Research on Remote eSIM Provisioning Management Technology for 5G Terminal

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Abstract

The use of eSIM in mobile terminals such as the Internet of Vehicles has become the general trend, and more and more enterprises have put forward clear requirements for the remote provisioning of eSIM. This paper aims to combine 5G technology to analyze remote eSIM provisioning management technology for terminal, and combine algorithm improvement to improve remote eSIM information management and control effects. Moreover, this paper describes in detail the three-layer communication structure in the communication model, the design of edge gateway nodes, and the query mechanism for cloud center request names and data resources. In addition, this paper uses experiments to evaluate the connectivity of the eSIM three-layer communication model and the characteristics of the NDN network. Through experimental research, it can be seen that the remote eSIM provisioning management model proposed in this paper has certain advantages when applied to the Internet of Vehicles compared with the existing remote provisioning management technologies for the Internet of Vehicles. This

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article takes the Internet of Vehicles as an example to conduct research. At the same time, its support for mobility can be well applied to the Internet of Vehicles to meet the mobility of terminal vehicles. Therefore, it can provide some reference in the subsequent development of Internet of Vehicles technology.

Keywords: 5G terminal, eSIM, remote, management.

1 Introduction

The most significant difference between an eSIM card and an ordinary SIM card is the shape and packaging form. Ordinary SIM cards are mainly used in mobile phones or tablet devices to support basic mobile communication services and value-added services. Meanwhile, the use environment has no special requirements for SIM packaging technology and software and hardware, and it adopts plug-in packaging. In order to ensure the stability of mobile communication and the physical security of the device itself, IoT terminals often use eSIM cards to replace traditional plug-in SIM cards, that is, eUICC chips are directly soldered on the terminal circuit board (SMD mode) or directly packaged into the communication module (SIP mode).

Most IoT application terminals use mobile communication networks for data communication, especially high-speed mobile carriers such as cars, which rely more on high bandwidth and low latency mobile networks [1]. The SIM card, widely used by various operators as a carrier of user authentication information for mobile communication, is an essential component of mobile communication terminals. However, traditional plug-in SIM cards are difficult to meet the needs of in car devices that often work in extreme temperature and violent vibration environments. Embedded SIM cards have been increasingly applied. ESIM (embedded SIM) is a device that writes the customer identification information of mobile operators into an embedded universal integrated circuit card (eUICC) and is fixed on the embedded terminal device. It cannot be easily removed or replaced, and users cannot directly replace it. Remote management of code resources is required in the later stage, so that mobile communication networks of different operators can be switched when the terminal sells or travels across regions [2]. Many eSIM card manufacturers have developed remote code management systems based on eSIM. In order to establish a more compatible remote code writing system among more operators worldwide, international standards are also being developed one after another [3].

The use of eSIM in the Internet of Vehicles is the general trend, and more and more car manufacturers have put forward clear requirements for the remote provisioning of eSIM. However, the reduction in potential user stickiness brought about by code number switching across operators is something operators do not want to see. From the perspective of operators, providing code number remote provisioning and handover capabilities on a global scale is an opportunity for operators to improve their competitiveness and expand their service scope.

Traditional physical SIM cards are beginning to evolve towards embedded user identification modules (E-SIM) and software user identification modules (SoftSIM). On the other hand, operators have built a large amount of public WLAN infrastructure, hoping to alleviate network pressure by diverting traffic to cellular mobile networks through WLAN. Using E-SIM and SoftSIM to achieve Wi Fi access becomes very meaningful, which will be beneficial for operators to provide better services to users.

This paper describes in detail the three-layer communication structure in the communication model, the design of edge gateway nodes, and the query mechanism for cloud center request names and data resources. In addition, this paper uses experiments to evaluate the connectivity of the eSIM three-layer communication model and the characteristics of the NDN network. Through experimental research, it can be seen that the remote eSIM provisioning management model proposed in this paper has certain advantages when applied to the Internet of Vehicles compared with the existing remote provisioning management technologies for the Internet of Vehicles. This article takes the Internet of Vehicles as an example to conduct research, and combines examples for technical verification

2 Related Work

Mobile data services mainly originate indoors and are concentrated indoors. People are usually accustomed to using cellular mobile data in hot indoor areas, so the requirements for mobility are not high. Most of the time, people use applications that are not sensitive to Quality of Service (QoS), such as browsing web pages and sending and receiving messages. Therefore, good service quality assurance is also needed [4].

At present, the public Wi Fi hotspots deployed by operators enrich the access methods of users and supplement the access methods of cellular mobile communication networks. Most of the public WLAN services provided by operators also exist as a complimentary part of cellular network packages. The current public Wi Fi hotspots mostly adopt the authentication method of Web+Portal, which uses mobile SMS or username and password for access authentication [5]. Before each network connection, it is necessary to enter the phone number, obtain and correctly enter the verification code or enter the correct username and password to access the network. It cannot achieve automatic access without human intervention, so its convenience of use is still significantly different from cellular networks. The development of the Internet of Things and smart terminals has put forward new requirements for SIM cards in cellular mobile networks. Simply reducing the physical size of SIM cards is becoming increasingly inadequate to meet application requirements. The embedded user identification module (E-SIM) and software user identification module (SoftSIM) can not only achieve the functions of traditional physical user identification modules, but also support multiple IMSI, remote management, and online downloading and switching of user identification modules, which can enrich the user experience [6]. Traditional physical SIM cards are beginning to evolve towards embedded user identification modules (E-SIM) and software user identification modules (SoftSIM). In addition, operators have invested a considerable amount in WLAN infrastructure construction, hoping to use WLAN to divert cellular mobile networks and alleviate network pressure. The use of E-SIM and SoftSIM to achieve Wi Fi access authentication has become very meaningful, which will be beneficial for operators to manage users and provide users with a better service experience [7].

