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Design and application of fog computing and Internet of Things service platform for smart city

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ABSTRACT

Fog computing and Internet of Things technology play a prominent role in the construction of smart cities, which can greatly promote the exchange and management of urban information. Emerging network technologies such as fog computing and the Internet of Things can be used to make it easier to build smart cities, which is conducive to the development of urban business, industry and other industries, as well as tourism and transportation management. Therefore, the realization of a smart city will greatly enhance the comprehensive development strength of the city. We analyze the advantages of fog computing and propose an IoT architecture based on fog computing, which effectively solves the problems of big data processing and network scalability. On this basis, a layered fog computing network architecture is proposed to make the city's operation more coordinated, efficient and harmonious through various intelligent perceptions, information processing and network transmission means.

1. Introduction

With the increasing progress of science and technology, China's urban construction has made new developments, especially after the application of Internet of Things technology and cloud computing technology, which optimizes all aspects of the city and achieves the goal of urban intelligent construction [1]. With the development of urbanization, smart cities have gradually become an inevitable development trend, so we need to focus on exploring the role of cloud computing and Internet of Things technology in smart cities and promote the realization of smart cities [2]. After exploring the theories of cloud computing, Internet of Things technology and smart cities, this paper determines the role of cloud computing and Internet of Things technology and then applies them reasonably to the construction of smart cities, ultimately promoting the rapid development of smart cities.

Fog computing can make full use of the distributed computing, storage, communication and control capabilities in the network environment. Through the resource sharing mechanism and collaborative service architecture, it can achieve a shorter service response time, stronger localized computing capability, lower data transmission load, safer decentralized service architecture, and faster and more accurate analysis, decision-making and control. With the continuous development, maturity and popularization of fog computing technology, the intelligent Internet of Things will become increasingly convenient and efficient. Fog computing and cloud computing will complement each other, provide everyone with accessible and ubiquitous intelligent services, and inject development power into the intelligent city where everything is interconnected.

Overseas research on Internet of Things (IoT) technology in the construction of smart cities, such as D. Menniti and N. Sorrentino, have studied the coordination of microsmart grids in virtual energy zones in future smart cities. They believe that in future smart cities, new information and communication technologies will more effectively manage existing resources [3]. A. Lavric et al. proposed a street lamp remote control system based on large-scale wireless sensor networks, which can decrease power and maintenance costs [4]. Z. Liang and Y. Wakahara studied the urban traffic prediction of ITS based on real-time traffic information and proposed two different urban traffic prediction models with different modeling methods [5]. I. A. T_Hashem, V. Chang and N. B. Anuar discussed the feasibility of applying big data to the construction of smart cities. They believed that big data could provide potential valuable clues for cities from large quantities of data from different data sources and serve for decision-making [6]. Domestic research started late, but relevant scholars have also performed considerable work, such as Sun Ting and other scholars who proposed the requirements of heterogeneous information resource integration, introducing big data and other technical concepts to reconstruct the basic model of information resources, and establishing an integrated retrieval framework of unstructured and structured of data to apply to smart cities [7]. Guo Xian, Li Jun and other scholars analyzed the information security risks faced by various parts of the smart city and constructed the

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information security guarantee system of the smart city from the aspects of organization, system, management, technology, emergency and disaster preparedness [8]. Based on data elements and information utilization, Qin Honghua and other scholars analyzed how to make data open and shared and how to make better use of these data in the process of building smart cities and smart parks and provided suggestions for data mining technology in the construction of smart cities and smart parks [9]. Sun Hongchang and other scholars proposed ZigBee technology in smart homes and smart park wireless network solutions [10].

At present, there are some problems in the construction of smart cities in China, such as a high degree of data fragmentation, fragile security, a high degree of design limitation and a poor degree of intelligence. These problems are applied comprehensively in the Internet of Things, cloud computing, big data and other technologies, especially in how to carry out high coverage of perceptual data technology and network transmission technology [11,12]. How to intelligently process unstructured data (such as audio and video) and how to centralize polymorphic data into the cloud for processing to achieve high data sharing and intelligent decision-making are relatively rare [13,14]. To solve the above problems, this paper combines the fog computing method with Internet of Things technology and carries out applied research in the construction of smart cities. The idea of fog computing is to deploy virtual machines initially deployed in cloud processing centers on the edge of the network. Through wireless access to the network, the functions of the control layer and data layer can be completed on the local CPU. Therefore, fog computing can effectively reduce the computational burden and resource waste. In addition, because fog nodes are closer to the Internet of Things, it can effectively reduce end-to-end delay. The application of cloud computing, the Internet of Things, computers and other technologies can provide necessary technical support to effectively develop urban construction. Therefore, only by reasonably combining cloud computing, fog computing and Internet of Things can we accomplish the task of intelligent city construction and promote the smooth development of urbanization.

2. The concept of the Internet of Things and the significance of building a smart city

2.1. Internet of things concept

The Internet of Things (IoT) is the connection between networks and objects. Through the Internet of Things, a variety of devices can be controlled remotely. The Internet of Things is widely used in many fields, including intelligent transportation, environmental protection, government work, public security, safe homes, intelligent fire control, industrial monitoring, environmental monitoring, elderly care, personal health, flower cultivation, water system monitoring, food traceability, enemy investigation and intelligence collection. Here are ten application fields. The Internet of Things (IoT) is based on the Internet, but it has higher technical requirements. It needs not only network connections and extension of the Internet but also the assistance of satellite remote sensing and other positioning systems. In this way, the Internet of Things can accurately locate any object and realize remote operation [15]. It has strong practicability in many fields, such as power grid construction and maintenance, bridge design, highway maintenance and other people's livelihood projects. In a small way, the Internet of Things can facilitate people's daily life and improve the level of intelligent home life. The Internet of Things can play an important role in the early construction of smart cities. Intelligent cities are mainly composed of four layers, i.e., the layered structure of the network, including the application layer, support platform, network layer and perception layer.

The idea of an intelligent city is very important for the further development of the city. It is mainly embodied in commercial operations, logistics and transportation, medical management, tourism management and other aspects of the city. To improve the intelligent level of the city, it is necessary to apply the Internet of Things technology as new network technology. The realization of intelligent cities will contribute to the development of science and technology and the intellectualization of cities. It is extremely advantageous to the development of the city. Moreover, in the long run, the realization of intelligent cities will create more development opportunities in the city's business, tourism, industry and other sectors. A smart city has a systematic structure, its degree of intelligence is relatively high, and it has a sensitive perception, which is also one of the basic properties of information transmission [16]. Additionally, the intelligent city has a complete structure, reliable information transmission, and high intelligence, which can quickly process a large amount of information. The wisdom of smart city design lies in fewer requirements for management and more dependence on the operation of the system. To a great extent, this can reduce the occurrence of manual errors and improve the efficiency and quality of intelligent management.

The Internet of Things has good significance in the construction of smart cities. The Internet of Things (IoT) has a positive significance in promoting the development of urban industry, involving the industry around the city and commercial development in the central area of the city as well as other industries. In a large sense, the realization of Internet of Things (IoT) technology is of great significance to the readjustment of the industrial structure of a city, which embodies the characteristics of the centralized utilization of resources and the optimization of the structure in a smart city [17–19]. The direct effect of the implementation of the Internet of Things technology is to reduce the cost of urban information management. Because the Internet of Things is based on the network, it processes and quickly stores and transmits a large amount of information. As a new type of technology, physical network technology not only brings new opportunities and vitality to urban economic development but also promotes the formation of new production and management methods. In the direction of urban development, it should be more coordinated with emerging technologies and the trend of the future information age. Internet of Things (IoT) technology is a product of the current information age, and the realization of physical networks will contribute to the overall development of the city, especially in the intellectualization of the city, which is also the basic direction of the construction of smart cities [20–22].

