. In the future, reinforcement learning should also be considered in the object processor, allowing the object processor (depending on the environment) to automatically learn the requested content.

## Conclusion

In this article, the concept of the 5G Intelligent Internet of Things (5G I-IoT) has been proposed, which is a novel paradigm of the 5G, IoT, and interactive intelligent technologies. It is envisioned to address some issues, such as enormous data processing and communication channel congestion. Therefore, the prospect of the 5G I-IoT is

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to process big data intelligently, improve channel utilization, and optimize communication channels to realize 4A. This article first introduces three building blocks of the 5G I-IoT, namely the processing center, object processor, and sensing regions. We also discuss the interactions between the main components. Then we have presented some key methods and technologies, which are applied to the 5G I-IoT, such as big data mining, deep learning, and reinforcement learning. To prove the efficiency of the proposed 5G I-IoT, we have provided an experiment, such as the EUOC curve, and analyzed the changes of the key evaluation indicators. Finally, some applications and open issues have been described. We hope this article gives a novel perspective on IoT in which intelligent technologies are applied to the 5G's interaction with the Internet of Things.

## References


[1] A. Whitmore, A. Agarwal, and L. Da Xu, "The Internet of Things — A Survey of Topics and Trends," *Info. Systems Frontiers*, vol. 17, Apr. 2015, pp. 261–74.

[2] M. Agiwal, A. Roy, and N. Saxena, "Next Generation 5G Wireless Networks: A Comprehensive Survey," *IEEE Commun. Surveys & Tutorials*, vol. 18, 2017, pp. 1617–55.

[3] L. Atzori, A. Iera, and G. Morabito, "Understanding the Internet of Things: Definition, Potentials, and Societal Role of a Fast Evolving Paradigm," *Ad Hoc Networks* , vol. 56, Mar. 2017, pp. 122–40.

[4] S. H. Shah and I. Yaqoob, "A Survey: Internet of Things (IOT) Technologies, Applications and Challenges," *Smart Energy Grid Engineering*, Aug. 2016, pp. 381–85.

[5] X. Du *et al.*, "A Routing-Driven Elliptic Curve Cryptography Based Key Management Scheme for Heterogeneous Sensor Networks," *IEEE Trans. Wireless Commun.*, vol. 8, Mar. 2009, pp. 1223–29.

[6] X. Du *et al.*, "An Effective Key Management Scheme for Heterogeneous Sensor Networks," *Ad Hoc Networks*, vol. 5, Jan. 2007, pp. 24–34.

[7] Z. Yan, P. Zhang, and A. V. Vasilakos, "A Survey on Trust Management for Internet of Things," *J. Network & Computer Applications*, vol. 42, June 2014, pp. 120–34.

[8] M. Mohammadi *et al.*, "Deep Learning for IoT Big Data and Streaming Analytics: A Survey," arXiv:1712.04301, 2017.

[9] M. L. Littman, "Reinforcement Learning Improves Behaviour from Evaluative Feedback," *Nature*, vol. 521, May 2015, pp. 445–51.

[10] H. Zhang *et al.*, "Interference Management for Heterogeneous Network with Spectral Efficiency Improvement," *IEEE Wireless Commun.*, vol. 22, no. 2, Apr. 2015, pp. 101–07.

[11] L. D. Xu, W. He, and S. Li, "Internet of Things in Industries: A Survey," *IEEE Trans. Industrial Informatics*, vol. 10, Jan. 2014, pp. 2233–43.

[12] P. K. Agyapong *et al.*, "Design Considerations for a 5G Network Architecture," *IEEE Commun. Mag.*, vol. 52, no. 11, Nov. 2014, pp. 65–75.

[13] A. Niruntasukrat *et al.*, "Authorization Mechanism for MQTT-based Internet of Things.," *IEEE ICC Wksps.*, July 2016, pp. 290–95.

[14] C. X. Wang *et al.*, "Cellular Architecture and Key Technologies for 5G Wireless Communication Networks," *IEEE Commun. Mag.*, vol. 52, no. 2, Feb. 2014, pp. 122–30.

[15] W. Feng *et al.*, "A Survey on Security, Privacy and Trust in Mobile Crowdsourcing," *IEEE Internet of Things J.*, Oct. 2017, pp. 1–1.


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