With the development of communication technology, wireless remote collection terminals can have multiple network transmission methods, and each network technology has its own characteristics. Overall, GPRS technology adopts packet switching and has the characteristic of flexible use of resource channels. By upgrading some software of the GSM system, it provides an efficient and low-cost communication method, meeting the needs of production and life [8]. Wireless data acquisition systems based on GPRS technology have been widely used in industrial scenarios such as remote meter reading, agricultural detection, and oil field monitoring in foreign countries. However, GPRS technology also has disadvantages such as slow transmission speed and the need for operator networks. In order to solve these problems of GPRS, LoRa and NB IoT technologies have emerged [9]. Internationally, countries such as the United States, France, India, and South Korea have successively built remote wireless acquisition systems based on LoRa technology. Among them, American cable TV companies have used LoRa technology to complete multi location network deployment and applied it to industries such as meter reading and environmental monitoring, achieving good results. Compared to unauthorized LPWAN technologies such as LoRa, NB IoT technology, although having a one-year lag, is very active internationally; From a regional perspective, it is developing faster in Europe and Asia, with a focus on eMTC technology in the North American market. Based on the analysis of EC-GSM-IoT and LTE-M technologies, OlofLiberg et al. focused on how to design NB IoT physical channels to achieve flexible deployment and wide coverage. They also described the transition process from idle mode to connection mode, and finally described the control process including scheduling, power control, and multi carrier operation [10]. Based on the current disadvantage of mobile NB IoT terminals only supporting cell reselection in idle state, reference [11] studied the cell reselection of NB IoT, analyzed the characteristics of NB IoT cell reselection, designed a method to optimize cell reselection parameters, and achieved good results.

There are many communication methods between IoT devices, and each technology has its own characteristics. According to the different requirements of the application layer, suitable technologies can be selected.

In terms of networking methods, self-organizing network technology includes four technologies: WiFi, Bluetooth, ZigBee, and LoRa. The first three technologies have close transmission distances, and Bluetooth and ZigBee belong to individual area network communication technology, WiFi belongs to local area network communication technology, and LoRa has a long communication distance, belonging to wide area network communication technology. 2G/3G/4G, eMTC, and NB IoT utilize existing cellular mobile networks for data transmission, and all have the characteristic of long transmission distances. In terms of power consumption, ZigBee, LoRa, eMTC, and NB IoT technologies belong to low-power technologies, with general power consumption values below 10 mA; WiFi, Bluetooth, and 2G/3G/4G transmission technologies have high power consumption, ranging from 10–50 mA [12]. In terms of application areas, WiFi is mainly used for wireless internet access to terminals; ZigBee is used as a sensor for wireless sensor networks; Cellular network technology is used for outdoor equipment, and the demand scenarios for different cellular network technologies also vary [13]. In terms of transmission rate, for scenarios with a speed greater than 10 Mbps, low latency, and high reliability, such as virtual reality, video surveillance, vehicle networking, etc., transmission technologies such as 4G/5G are usually used; For scenarios with a transmission rate requirement of around 1Mbps, low mobility, and voice requirements, such as smart homes, wearable devices, handheld terminals, etc., access technologies often use technologies such as 2G, GPRS, 3G, etc; For LPWAN scenarios, technologies such as LoRa/Sigfox/NB IoT are commonly used. NB IoT technology has the advantages of low power consumption, long transmission distance, and low cost compared to other technologies, making it suitable for application in low-speed terminal devices widely present both indoors and outdoors [14]. The NB IoT technology in authorized frequency bands can alleviate network heterogeneity, form unified standards and formats, and promote the development of smart cities [15].

As typical representatives of eSIM card applications, MFF1 and MFF2 cards used in the M2M field of the Internet of Things have made corresponding improvements and upgrades in smart card chips, packaging forms, electrical characteristics, environmental adaptability, memory management, security mechanisms, etc. They are also different from existing management modes in number allocation, production and distribution, network access management, etc. At the same time, they have also been optimized and improved in card interfaces and communication protocol processes to adapt to the characteristics of IoT business applications [16].

ESIM is not limited to the field of IoT business. With the development of related technologies and the gradual improvement of standards, its application scope can be expanded to the original SIM card issuance mode, number resource allocation mechanism, user contract management system, etc., which will be overturned. The industrial relationship and business support system between card merchants, operators, chip manufacturers, and terminal manufacturers will also undergo significant changes, and corresponding regulatory measures and strategies need to be adjusted appropriately [17].

In this paper, the implementation of eSIM technology, the status quo of standard formulation, application scenarios and remote provisioning management are analyzed and studied accordingly. Moreover, this paper innovatively proposes a three-layer communication model, which aims to improve the effect of eSIM in mobile terminal information intelligent management.

3 Research Methods

With the wide application of the Internet of Vehicles, terminal devices are constantly increasing, and the data generated by terminal devices is also exploding. The traditional TCP/IP architecture based on the “end-to-end” communication method has gradually exposed many aspects of discomfort, and cannot meet the development needs of the Internet of Vehicles in terms of reliability, security and mobility.

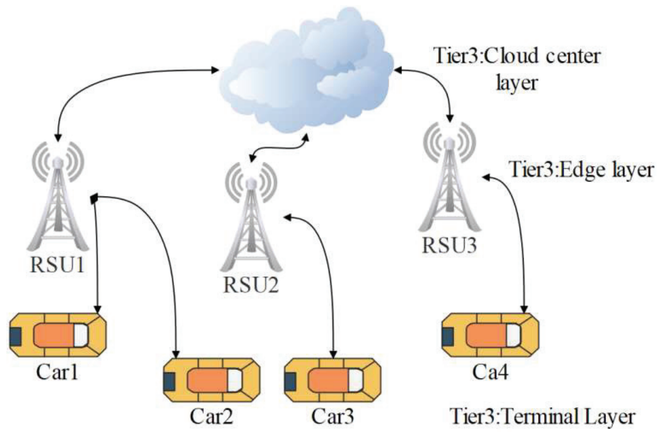


Figure 1 Communication architecture diagram.