Fog computing can make full use of distributed computing, storage, communication and control capabilities in the network environment. Through the resource sharing mechanism and collaborative service architecture, it can achieve shorter service response time, stronger localized computing capability, lower data transmission load, safer decentralized service architecture, and faster and more accurate analysis, decision-making and control. China's smart city construction is gradually developing. Although the application of cloud computing and Internet of Things technology is conducive to a wide range, there are still many deficiencies that still need to be improved to achieve the goal of urban construction. Therefore, we need to use the existing technology reasonably according to the actual situation so that the construction of smart cities can have perfect technical support and finally promote the construction of smart cities. It can be predicted that with the continuous development, maturity and popularization of fog computing technology, the intelligent Internet of Things will become increasingly convenient and efficient. Fog computing and cloud computing will complement each other, provide everyone with accessible and ubiquitous intelligent services, and inject development power into the intelligent city of everything interconnection.

2.2. The necessity of smart city construction

The development of smart cities is a dynamic process. The concept and development goal of cities will be sublimated with the development goal of society. Building a smart city is actually a process from traditional development to intelligent development, which is committed to the rational use of resources and the improvement of environmental quality. At present, China's smart city construction is in full swing, and many cities have introduced relevant measures and action plans. By 2018, 95% of the cities were above the subprovincial level and 83% of the prefecture-level cities in China, and more than 500 cities have clearly proposed or are building smart cities in the government work report or the 13th five-year plan.

The construction of China's smart city is mainly driven by four internal factors: the requirements of the urbanization process with Chinese characteristics, the promotion of national and local policies, the "promotion" role within the government, and the "traction" role of people's living needs. China's smart city construction has developed rapidly in the past five years, and some driving factors (such as economic development level, urbanization speed, digital infrastructure and technological innovation) are at a high level among the major smart cities in the world. However, in general, China's smart city construction is still in the development stage. Compared with the developed regions in Europe and America, the construction of smart cities in China is characterized by government-oriented, diversified application scenarios, flexible use of advanced technologies and diversified investment models.

The development of smart cities in China has several characteristics:

(1) Need to meet the needs of industrialization, information technology, agricultural modernization, new urbanization and other economic development;
(2) China's smart city construction emphasizes the overall planning and management of the government, and government departments play an active leading role in the construction of smart cities. The source of funds is quite different from that of foreign countries;
(3) The population density and scale of China's large cities in the world are low, which leads to substantial congestion and pollution. The public service level needs to be improved. The multiparty sharing and intelligent use of big data can help solve these problems.

A smart city represents a new urban development concept and innovation-driven model, which is related to the long-term and comprehensive development of the city. The advantage of smart city construction lies in resource integration and optimal allocation, which is conducive to industrial chain integration and promotion and regional development coordination. The construction of smart cities not only helps to improve the resource concentration, influence and radiation of the central city but also promotes the development of related industries of surrounding small and medium-sized cities and realizes the cooperation and coordination of urban agglomerations. Therefore, it is very important to study smart cities. In this paper, the application of fog computing and the Internet of Things in the construction of smart cities is studied.

3. Internet of Things architecture based on fog computing

Currently, the popular cloud computing puts considerable data into the "cloud" to calculate or store to compensate for the lack of storage space or computing power of our electronic products. Compared with cloud computing, which is more popular in concept, fog computing is unfamiliar to many people. Let us define it in a popular way: fog computing can be understood as localized cloud computing.

(1) Cloud computing focuses on computing, and fog computing emphasizes the location of computing.
(2) Fog computing is closer to the ground than cloud computing! More specifically, they are in different positions in the network topology.

In fact, there are many similarities between fog computing and cloud computing: they are all based on virtualization technology, providing resource services for multiple users from the shared resource pool. Compared with cloud computing, fog computing is closer to the place where data are generated, "fog is closer to the ground than clouds" is not unreasonable! Therefore, we define it as follows: fog computing is localized cloud computing, which is intuitively understood.

Fog computing is between cloud computing and personal computing. It is a semivirtualized service computing architecture model. In addition, fog computing actually does not have strong computing power. Fog computing combines physically dispersed computers to form weak computing power. However, such computing power is sufficient for small and medium-sized data centers.

Fog computing is the extension of cloud computing, not the replacement of cloud computing. In the Internet of Things ecosystem, the fog can filter and aggregate user information, anonymously process user data to ensure privacy, initially process data to make real-time decisions, and provide temporary storage to improve user experience.

In contrast, clouds can be responsible for a large number of computations or long-term storage tasks (such as historical data storage, data mining, state prediction, integrity decision-making), to compensate for the shortage of a single fog node in computing resources. In this way, the cloud and the fog form a mutually beneficial computing model, which can better adapt to the application scenarios of the Internet of Things.

At present, there are a large number of base stations or routing devices in mobile networks to ensure seamless coverage of users. These distributed base stations or routing devices can also provide services for Internet of Things devices. Due to the diversity of Internet of Things devices, to support the various transmission requirements of Internet of Things devices, each base station or routing equipment should have a variety of access modes, such as Wi-Fi, Bluetooth, ZigBee and LTE. This kind of base station or routing device with multiple access schemes can be considered a wireless gateway for collecting initial data [23]. Connecting fog nodes with these base stations or routing devices can effectively process the collected data.

Because fog computing has many advantages, it can be used in the Internet of Things architecture. Fig. 1 shows the proposed Internet of Things architecture based on fog computing. In this architecture, fog nodes are connected to base stations or routing devices through high-capacity fibers, which can reduce the end-to-end transmission delay. In addition, fog nodes can be deployed on the edge of the cell network so that different base stations or routing devices can use the same fog node to process data. Traditional core networks have low data processing efficiency and poor scalability. A software defined network (SDN) can be used to design a fog node core network. SDN separates the control plane of the network from the data forwarding plane and realizes the programmable control of the underlying hardware through the software platform of the centralized controller, thus realizing the flexible allocation of network resources on demand [24,25]. All switches in SDN are managed by the control plane using the

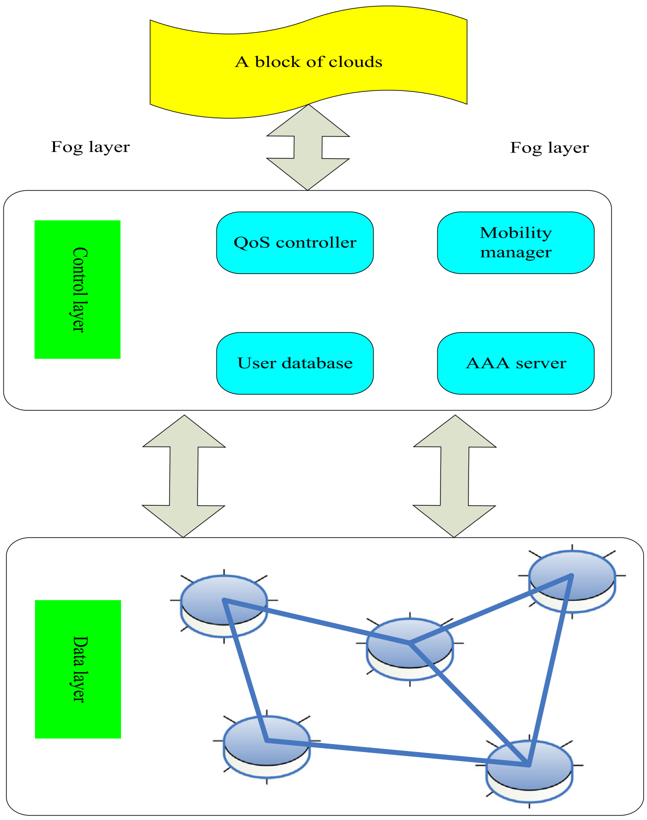


Fig. 1. Internet framework based on fog computing.

OpenFlow protocol. In addition, the control plane can monitor the traffic in the data forwarding plane, establish conversations among users, manage the mobility of users, authenticate users and virtualize network functions.

The fog nodes in the network can be connected with the cloud, which can make full use of the computing power of the cloud to improve the flexibility of network deployment. When there is a large quantity of data to be processed in the network and the fog node does not have enough computing power, the fog node can upload the data to the cloud for processing, but the disadvantage of doing so is that it will cause a large communication delay.

In the Internet of Things, considerable data generated by users may contain personal information, such as photos and videos taken by smartphones, GPS information in smart vehicles, health information perceived by wearable devices and housing status in smart homes [26]. The analysis of these big data is beneficial not only to individuals but also to society as a whole. For example, analyzing photos/videos taken by Internet of Things devices can identify and track terrorists. When an Internet of Things device transmits a terrorist's photo to a fog node, each fog node compares the photo with the photo stored locally. If the comparison is successful, the fog node will transmit the photos to the cloud for further processing. However, the premise of doing this is that users need to share their own data, so protecting users' privacy has become an urgent problem to be solved.

In an intelligent video surveillance system, the basic process of "target detection, behavior analysis and behavior judgment" is usually adopted; that is, the target entry scene is detected by the background-based modeling method. Then, the constraint equation is calculated for the image, and a convolutional neural network is used to judge whether the behavior is abnormal and whether an alarm is needed. The optical flow method is used in the system, which is a two-frame differential optical flow estimation method. The principle is that this method evaluates whether there is distortion between two images. First, it assumes that the image pixels and voxels are conservative and then assumes that the color of an object does not change significantly or dramatically between two adjacent frames. Therefore, according to this idea, the constraint equation of the image is obtained. The calculation is shown in formula (1).

$$I(x_t, y_t, t) = I(x + \Delta x_t, y + \Delta y_t, t + \Delta t) \tag{1}$$

For example, Eq. (1) is a constraint equation. Its function is to calculate the state of the pixel movement between t and Δt of two frames. Because it is based on a Taylor series of image signals, this method can be called difference; that is, for partial derivatives used in time coordinates and space, $f(x, y, t)$ is a pixel at (x, y). If the moving position is rather small, the Taylor formula is used to obtain formula (2) for the image constraint equation.

$$I(x + \Delta x_t, y + \Delta y_t, t + \Delta t) = I(x_t, y_t, t) + \frac{\partial F}{\partial x}\Delta x + \frac{\partial F}{\partial y}\Delta y + \frac{\partial F}{\partial t}\Delta t \tag{2}$$

Formula (3) is deduced by simplifying formula (2) according to the equivalence relation in formula (1):

$$\frac{\partial F}{\partial x}\frac{\Delta x}{\Delta t} + \frac{\partial F}{\partial y}\frac{\Delta y}{\Delta t} + \frac{\partial F}{\partial t}\frac{\Delta t}{\Delta t} \tag{3}$$

Formula (3) consists of x and y directions of I (x, y, t) light flow, and $\frac{\partial F}{\partial x}, \frac{\partial F}{\partial y}, \frac{\partial F}{\partial t}$ is the direction difference of the image at corresponding points (x, y, t), such as formula (4).

The $\frac{\Delta x}{\Delta t}, \frac{\Delta y}{\Delta t}$ in formula (3) is composed of x and y directions in the optical flow direction of $I(x, y, t)$, and $\frac{\partial F}{\partial x}, \frac{\partial F}{\partial y}, \frac{\partial F}{\partial t}$ is the direction difference of the image at the corresponding points of (x, y, t), such as formula (4).

$$I_x V_x + I_y V_y = -I_t \tag{4}$$

Formula (4) is composed of the directions of x and y in the optical vector of V_x, V_y, where $I_x, I_y\, and\, I_t$ are the difference of the corresponding directions of the image (x, y, t). This formula contains five unknowns, so the flow (V_x, V_y) is constant in a small window of 3 × 3, so Eq. (5) can be obtained.

$$\begin{cases} I_{x1}V_x + I_{y1}V_y = -I_{t1} \\ I_{x2}V_x + I_{y2}V_y = -I_{t2} \\ \quad\vdots \\ I_{x9}V_x + I_{y9}V_y = -I_{t9} \end{cases} \tag{5}$$

Convert formula (5) into a linear determinant as formula (6):

$$\begin{vmatrix} I_{x1} & I_{y1} \\ I_{x2} & I_{y2} \\ \vdots & \\ I_{x9} & I_{y9} \end{vmatrix} \begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} -I_{t1} \\ -I_{t2} \\ \vdots \\ -I_{t9} \end{bmatrix} \tag{6}$$

Formula (6) is converted to Formula (7):

$$A\vec{V} = -b \tag{7}$$

According to formula (7), the least squares method is introduced to solve Eqs. (8) and (9):

$$A^T A\vec{V} = A^T(-b) \tag{8}$$

$$\vec{V} = \left(A^T A\right) A^T(-b) \tag{9}$$

According to formulas (8) and (9), formula (10) is:

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum I_{xi}^2 \sum I_{xi}I_{yi} \\ \sum I_{yi}^2 \sum I_{xi}I_{yi} \end{bmatrix}^{-1} \begin{bmatrix} -\sum I_{xi}I_{ti} \\ -\sum I_{yi}I_{ti} \end{bmatrix} \tag{10}$$