3.1 Communication Model

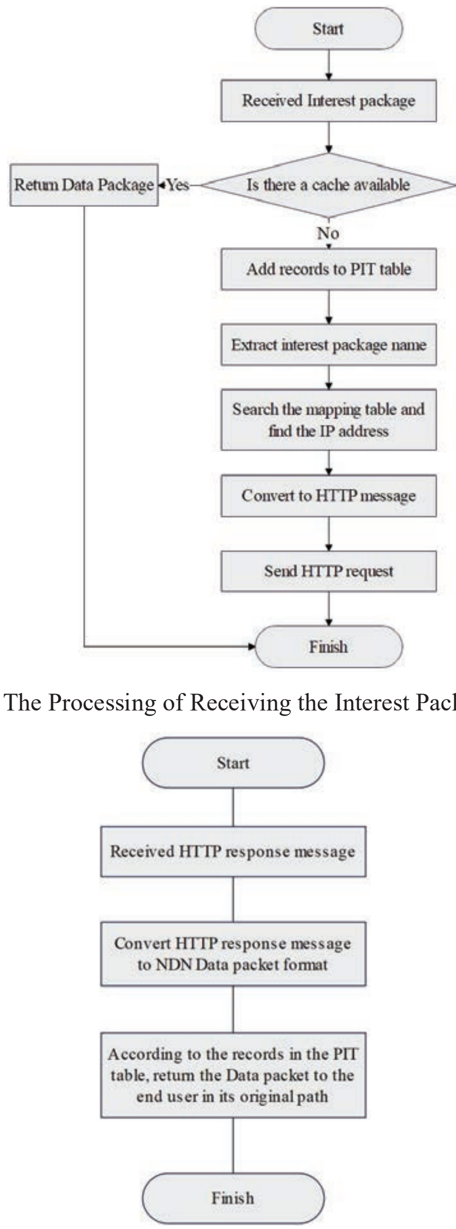
The design of eSIM communication model is based on three-layer mode, the communication between the terminal device layer and the edge layer uses the NDN network, and the communication between the edge layer and the cloud center uses the IP network. The eSIM communication model is specifically shown in Figure 1 [18].

In the communication model based on NDN edge network and IP network, the edge gateway mainly handles two types of data. One is to receive the Interest packet request sent by the NDN edge network, and the other is to return the HTTP response message from the cloud center. The edge gateway processes two types of data.

As shown in Figure 2, the main function of the edge gateway is to convert the received Interest packet request into an HTTP request message, look up the mapping table through the Interest packet name, find the IP address of the request content, and add it to the HTTP request message. Then, the edge gateway forwards the HTTP request. After that, for the received HTTP response message, it extracts the name of the Data and converts the response message into a Data packet, and then returns to the end user according to the original path.

3.2 Application Scenarios

As shown in Figure 3, the application scenario of the Internet of Vehicles is modeled as a cloud center, edge RSU nodes and terminal nodes. Among



(a) The Processing of Receiving the Interest Package

(b) The Processing of Receiving HTTP Response Messages

Figure 2 Data processing flow.

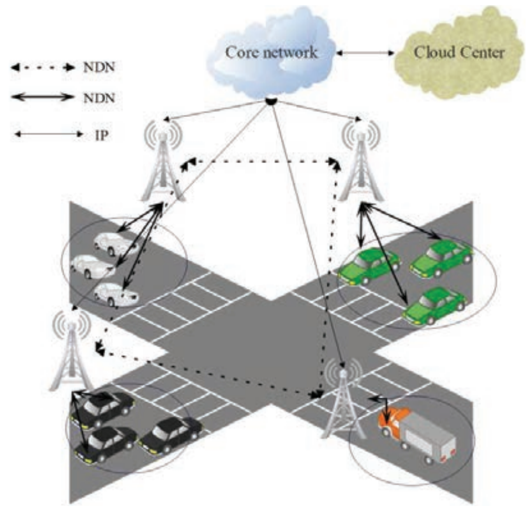


Figure 3 Application scenario of caching policy.

them, the cloud center serves as a server that provides all data resources and is deployed in the remote cloud. Edge RSU nodes provide simple computing and caching services, mainly responsible for realizing the communication functions between NDN network and IP core network, and are deployed at the edge of the network. As the requester of data resources, the terminal node is deployed in the edge network, and as the forwarder, it also has the cache function [19].

The full name of BRICH clustering algorithm is Balanced Iterative Reducing and Clustering Using Hierarchies, which is a method based on hierarchical clustering. At the end of each time slice, the cloud center node uses the BRICH algorithm to cluster the data content in the previous time slice t. The algorithm gets the content category $F_I(t)$ to which each data d_i belongs, and counts the number of Interest packets in the content category $n\_in_{cloud,F_I(t)}$, and the node counts the number $n\_in_{cloud,F(t)}$ of all Interest packets received. Based on the number of data categories to which the content name belongs and the number of all Interest packets received by the node, the algorithm calculates the popularity and preference of the data content. The global popularity of content d_i at the cloud center node is calculated as shown in formula (1) [20]:

$$po_{cloud,d_i}(t+1) = \frac{n\_in_{cloud,F_I(t)}}{n\_in_{cloud,F(t)}} \tag{1}$$

Among them, $n\_in_{cloud,F_I(t)}$ represents the number of Interest packets of the data category to which data d_i belongs, and $n\_in_{cloud,F(t)}$ represents the total number of Interest packets received by the cloud center node within a unit time slice. The preference degree of a certain RSU node R_j to the data content d_i can also be obtained from the above formula, and the calculation is shown in formula (2):

$$pr_{R_j,di}(t+1) = \frac{n\_in_{R_j,F_I(t)}}{n\_in_{R_j,F(t)}} \tag{2}$$

Among them, $n\_in_{R_j,F_I(t)}$ represents the number of Interest packets of data category F_I to which data d_i belongs, and $n\_in_{R_j,F(t)}$ represents the number of total Interest packets received by edge RSU nodes per unit time slice. At the end of each time slice, the content name with the highest preference in the RSU node R_j and the content name with the highest global popularity received from the cloud center are recorded into the node name table. The preference degree of the terminal node R_j belonging to the RSU node C_j^k to the data content is calculated as shown in Formula (3):

$$pr_{C_j^k,d_i}(t+1) = \frac{n\_in_{C_j^k,F_I(t)}}{num_{C_j^k,F(t)}} \tag{3}$$

Among them, $n\_in_{C_j^k,F_I(t)}$ represents the number of Interest packets of the data category $F_I(t)$ to which the data d_i belongs, and $num_{C_j^k,F(t)}$ represents the number of total Interest packets received by the terminal node per unit time slice. At the end of each time slice, the content name with the highest preference in the terminal node C_m^n and the received content name with the highest global popularity from the cloud center are recorded in the node name table.

The number of hits of the data content d_i in the edge RSU node R_j is H_{R_j,d_i}, the data content is sorted in descending order of the number of hits, and the data content with the highest number of hits is recorded in the name table of the RSU node. The number of hits of data content d_i in terminal node C_j^k is $H_{C_j^k,d_i}$.

The activity of a node is defined, which is expressed by the number of times a node interacts with other nodes in a unit time slice. The activity of the terminal node is characterized by the ratio of the number of interest packets received by the terminal to the number of data packets returned by the node in response. The activity of the terminal node is calculated as shown in formula (4):

$$Ar_{C_j^k}(t+1) = \frac{n\_da_{C_j^k,F_I(t)}}{n\_in_{C_j^k,F(t)}} \tag{4}$$

Among them, $n\_da_{C_j^k,F_I(t)}$ represents the number of interest packets received by the terminal node C_j^k within the coverage area of cluster head R_j in a unit time slice, and $n\_in_{C_j^k,F(t)}$ represents the number of return packets after the node receives the interest packet request. The activity range of all nodes is 0–1.

The RSU node calculates the cache probability of the data content on the RSU node according to the global popularity carried by the content and the preference of the RSU node for the data content, and the cache probability of the data content on the node is calculated as shown in formula (5):

$$q_{R_j,d_i}(t+1) = w_1 \times po_{cloud,d_i}(t+1) + w_2 \times pr_{R_j,d_i}(t+1) \tag{5}$$

Among them, w_1 and w_2 are the weight parameters of global popularity and preference, and they satisfy the normalization condition $w_1 + w_2 = 1$, and $po_{cloud,d_i}(t+1)$ is the global popularity of the data content in this time slice, and $pr_{R_j,d_i}(t+1)$ is the preference of cluster head RSU nodes for data content in this time slice.

The similarity is solved using a string comparison algorithm, and the similarity is calculated as shown in formula (6) and formula (7):

$$sim(s_1, s_2) = \begin{cases} 0 & if\ m = 0 \\ \frac{1}{3}\left(\frac{m}{|s_1|} + \frac{m}{|s_2|} + \frac{m-t}{m}\right) & otherwise \end{cases} \tag{6}$$

Among them, $|s_1|$ and $|s_2|$ respectively represent the length of the content name, m represents the number of matching characters of the two content names, and t represents half of the number of transpositions.

$$sim_w(s_1, s_2) = sim_j(s_1, s_2) + l\rho[1 - sim_j(s_1, s_2)] \tag{7}$$

Among them, $sim(s_1, s_2)$ is a value obtained from formula (6), l represents the number of common prefix characters of two strings, ρ is a scaling factor constant, describing the contribution of the common prefix to the similarity, and the larger ρ is, the greater the weight of the common prefix is. Then, the normalized name similarity is used to characterize the weight value, and the weight is calculated as shown in formula (8) and formula (9):

$$w_1 = \frac{sim_w(d'_a, d'_c)}{sim_w(d'_a, d'_c) + sim_w(d'_b, d'_c)} \tag{8}$$

$$w_2 = \frac{sim_w(d'_b, d'_c)}{sim_w(d'_a, d'_c) + sim_w(d'_b, d'_c)} \tag{9}$$

Therefore, the cache probability of the RSU node for the data content is q_{R_j,d_i}. The RSU node calculates the cache probability of all the received data content in the time slice, and then sorts them from large to small, and buffers the data content that meets the cache capacity S_R of the RSU node.

The terminal node calculates the cache probability of the data content on the terminal node according to the global popularity carried by the content and the preference degree of the terminal node for the data content. The cache probability of the data content on the node is calculated as shown in formula (10):

$$q_{C_J^K,d_i}(t+1) = w_3 \times po_{cloud,d_i}(t+1) + w_4 \times pr_{C_J^K,d_i}(t+1) \tag{10}$$

Among them, w_3 and w_4 are the weight parameters of global popularity and preference, they meet the normalization condition $w_3 + w_4 = 1$, $po_{cloud,d_i}(t+1)$ is the global popularity of data content in this time slice, and $pr_{C_J^K,d_i}(t+1)$ is the preference of terminal nodes in this time slice to data content.

According to the formula (6) and formula (7), the similarities of the names of the data contents are respectively solved, and then the normalized name similarities are used to characterize the weight values, and the weight calculations are shown in the formula (11) and formula (12):

$$w_3 = \frac{sim_w(d'_a, d'_c)}{sim_w(d'_a, d'_c) + sim_w(d'_b, d'_c)} \tag{11}$$

$$w_2 = \frac{sim_w(d'_b, d'_c)}{sim_w(d'_a, d'_c) + sim_w(d'_b, d'_c)} \tag{12}$$

Therefore, the cache probability of the terminal node for the data content is $q_{C_J^K,d_i}$.

When the RSU cluster head node completes the caching decision, it adds a field to the packet, such as $RSU\_Cached : 1$ or $RSU\_Cached : 0$. $RSU\_Cached : 1$ means that the RSU node has cached the data content, and the probability of the terminal node in the cluster caching the data content is reduced. RSU_Cached : 0 means that the RSU node does not cache this data content, the probability of the terminal node in the cluster caching this data content remains unchanged. The probability of a terminal node caching content is shown in formula (13):

$$q^*_{C^k_j}(t+1) = \begin{cases} q_{C^k_j,d_i}(t+1), & if\ RSU\_Cached = 0 \\ \delta \times q^k_{C_j}, d_i(t+1), & else \end{cases} \tag{13}$$

Among them, $0 < \delta < 1$ is the weight of the probability of caching data. When the RSU cluster head node caches data, it will reduce the probability of data caching by the terminal node.

In order to make the nodes with high activity cache the popular content, the nodes with low activity cache the unpopular content. Terminal nodes cache content according to the ranking of their own environment activity, where the top-ranked terminal nodes cache popular content, and the lower-ranked nodes cache unpopular content. Then, the probability of the terminal node caching the data content is shown in formula (14):

$$Q^*_{C^k_j}(t+1) = \begin{cases} q^*_{C^k_j,d_i}(t+1), & if\ Rank_C \geq \lambda Num_{Rank_C} \\ 1 - q^*_{C^k_j,d_i}(t+1), & else \end{cases} \tag{14}$$

Among them, $Rank_C$ represents the ranking of the importance of nodes, Num_{Rank_C} represents the number of nodes around the terminal, and it is a threshold that represents how many terminal nodes to take to cache data normally. The cache probability of the terminal node for the data content is $q^*_{C^k_j,d_i}(t+1)$. The terminal node calculates the cache probability of all the received data content in the time slice, and then sorts them from large to small. If the ranking of the terminal node is in the first name of the total number of nodes, the terminal node caches the popular data content. If the ranking of the node is in the last $1 - \lambda$, the terminal node caches the unpopular data content. The terminal node buffers the data content that satisfies the node capacity.