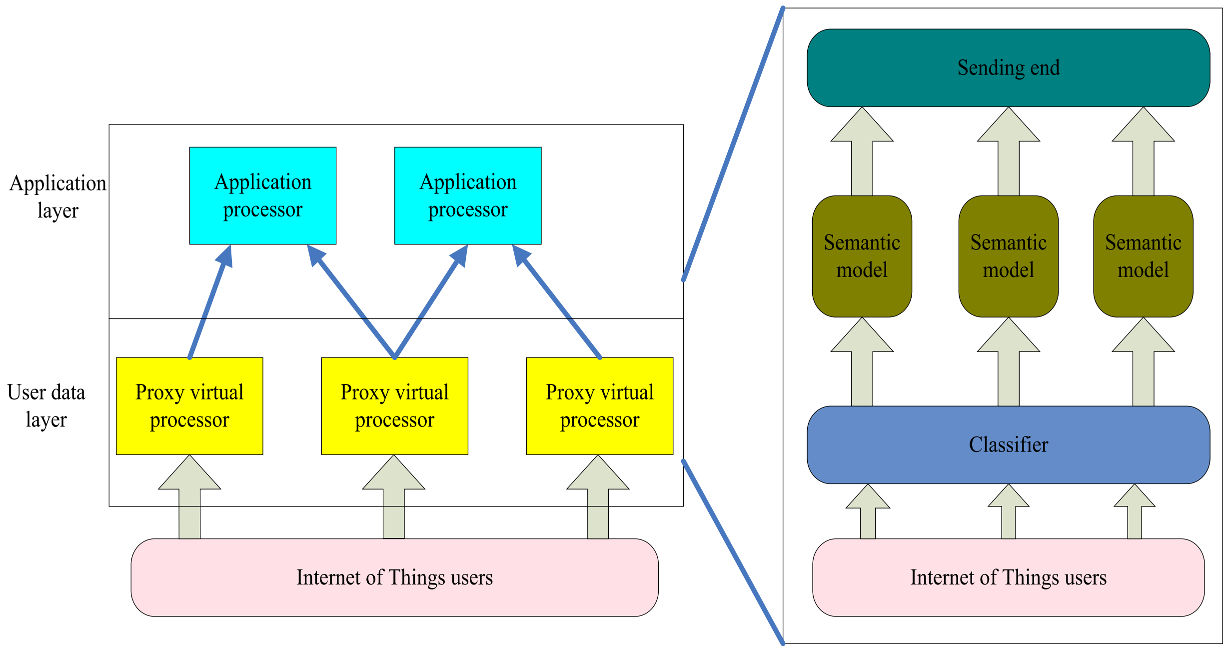


Fig. 2. Hierarchical network architecture.

To solve this problem, we propose a layered fog computing architecture. As shown in Fig. 2, each type of user (the user here refers to a kind of user who owns private Internet of Things devices, such as Internet of Things devices deployed within a company/enterprise, which can share information with each other) is connected to a proxy virtual processor (VM), which has the ability to calculate and store information. Each type of user's Internet of Things device is connected with a proxy virtual processor through a variety of access devices, such as base stations or routers. The proxy virtual server classifies the original data received according to different types and then transmits the data to the corresponding application virtual processor after analysis and processing [27,28]. It should be noted that the data processed by proxy virtual processors remove personal privacy. Virtual processors are used to classify data and provide semantic models for each proxy virtual processor to obtain the information they want.

The deployment of proxy virtual processors can be dynamic, and proxy virtual processors can be deployed near fog nodes if the Internet of Things devices are static (e.g., sensors in smart homes). If the Internet of Things device is dynamic (such as smartphones and wearable devices moving from home to company), the proxy virtual processor can be divided into two parts: one part is still static deployment, and the other part can move with the Internet of Things device. The purpose of this method is to reduce the network load and end-to-end delay effectively.

There are usually two schemes for the deployment of application virtual processors: local application virtual processor deployment and remote application virtual processor deployment. Local application virtual processor deployment refers to the deployment of application virtual processors in fog nodes to process and analyze the data received by local proxy virtual servers. For example, in parking applications, the local proxy virtual server can receive the vehicle information perceived by the intelligent vehicle and transmit it to the local application virtual processor for processing to help users find the appropriate parking place. Remote application virtual processor deployment deploys application virtual processors in remote cloud nodes to process data transmitted by proxy virtual processors of different fog nodes [29,30]. When virtual processors need to know a wide range of information, this deployment becomes necessary. For example, in intelligent transportation, only when virtual processors obtain large-scale traffic information can they provide road congestion information for users to plan the optimal operation path.

4. Smart city architecture based on cloud computing technology

Intelligent cities are the product of the combination of digital cities, the Internet of Things and cloud computing. The ultimate idea of smart cities is to apply perceptual devices to various facilities in urban life to form a massive Internet of Things and to integrate the Internet of Things through backstage supercomputers to realize the data processing, analysis and storage of the front-end Internet of Things to reflect the transformation of urban management and services created by smart cities. As shown in Fig. 3, the architecture of the whole smart city includes four parts: the perception layer, network layer, application support platform and smart application layer.

The front-end perception layer collects data through devices with sensors, RFID, cameras and other modules, and the collected data information reaches the back-end data center through the basic network (wireless network, wired network), local area network and other networks. The data center includes professional databases of various industries. The data center platform has comprehensive abilities of management, calculation, decision-making, and storage. It can provide support for intelligent city applications such as intelligent government, intelligent transportation, intelligent environmental protection, intelligent and campuses.

The construction of smart cities will inevitably result in a large quantity of data coming into the data center through sensors and other terminals, which need to be processed by the data center to realize the intellectualization of various applications. However, the traditional hardware architecture server will have difficulty meeting the management and processing requirements of massive data. If cloud computing is applied to the transport layer and application layer of the Internet of Things and the Internet of Things based on cloud computing is used to make cloud computing serve it, the storage and calculation of massive

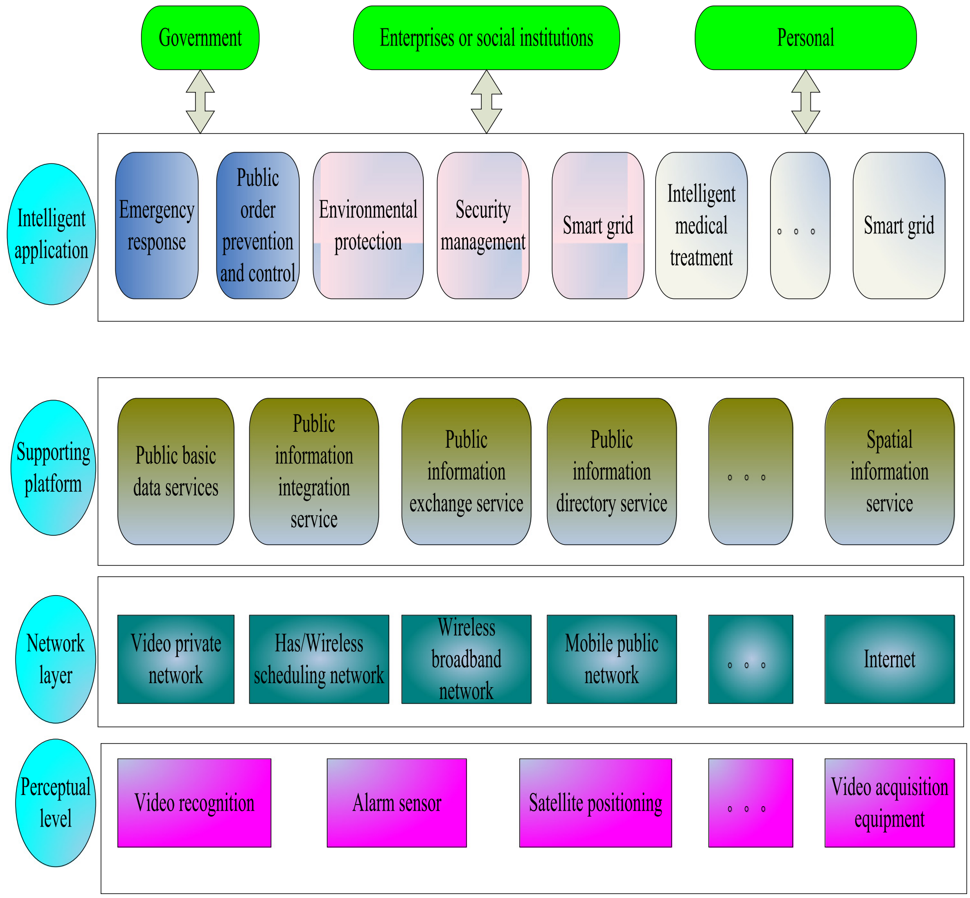


Fig. 3. Smart city architecture.

data in the future development of the Internet of Things and smart cities will be solved, which will also greatly improve the operating efficiency of the application systems. Additionally, the core idea of building a smart city is to achieve a high degree of integration and sharing of information resources, and the most important characteristic of cloud computing technology is to achieve large-scale integration and sharing of resources through sharing to improve the reuse rate of resources. The smart city architecture based on cloud computing and the Internet of Things is shown in Fig. 4.

The system consists of the following parts:

(1) Cloud security layer

Cloud security in the system architecture will cover all levels of smart cities and ensure the smooth development of smart city applications.

(2) Intelligent city operation support system

Establish a smart city operation support system aiming at the new characteristics of smart application construction, operation and maintenance, and management to ensure the application system to run continuously, steadily and safely.

(3) Infrastructure layer

According to the basic architecture of cloud computing, the base of a smart city is the infrastructure layer, which includes intelligent access and basic resources. The smart access part includes Internet of Things perception devices and basic communication networks to ensure the access to smart applications. Basic resources embody the concept of the cloud resource pool and establish various thematic database resources. Each application can access the resource pool and database on demand according to the needs of the system, improve the efficiency of resource utilization, and realize the high sharing and coordination of resources. This is also one of the core ideas of the construction of smart cities.

(4) Cloud service platform and application layer

The middle layer of a smart city is a cloud service platform, and its application is oriented to smart applications. Through the construction of cloud service platforms, information management, sharing and application publishing can be realized. Intelligent processing, such as data mining and data analysis, can better support users' decision-making and action. The application of smart cities mainly focuses on three fields: smart government, smart people's livelihood and smart industry. It realizes the refinement and intellectualization of information applications and meets the emerging information needs in various fields.

(5) Portal level

The upper level of the smart city is the portal layer, which provides various kinds of smart city application results to the government, enterprises and public customers. It is the entrance for urban citizens to experience the smart services directly. The Internet of Things (IoT) is the extension and expansion of Internet applications, which makes the network more interconnected and interoperable. Therefore, the Internet of Things (IoT) has become an important part of a smart city. Because the computing and storage capacity of network terminals is very limited and cloud computing technology has a strong resource integration ability, which can achieve the storage and calculation of massive data and ensure the security of information and the realization of smart cities depends on cloud computing technology. Cloud computing and Internet of Things technology can achieve more thorough perception, wider interconnection and deeper urban intelligence. The intelligent city built on the Internet of Things based on cloud

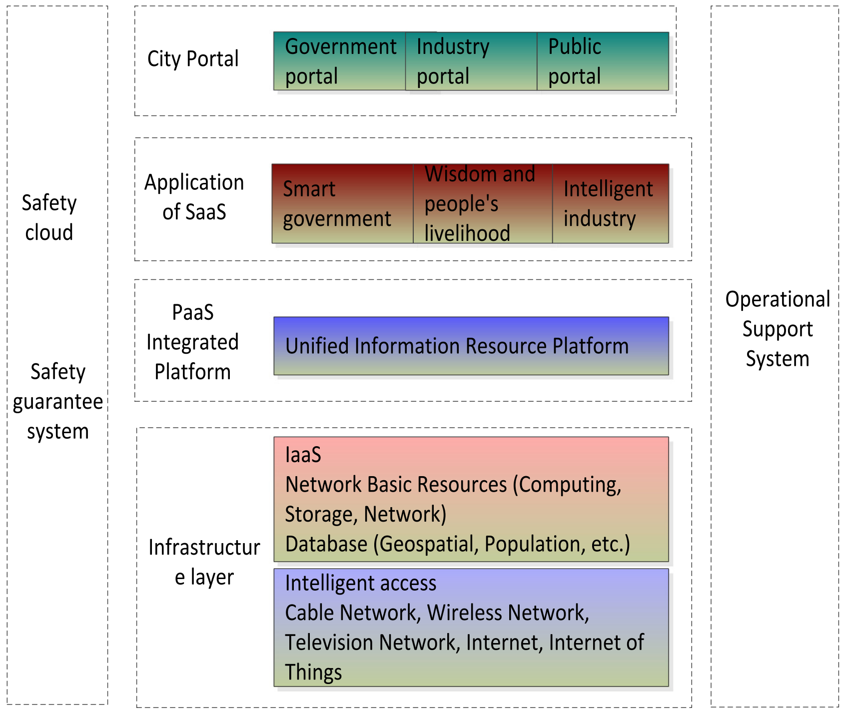


Fig. 4. Smart city architecture based on cloud computing and Internet of Things.

computing will have stronger centralized wisdom to discover and solve problems. Therefore, the construction of smart cities is the construction of efficient urban management mechanisms based on the new generation of information technology, such as the Internet of Things and cloud computing.

The significance of fog computing and Internet of Things technology in smart city construction is as follows:

(1) Promoting the development of the modern service industry

Developing the modern service industry and promoting industrial restructuring is an important historical mission of China's information technology industry. Fog computing makes computing and information services socialized, intensive and specialized and enables more people to enjoy our information technology and information resource services at a low cost. It is an important information technology to promote the development of the modern service industry in China.

Fog computing is an intersection of the modern service industry. On the one hand, it belongs to the modern service industry. On the other hand, it can also provide computing services for other industries, agriculture and traditional service industries, forming a comprehensive supporting relationship. All kinds of computing services in the modern service industry can adopt fog computing solutions. Fog computing will further promote the development of urban intellectualization, and the growing demand for urban intellectualization will promote greater application and technological progress of fog computing services.

(2) Promoting faster development of regional society and economy

Fog computing is a computing model, and its important feature is the integration of resources, which can provide more powerful application support capabilities. Intelligent cities involve thousands of information resources. Fog computing can effectively integrate them, further promote the development of regional information construction, and provide a strong guarantee for faster and better development of regional society and economy.

After years of construction, the traditional wireless city has formed many application platforms in e-government, e-commerce and other aspects and accumulated a large quantity of data, but these platforms are independent of each other, forming a number of data islands, and there are widespread problems such as low equipment utilization, and the high cost of management and maintenance. The construction of a fog computing center enables us to integrate computing resources and data effectively, support the large-scale application of smart city platforms, process larger-scale data, and mine data in depth to provide a better platform for government decision-making, enterprise development and public service.

(3) Reducing the overall cost of regional informatization.

Fog computing, through resource integration, unified management and efficient resource flow, can effectively reduce the overall cost of regional informatization, thereby reducing the threshold of informatization.

First, it reduces investment costs. Usually, IT resource investment planning is purchasing according to the demand of peak business load, which is a form of load maximization planning. Cloud computing can realize the sharing of physical resources by multiple services under the condition of data isolation, that is, to effectively improve the utilization of physical resources on the premise of achieving security. Therefore, using cloud computing to build data centers can increase the utilization rate of IT physical resources to more than 80%, effectively reducing the scale of investment in physical equipment, which is a more efficient direction of investment planning.

Second, the flexibility of IT physical resource allocation improves utilization and reduces daily operating costs.