3.3 Remote eSIM Provisioning Technology

After eSIM is issued, in order to realize the provisioning management of the files and parameter sets on the card, it is necessary to design a set of remote eSIM provisioning (RSP) management system. The system can manage the whole life cycle of the operator's profile under a set of secure mechanisms,

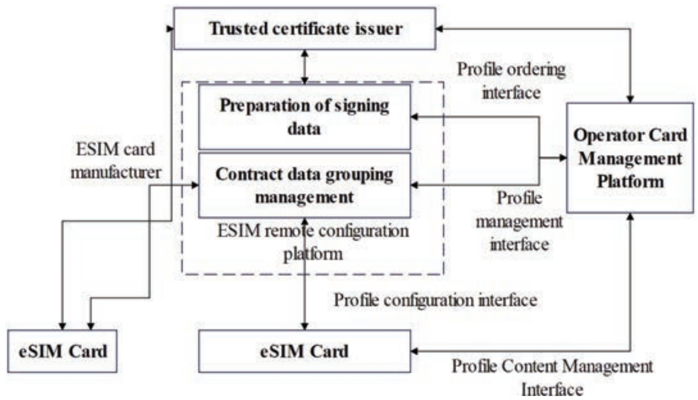


Figure 4 Architecture and interface of typical remote card writing system.

including the download, installation, activation, deactivation and deletion of the profile.

The architecture of a typical remote eSIM card writing system is shown in Figure 4. The remote eSIM provisioning platform includes two main functional modules: contract data preparation and contract data packet management.

As shown in Figure 4, users develop eSIM services based on their own needs, sign contracts with operators, select suitable packages, and the operators group and manage users. The eSIM provided by the manufacturer is then provided to customers, and certificate processing is carried out according to the network type and protocol selected by the user. Users are then allowed to transfer data on the operator's management platform, including text and voice transmission, in order to achieve the use of mobile terminals

At present, eSIM technology is applied to consumer electronic devices. In response to this trend in the field of consumer electronics, the GSMA organization has formulated a unified architecture and standards in the field of consumer electronics and the Internet of Things, which can be applied to the fields of the Internet of Things and consumer electronics at the same time, and provide remote provisioning management ability. for M2M devices and consumer electronics devices. The fusion RSP architecture is shown in Figure 5.

3.4 System Model and Protocol Description

As shown in Figure 6, it is a basic vehicle communication diagram. This section uses the characteristics of CR (Cognitive Radio) and NOMA

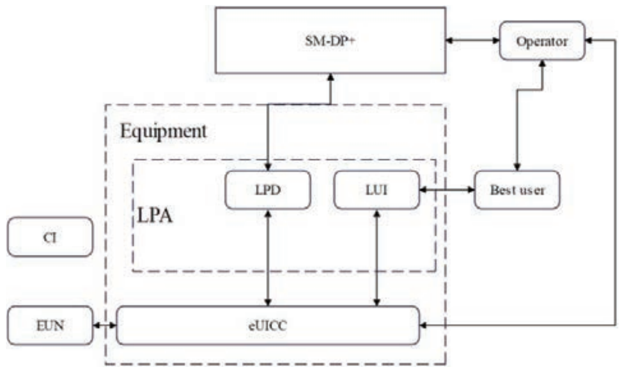


Figure 5 RSP fusion architecture of e-SIM proposed by GSMA.

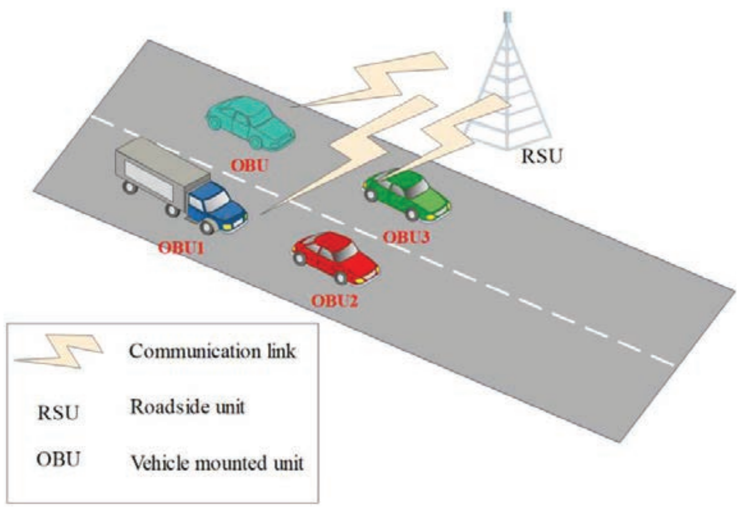


Figure 6 Vehicle communication diagram.

(Non-Orthogonal Access) to establish a hybrid cooperative spectrum sharing protocol to improve the spectrum efficiency of RSUs and OBSs.

The positioning module is connected to serial port 3 of the main control STM32. The positioning data of the positioning module adopts the NMEA-0183 protocol, and the control protocol is SkyTrag. The protocol used by the positioning module is also a unified standard protocol for navigation devices such as GPS/Beidou, which uses ASCII code for transmission. Due to the passive nature of GPS+Beidou dual-mode positioning, it only requires parsing the commands received from the module.

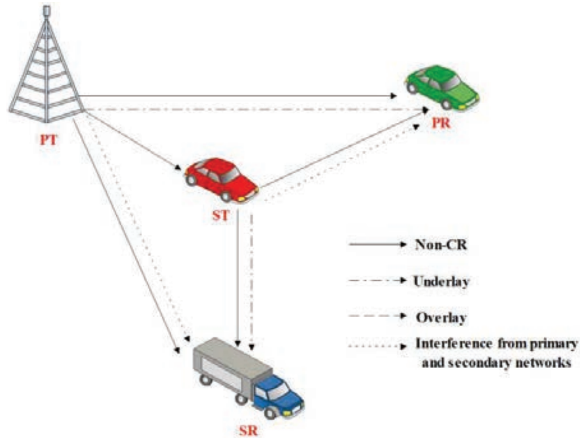


Figure 7 System model.