Finally, the cost of management and maintenance is reduced. Traditional government IT systems have decentralized servers. Every department and enterprise has to devote considerable manpower and material resources to daily maintenance, including hardware maintenance, software upgrade, bug repair, and virus detection. Even a personal computer reinstalling system wastes considerable time. Cloud computing reduces the daily maintenance workload of these departments and enterprises through centralized and unified management of resources. Much work is transferred to the background to be completed by professionals, which effectively reduces the cost of management and maintenance.

(4) Providing security for data

The data of smart cities are related to the normal operation of the whole city, and its importance is self-evident. Cloud computing reduces the risk of data loss or leakage in the hands of enterprises by storing data in a centralized way. Additionally, cloud computing centers also use a variety of security means and disaster recovery backup means to ensure that data will not be lost, nor will the data be illegally tampered with.

5. Experiments and analysis

5.1. Computing resource allocation

We tested the resource allocation time according to different tasks, the initial number of idle service devices and the number of new service devices. The number of new service devices represents the number of new service devices added to the service device queue in a dynamic time window. This paper assumes that the arrival speed of service equipment is stable, and the arrival speed of service equipment is related to the number of subtasks allocated in the previous round. Therefore, this paper assumes that the amount of new service equipment allocated in each round is equal to a preset proportion (the rate of new equipment) multiplied by the number of service equipment matched in the previous round. We set the total task size to 100 and 200, the initial number of idle devices is 20 and 40, and the rate of new equipment is 50% to 120%. The rejection rate of assigning neuron tasks per round (subtask rejection rate means the proportion of subtasks that cannot obtain suitable service equipment in each round matching) is 10%, 30%, 60% and 80%.

It can be seen in Figs. 5 and 6 that when the total number of subtasks is fixed, the resource allocation time when the initial number of service devices is 40 is significantly higher than that when the initial number of service devices is 20. Additionally, the resource allocation time increases with increasing new equipment rates, and the overall trend is stable. With the increase in new service equipment, although the total number of allocation times decreases as the number of devices participating in each round increases, the experimental results show that the allocation time continues to increase. It can be seen that in this scheme, the small-scale multiple matching (the number of devices participating in each round is smaller) operation has advantages over large-scale wireless matching at running time. However, too small of a matching scale will restrict the selection scope of subtasks and service devices to a certain extent and is not conducive to the overall better choice. Therefore, when conditions permit, we can control the number of initial idle service equipment and new service equipment and attempt to avoid a too large or too small-scale allocation. The changing trend of resource allocation time is periodic, which will tend to stabilize or even decline after a period of increase. This is because large-scale resource allocation causes a slight increase in allocation time but simultaneously causes the number of remaining tasks in the later stage of resource allocation to gradually decrease; thus, the growth in allocation time tends to be stable.

Figs. 5 and 6 show that although the allocation time of computing resources for a given quantum task increases with the increase in the new device rate, the larger the rejection rate, the smaller the increase in the allocation time. In Fig. 5(a), when the total number of tasks is 100, the initial number of devices is 20 and the rejection rate is 10%, the new device rate increases from 50% to 120%, the allocation time increases by 4 ms, and the allocation time only increases by 3.5 ms when the rejection rate

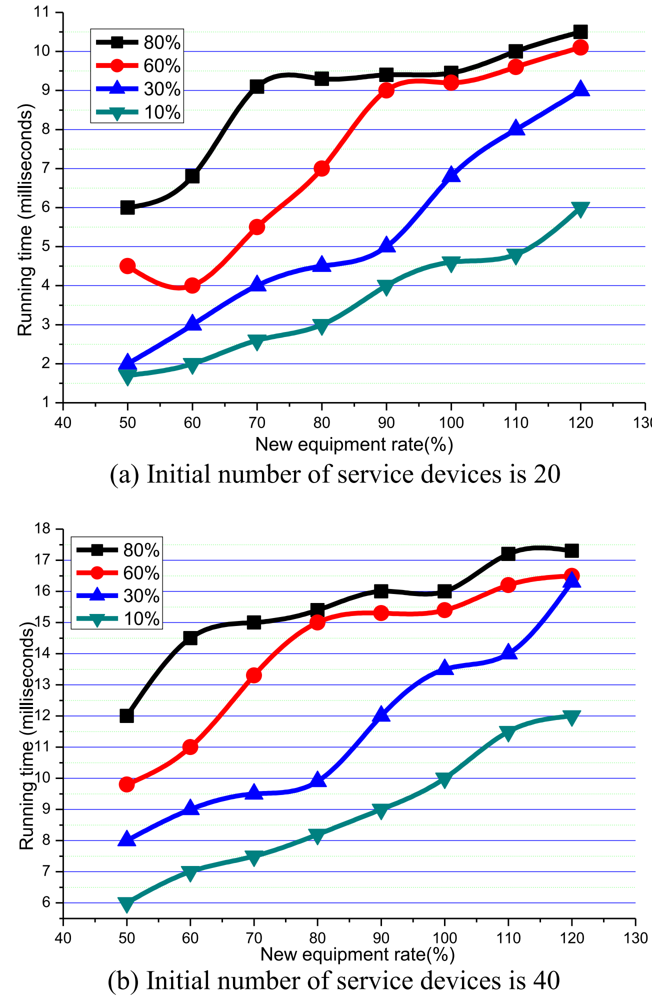
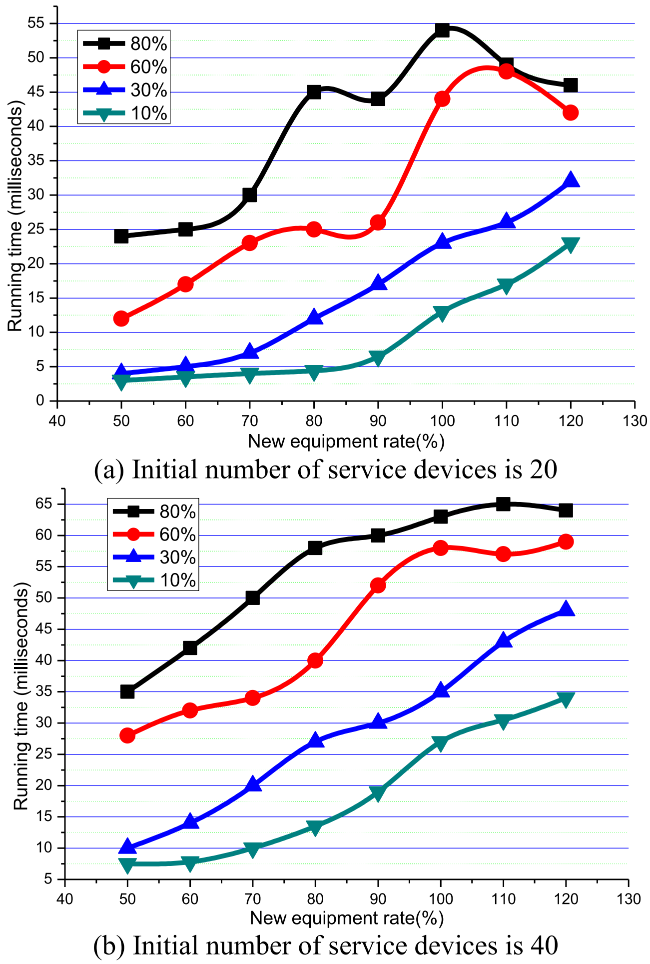


Fig. 5. Allocation of time when the total number of subtasks is 100 (Note: each curve in the figure represents the task rejection rate).

is 80%. This means that even when the rejection rate is high, the allocation of time will not increase dramatically. However, when the total number of tasks is large, the allocation time of computing resources is obviously larger, but the higher the rejection rate of tasks is, the greater the time gap of resource allocation under different tasks. For example, in Figs. 5(a) and 6(a), the initial number of idle devices is 20, and the new service device rate is 110%. When the task rejection rate is 10%, the total task volume is from 100 to 200, and the operation time is increased by 11.6 ms. When the task rejection rate is 60%, the operation time is increased by 38.3 ms. Therefore, when calculating the resource allocation, the smaller the rejection rate of the task, the higher the allocation efficiency and the more stable it becomes.