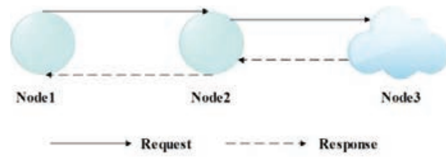
The system model shown in Figure 7 can be established, which is an OMA/NOMA cooperative hybrid cooperative spectrum sharing network. Its Pus (Primary User) consists of a roadside base station (primary transmitter, PT) and a live user vehicle (primary receiver, PR) far away from the base station. SUs consist of a secondary user vehicle (secondary transmitter, ST) closer to the base station and a further SU vehicle (secondary receiver, SR). If the base station and these vehicles are regarded as nodes, then each node is equipped with an antenna, and the transmission is half-duplex mode.

4 Experimental Analysis

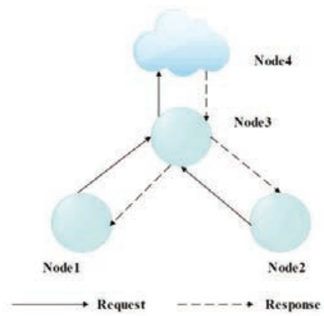
4.1 Experimental Environment

Based on the system communication method shown in Figure 6 and the system model shown in Figure 7, conduct experimental analysis on the process to verify whether eSIM's remote configuration management technology can meet practical needs in the context of 5G.

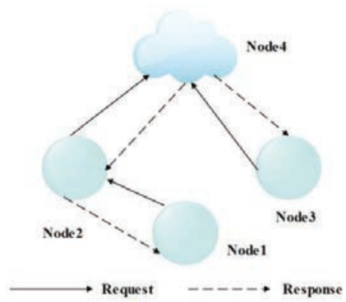
This paper performs experimental setup on the proposed eSIM three-layer communication model. The detailed hardware and software provisioning are as follows: the terminal device layer and edge layer are in the NDN network, and the ndnSIM simulation tool based on NS-3 is used. The ndnSIM runs on the Linux operating system of VMware, and VMware has a memory of 4GB and a CPU of 2 cores. The cloud center uses Alibaba Cloud servers and Microsoft AzurewindowsServer data centers.



(a) Static Three-Node Topology



(b) Static Four-Node Topology



(c) Dynamic Four-Node Topology

Figure 8 Experimental topology.

At the same time, this paper uses a simple static and dynamic topology, in which the terminal node is simulated using the ndnSIM simulation tool, and the communication between the edge gateway node and the cloud center is in a real network environment. Then, the connectivity in two scenarios is compared, one is the NDN-IP scenario, and the other is the pure IP scenario. The NDN-IP scenario means that the terminal device and the edge node are in the NDN network, and the communication between the edge node and the cloud center uses the IP network. In the pure IP scenario, IP networks are used from terminal devices to edge nodes, and from edge nodes to cloud centers. The topology of the experiment is shown in Figure 8.

4.2 Experimental Results

In the experimental result graph, E represents the edge gateway node, C represents the end user node, and cloud represents the cloud center node. Using the static three-node topology in Figure 8(a), this paper compares the connectivity NDN-IP communication model with pure IP network communication. The requester node1 sends a different number of interest packets per unit time, and the request sent by the user is not repetitive. The experimental results are shown in Figure 9.

Using the static four-node topology in Figure 8(b), the NDN-IP communication model is compared with the pure IP network communication mode. It can be seen from the connectivity experiment that the back-and-forth delay from the edge node to the cloud center node is about 50 ms. The specific setting of the experiment is that node1 sends the request first, and node2 sends the request later, and the time for node2 to send the interest packet request is after node1 sends the interest packet, and before the edge node receives the data response. That is, after the node1 sends out an interest packet 20 ms interval, the node2 sends the same interest packet.

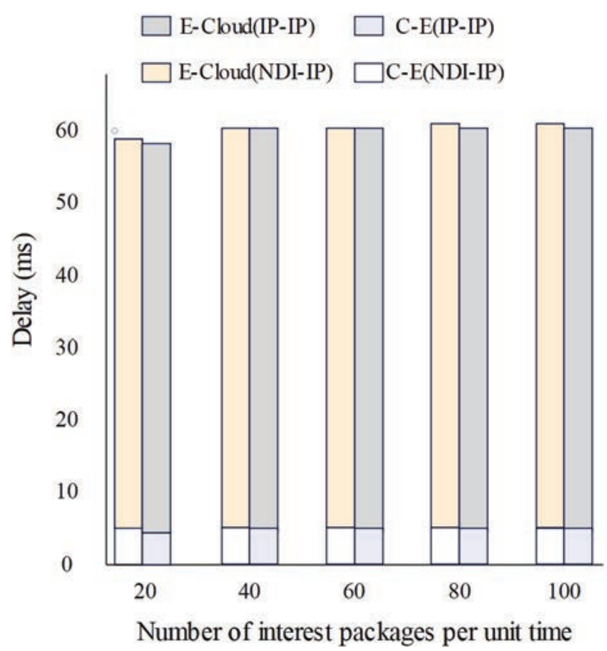


Figure 9 Comparison of connectivity delay.

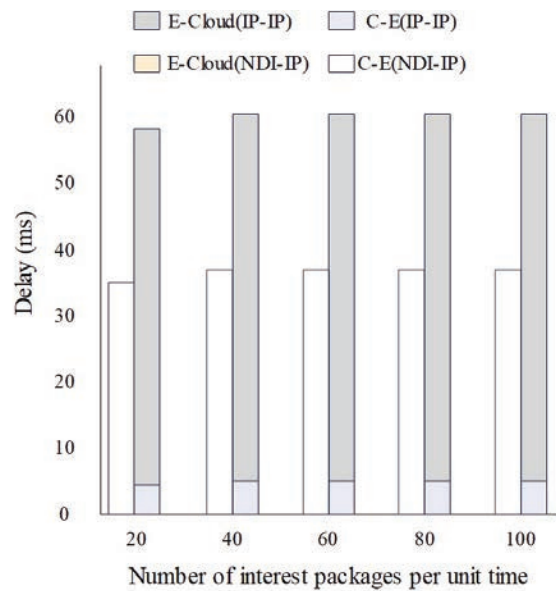


Figure 10 Delay comparison diagram of Node2.

Figure 10 is a comparison of the delay for the requester node2 to obtain the response data as the number of request packets sent by the requester increases in a unit time under the NDN-IP and pure IP communication architectures.

Figure 11 is a comparison of the number of interest packets received by the edge node and the number of interest packets forwarded under the NDN-IP and pure IP communication architectures.

Using the three-node topology of Figure 8(a), the NDN-IP communication model is compared with the pure IP network communication mode. It can be seen that the interest packets sent by node1 obey the Zipf distribution, indicating that 80% of the interest packets will request the 20% of the data content. The rate of sending interest packets by node1 is 100 per second, and the total data content requested by the user is 100, and the buffer capacity of the edge node is set to 100. Figure 12 is a comparison of the delay for node1 to obtain response data as the running time increases under the NDN-IP and pure IP communication architectures.

Using the mobile four-node topology of Figure 8(c), the NDN-IP communication model is compared with the pure IP network communication mode. Among them, node1 represents the requester of data, node2 and node3

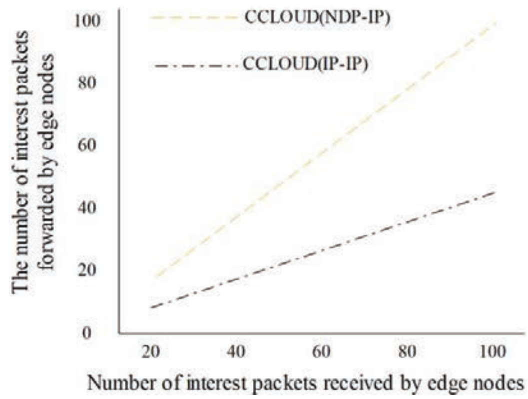


Figure 11 Comparison of the numbers of aggregated interest packet for NDNs.

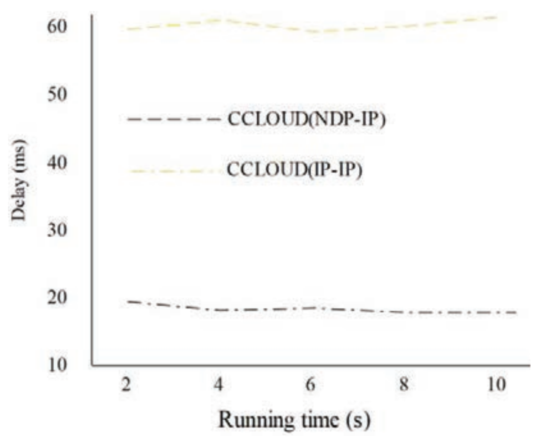


Figure 12 Delay comparison diagram of Node1.

represent the edge gateway node, and node4 represents the cloud node. node1 is a mobile node, the rate of sending interest packets per second by node1 is 50, and the cache capacity of edge nodes is 50.

Figure 13 is a comparison of the delay of node1 obtaining response data as the vehicle node movement speed increases under the NDN-IP and pure IP communication architectures.

The training results of the algorithm are shown in Figure 14.

On the basis of the above analysis, the remote eSIM provisioning management model proposed in this paper is applied to the Internet of Vehicles, and compared with the model proposed in reference [10], reference [11],

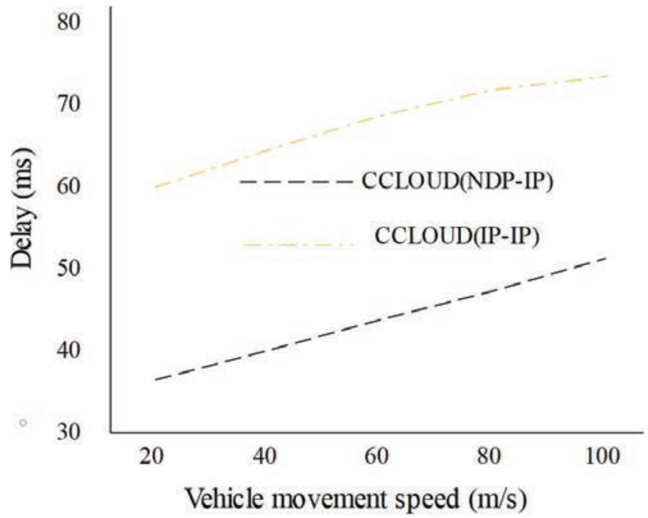


Figure 13 Comparison diagram of mobility delay.

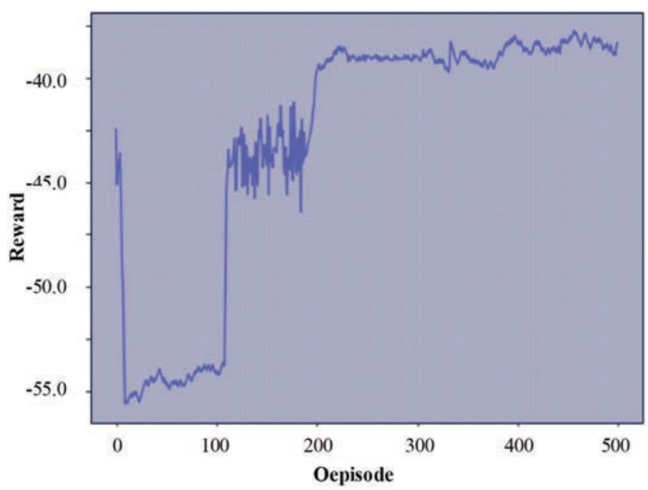


Figure 14 Convergence diagram of algorithm.

reference [12], reference [13], and reference [14]. The comparisons of the remote management effect, data acquisition effect, data transmission effect, and intelligent decision-making effect are all completed through expert evaluation, and the experimental comparison results shown in Table 1 are obtained.