5.2. Task calculation

To further study the performance of this scheme, this section compares it with the simple genetic algorithm (SGA) and improved ant colony optimization-simulated annealing (ACOSA) in the fog environment when scheduling the execution time and violation rate. The SGA genetic allocation algorithm imitates the selection, crossover and mutation process of genetic evolution to complete the adaptive matching between computing tasks and computing resources. Task completion delay is used as the fitness to control the evolution process, and the optimal matching between computing tasks and computing resources is



(a) Initial number of service devices is 20

(b) Initial number of service devices is 40

Fig. 6. Allocation of time when the total number of subtasks is 200 (Note: each curve in the figure represents the task rejection rate).

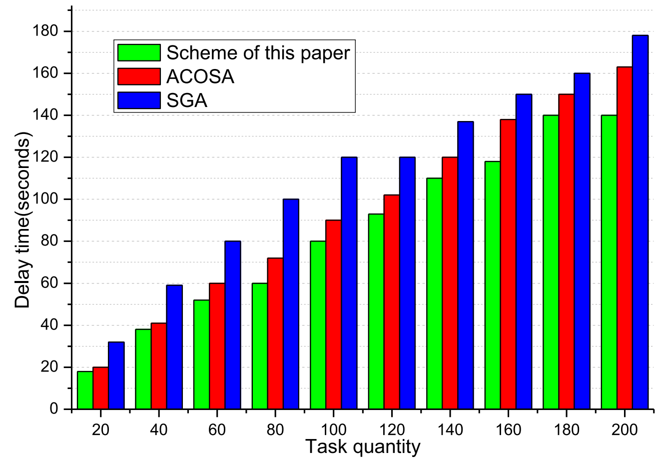


Fig. 7. Time delay comparison under different task volumes.

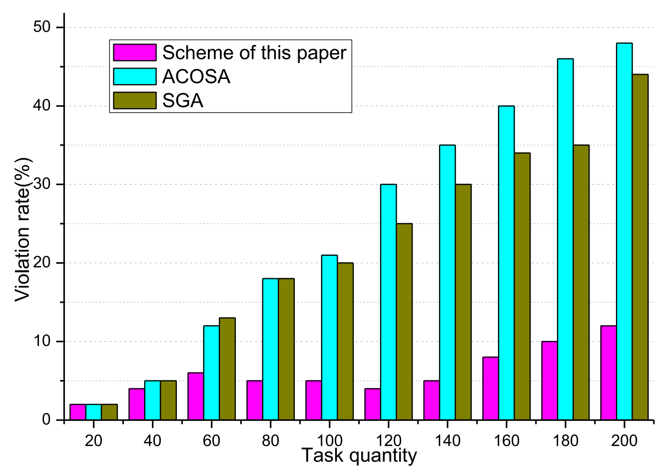


Fig. 8. Comparisons of violation rates under different tasks.

gradually found. The algorithm usually randomly generates a population, so the larger the task size is, the more difficult it is to converge within a limited number of iterations to obtain the optimal task completion delay. The ACOSA algorithm is a task assignment method based on ant colony simulated annealing. It releases pheromones on the path during the ant foraging process and chooses the local optimal assignment according to the concentration of the remaining pheromones. Additionally, it uses a simulated annealing algorithm to obtain a new assignment in a certain neighborhood to prevent the task delay from falling into the local optimal. This algorithm usually requires large computational overhead, and the efficiency of real-time task resource allocation is low. We set up 20 fog computing nodes. The simulation results are shown in Figs. 8 and 9.

As seen in Fig. 7, compared with SGA and ACOSA, the total execution time of this scheme has some advantages. When the number of tasks needing to be processed is small, the delay of the three resource allocation schemes has little difference. However, with the gradual increase in the number of tasks, the advantages of this scheme are gradually reflected. When the task is 80, the proposed scheme is obviously superior to the SGA and ACOSA algorithms. However, as the number of tasks increases, this advantage gradually weakens. This is because the number of fog nodes set up in this section is small, the performance of resource allocation in each round of this scheme is limited by the number of current fog nodes, and the new fog equipment can improve this problem to a certain extent.

Taking the rate of violation of tasks, i.e., the percentage of tasks with timeouts and budgets that do not meet the computational requirements as the measurement index, the three schemes are analyzed. In Fig. 8, we can see that the violation rate of the load balancing ACOSA algorithm is higher than that of the other two algorithms overall, while the violation rate of this scheme is lower than that of the other two algorithms, and the growth trend is slow. This is mainly because the deadline factor of tasks is considered in the resource allocation of this scheme. First, computing resources are allocated for time-critical tasks. However, the SGA and ACOSA schemes do not consider the need for time-critical tasks and increase the processing time and violation rate.

The number of fog computing nodes is 20–100, and the time delay of different numbers of fog computing nodes to complete task scheduling is also compared. The comparison results are shown in Fig. 9.

Fig. 9 shows that the delay difference between the SGA algorithm and ACOSA algorithm is small when the number of fog nodes is 20, but when the number of fog nodes is 100, the execution time of the ACOSA algorithm is approximately 11% better than that of the SGA algorithm. In the same way, it can be seen that the total execution time of the scheme proposed in this paper is significantly better than that of the two schemes with the increase in the number of calculation points of fog nodes, and the advantage is more obvious with the increase in fog equipment. When the number of nodes in fog computing is

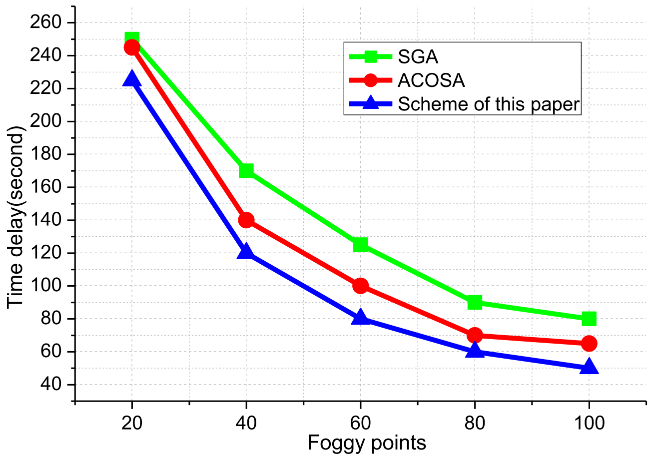


Fig. 9. Time delay comparison under different fog nodes.

20, the execution time of this scheme is 11.7% and 10% lower than the two, and when the number of nodes in fog computing is 100, the execution time is 43% and 29% lower than that of the other two, respectively. Therefore, this scheme is more suitable for the fog environment with more computing resources.