Table 1 Experimental comparison results

	Remote Management	Data Acquisition	Data Transmission	Intelligent Decision-making
The model proposed in this paper	94.152	89.429	96.690	84.823
The model proposed in reference [10]	87.618	81.887	91.570	79.214
The model proposed in reference [11];	87.319	82.974	91.032	77.465
The model proposed in reference [12];	87.076	80.550	88.426	79.123
The model proposed in reference [13];	88.344	82.705	88.866	77.143
The model proposed in reference [14];	85.527	82.897	89.841	80.418

4.3 Analysis and Discussion

This article aims to analyze the remote configuration management technology of terminal eSIM combined with 5G technology, and improve the remote information management and control effect of eSIM through algorithm improvement. A detailed description was given of the three-layer communication structure, design of edge gateway nodes, and query mechanism for cloud center request names and data resources in the communication model. Experimental evaluations were conducted on the connectivity of the eSIM three-layer communication model and the characteristics of the NDN network.

Figure 9 is a comparison of the delay in obtaining response data by the requester as the number of request packets sent by the requester increases in a unit time under the communication architecture of NDN-IP and pure IP. With the increase of the number of interest packets per unit time, whether it is NDN-IP or IP communication architecture, the delay for users to obtain data has generally increased, and the communication delay under NDN-IP and IP communication architecture is roughly the same. From the experimental results, it can be seen that the delay from end users to edge gateway nodes in NDN-IP is slightly higher than that in IP. The reason is that the edge nodes under the NDN-IP communication architecture need to find FIB tables, PIT tables, cache data and other operations, which have a certain processing delay. Therefore, the delay from the end user to the edge node under the NDN-IP communication architecture is slightly higher than that of the IP communication architecture. Moreover, it can be concluded that because they are all in the real and same IP network environment, the communication delay from the edge gateway node to the cloud center node is roughly the same.

It can be seen from Figure 10 that under the IP communication architecture, the edge gateway nodes do not have an aggregated structure and function, so the communication delay under the IP communication architecture is no different from the delay under the connectivity experiment. Under the NDN-IP architecture, there is a PIT table structure in the edge gateway node, and the interest packets with the same name sent by node1 and node2 will be aggregated in the PIT table, and then the edge node will add the interface that receives the interest packets of node2 to the corresponding table entry, and delete the received node2 interest packets. When node2 has not reached the edge node, node2 is in the waiting stage. When the data resource reaches the edge node, the data resource is forwarded to node1 and node2 at the same time. Therefore, the delay for node2 to obtain data resources includes the waiting delay from the terminal node to the edge node and at the edge gateway node, which effectively reduces the delay for node2 to obtain data, reduces the number of requests to the cloud, and reduces the cloud burden.

It can be clearly seen from Figure 11 that under the IP communication architecture, edge nodes do not have a PIT structure, and all requests will be forwarded to other nodes or cloud centers. Under the NDN-IP communication model, only half of all the Interest packet requests received are forwarded, and the other half are aggregated in the PIT table of edge nodes. Through the aggregation characteristics of NDN, about 50% of the traffic is aggregated at edge nodes. When there is no aggregation function in the pure IP communication architecture, 100% of the traffic is forwarded to the cloud central node. Therefore, using the aggregation function of the NDN, a large amount of incoming traffic to the core network can be reduced.

As can be seen from Figure 12, under the IP communication architecture, the edge node does not have the function of in-network caching, and all requests will be forwarded by the edge node to the cloud center to obtain response data, which not only increases the acquisition delay, but also increases the access rate. core network traffic. Under the NDN-IP communication architecture, 20% of the Data resources are cached at the edge node, so about 80% of the requests will be satisfied at the edge gateway node. Once the edge node can meet the request of the Interest packet, it can directly return the corresponding data packet without further forwarding the request, which can effectively reduce the time for end users to obtain response data and reduce the traffic to the core network.

As can be seen from the result in Figure 13, as the movement speed of the node1 changes, the delay for the node1 to acquire data increases. Through comparison, it can be found that the delay under IP is about twice that under NDN-IP. The reason is that under the IP communication architecture, as the vehicle node moves, the vehicle node needs to re-send the request and re-establish the communication path, and there is no aggregation and cache function at the edge node. Under the NDN-IP communication architecture, the edge gateway node will cache the previously requested data resources. When the same request sent by the vehicle node reaches the edge node again, the data resources will be directly returned to the vehicle node, and there is no need to forward the interest packet to the cloud center, which effectively reduces the delay for the terminal node to obtain data resources, and reduces traffic to the core network.

As can be seen from Figure 14, after several fluctuations, the algorithm reaches a steady state at turn 400. The reason why the effect of the model rises rapidly around 100 rounds is that the multi-agent model first stores the experience group in its own experience pool in interactive learning, and then conducts network training when the capacity of the experience pool is full. In fact, the model has achieved a good training effect at about 250 rounds, so the training speed of the algorithm proposed in this paper is still relatively fast, and it can obtain a reasonable unloading scheme with the minimum delay and energy consumption based on the trust model.

As can be seen from Table 1, the remote eSIM provisioning management model proposed in this paper has certain advantages in the application of the Internet of Vehicles compared with the existing remote provisioning management technology of the Internet of Vehicles. Moreover, it has a certain lead in remote management effect, data collection effect, data transmission effect, and intelligent decision-making effect.

5 Conclusion

This paper describes in detail the three-layer communication structure in the communication model, the design of edge gateway nodes, and the query mechanism for cloud center request names and data resources. In addition, this paper uses experiments to evaluate the connectivity of the eSIM three-layer communication model and the characteristics of the NDN network.

The mobility support of eSIM network proposed in this paper can be well applied to the Internet of Vehicles and meet the mobility of terminal vehicles. The eSIM network focuses on the data content itself, not the location of the data content. When the terminal node sends an Interest packet request to the network, the position moves, and the corresponding data packet cannot find the requesting terminal node within the original edge node range when it returns according to the forwarding path of the Interest packet.

There are some problems in this paper that need to be optimized. The first is to further optimize the interface between the NDN network and the IP network, so as to realize the interaction of more types of requests. The second is to further optimize the mapping table mechanism and improve the lookup efficiency. The third is to optimize the naming method of interest packs and improve the efficiency of nodes clustering data. These are also the research directions that need to be carried out in the next step.

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