6. Conclusion

Under the background of the continuous renewal of times, the construction of smart cities has become an inevitable urban development process in China. However, to build a smart city, we need to deal with the existing urban resources rationally, make up for the shortcomings of urban construction, and build a long-term urban development plan so that smart cities can be completed smoothly according to the established plan. To enable all aspects of the city to be considered, cloud computing and Internet of Things technology can be reasonably utilized in the construction of smart cities. Advanced information technology and communication technology can be applied in industry, medical industry, transportation industry and infrastructure to meet the requirements of related industry development and promote the perfection of the whole smart city construction. China's smart city construction is gradually developing. Although cloud computing and Internet of Things technology are beneficial to a wide range of applications, there are still many shortcomings that still need to be improved to achieve the goal of urban construction. Therefore, according to the actual situation, we need to rationally use the existing technology so that the construction of smart cities can have perfect technical support and ultimately promote the sound construction of smart cities.

This scheme can effectively reduce the task processing delay and task violation rate, and the running time of the resource allocation process also maintains a certain stability. The computing power of the fog node is the most critical factor affecting the completion of user tasks. However, due to the limitation of the hierarchy of the fog network, network communication resources and storage resources, the competition of multiple resources may have a certain impact on the effective allocation of resources in the fog environment. Therefore, future research will focus on the optimization of computing resource allocation under the constraints of computing power, communication capacity, storage capacity, etc. in the fog computing environment with different requirements to improve the overall efficiency of distributed fog computing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J.G. Ibanez, S. Zeadally, J. Contrerascastillo, Integration challenges of intelligent transportation systems with connected vehicle, cloud computing, and internet of things technologies, IEEE Wirel. Commun. 22 (6) (2015) 122–128.
[2] S.R. Chandra, W. Yafeng, Cloud things construction - The integration of internet of things and cloud computing, Future Gener. Comput. Syst. 56 (C) (2016) 684–700.
[3] D. Menniti, N. Sorrentino, A. Pinnarelli, et al., In the future smart cities: Coordination of micro smart grids in a virtual energy district, in: International Symposium on Power Electronics, IEEE, 2014, pp. 676–681.
[4] A. Lavric, V. Popa, S. Sfichi, Street lighting control system based on large-scale WSN: A step towards a smart city, in: 2014 International Conference and Exposition on Electrical and Power Engineering (EPE), IEEE, 2014, pp. 673–676.
[5] Z. Liang, Y. Wakahara, City traffic prediction based on real-time traffic information for intelligent transport systems, in: International Conference on Its Telecommunications, IEEE, 2013, pp. 378–383.
[6] I.A.T. Hashem, V. Chang, N.B. Anuar, et al., The role of big data in smart city, Int. J. Inf. Manage. 36 (5) (2016) 748–758.
[7] T. Sun, Q.S. Man, Intelligent city architecture based on system engineering theory, Command Inf. Syst. Technol. 5 (2) (2014) 1–6.
[8] X. Guo, J. Li, J. Sun, Construction of information security system in smart city, Telev. Technol. 40 (5) (2016) 22–25.
[9] H.H. Qin, H.Q. Li, et al., Development status of intelligent cities at home and abroad, Global Gather. (9) (2010) 50–52.
[10] H.C. Sun, S.J. Wang, Intelligent city and network application architecture analysis, Pap. Collect. 11 (1) (2017) 17–21.
[11] K. Cui, X. Jing, Research on prediction model of geotechnical parameters based on BP neural network, Neural Comput. Appl. 31 (12) (2019) 8205–8215.
[12] Y. Sun, J. Xu, H. Qiang, et al., Adaptive neural-fuzzy robust position control scheme for maglev train systems with experimental verification, IEEE Trans. Ind. Electron. 66 (11) (2019) 8589–8599.
[13] P. Hu, H. Ning, T. Qiu, et al., Fog computing-based face identification and resolution scheme in internet of things, IEEE Trans. Ind. Inf. 13 (4) (2017) 1910–1920.
[14] P.G.V. Naranjo, Z. Pooranian, M. Shojafar, et al., FOCAN: A fog-supported smart city network architecture for management of applications in the internet of everything environments, J. Parallel Distrib. Comput. 132 (2019) 274–283.
[15] J. Ni, K. Zhang, X. Lin, et al., Securing fog computing for internet of things applications: Challenges and solutions, IEEE Commun. Surv. Tutor. 20 (1) (2018) 601–628.
[16] G. Chen, E. Wang, X. Sun, et al., An intelligent approval system for city construction based on cloud computing and big data, Int. J. Grid High Perform. Comput. 8 (3) (2016) 57–69.
[17] C. Fiandrino, F. Anjomshoa, B. Kantarci, et al., Sociability-driven framework for data acquisition in mobile crowdsensing over fog computing platforms for smart cities, IEEE Trans. Sustain. Comput. 2 (4) (2017) 345–358.
[18] Z.H. Wu, Research on the application of internet of things technology to digital museum construction, Acta Geosci. Sin. 38 (2) (2017) 293–298.
[19] W. Wei, X. Xia, W. Marcin, et al., Multi-sink distributed power control algorithm for cyber-physical-systems in coal mine tunnels, Comput. Netw. 161 (2019) 210–219.
[20] N. Mohamed, J. Al-Jaroodi, I. Jawhar, Towards fault tolerant fog computing for iot-based smart city applications, in: 2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC), IEEE, 2019, pp. 0752–0757.
[21] J. Zhao, X. Zheng, R. Dong, et al., The planning, construction, and management toward sustainable cities in China needs the environmental internet of things, Int. J. Sustain. Dev. World Ecol. 20 (3) (2013) 195–198.
[22] Y.B. Wang, Z. Wang, D.Y. Zhao, et al., Intelligent operation and maintenance of substations based on internet of things (iot) technology, Appl. Mech. Mater. 742 (1) (2015) 708–716.
[23] N. Zhu, T. Diethe, M. Camplani, et al., Bridging e-health and the internet of things: The SPHERE project, IEEE Intell. Syst. 30 (4) (2015) 39–46.
[24] H. Su, Y. He, J. Nie, et al., Research on application of green building to urban carbon exhaustion reduction based on the internet of things, J. Nat. Disasters 23 (6) (2014) 88–94.

[25] C. Cao, F. Cui, L. Xu, Research on intelligent traffic control model and simulation based on the internet of things and cloud platform, J. Comput. Theor. Nanosci. 13 (12) (2016) 9886–9892.
[26] R. Gupta, Resource provisioning and scheduling techniques of iot based applications in fog computing, Int. J. Fog Comput. (IJFC) 2 (2) (2019) 57–70.
[27] H. Cheng, N. Wu, J. Lian, The management and monitor system of tunnel construction based on internet of things, Lect. Notes Electr. Eng. 334 (2015) 1019–1026.
[28] C.Z. Li, F. Xue, X. Li, et al., An internet of things-enabled BIM platform for on-site assembly services in prefabricated construction, Autom. Constr. 89 (2018) 146–161.
[29] L. Liang, Research on the application of PLC control cabinet in the construction of oil field internet of things, Int. Technol. Manage. (2) (2017) 29–31.
[30] B. Tang, Z. Chen, G. Hefferman, et al., Incorporating intelligence in fog computing for big data analysis in smart cities, IEEE Trans. Ind. Inf. 13 (5) (2017) 2140–2150.

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