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5G Message Service System Based on Artificial Immune Dynamic Adaptive Mechanism

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ABSTRACT When facing massive interconnection scenarios of terminals, 5G message service system needs to support large-scale information access and management and provides the efficient and reliable signal control to scheduling a variety of wireless access networks. In this paper, artificial immune theory is applied to the 5G message services. The simulating the immune response mechanism, a semi-distributed dynamic adaptive immune network architecture was proposed. The dynamic learning mechanism and immune memory mechanism of the detector were established, which improved the 5G edge computing capability and reduced the load of the 5G core network. The concept of the immune message distribution system (IMDS) is proposed, which uses clonal selection algorithm to classify and clone the message header, and combines with the affirmative selection algorithm to carry out high-frequency variation on the message body. On the premise of ensuring the diversity of antibodies, the space consumption problem of the hash-map algorithm is effectively solved, and the efficiency of message distribution is improved. The comparison of simulation results shows that the IMDS improves the message recognition ability and adaptive ability of the 5G system and proves the feasibility of semi-distributed immune dynamic learning mechanism.

INDEX TERMS Message service, semi-distributed, artificial immunity, clonal selection, message routing.

I. INTRODUCTION

With the continuous expansion of 5G system functional requirements, the future 5G system should have the following key capabilities: 1. Support the wired side and wireless side context messaging services of mass mobile terminals. 2. High throughput of scheduling and exchanging massive data and real-time key information. 3. Support various message communication models with advanced service capabilities and performance. Includes: point-to-point, application-to-point, group and broadcast message communication. 5G message service needs to provide very low end-to-end latency and high reliability of message delivery. At the same time, 5G message service needs to be in a resource efficient manner to optimize the resource usage of the both control plane and user plane. Message communications need to be well scheduled in order to save power and data traffic consumption in the device [1], [2]. Therefore, it is an important task to design and build an efficient, reliable and dynamic adaptive message scheduling module. Among the new challenges, the most important is to integrate distributed resources of 5G system and process signaling messages from user side and control side in base station and core network, including codec of protocol data unit (PDU) signaling, inter-process communication (IPC) messages of each module of the system, and interconnection and interworking messages between systems. All these factors will bring additional pressure to 5G system, and even affect the stability of the system.

One of the important ideas in the current development of science and technology is to simulate the remarkable ability of organisms. Artificial immune algorithm has its own advantages in distributed learning, memory and diversity. The antibody memory function and clonal selection mechanism can effectively improve the efficiency of message transmission. Literature [3] used the method of artificial immune system, based on the binding affinity between antibodies and antigens and the structure method of antibodies in the human immune system, to achieve fault-tolerant coordination through effective coordination strategy, and to achieve efficient and autonomous multi-robot cooperation system. Literature [4] proposed an improved clonal selection algorithm. By selecting the best individuals and cloning them

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to detect the intrusion, the accuracy of intrusion detection was improved and the false alarm rate was reduced, with good performance. Literature [5] proposed a clonal selection algorithm for solving the intelligent adaptive enhancement design of brain images in magnetic resonance imaging (MRI) in the medical field by using the artificial immune system. Inspired by the human immune system, literature [6] explored and developed a multi-detector for detecting information flow mobile malware in Android applications. Literature [7] describes a biological-inspired distributed infection immune model inspired by the immune mechanism of infected organisms, which improves the performance of multi-sensor networks.

In recent years, the international research on the application of artificial immune system in communication system has gradually become a hot spot, and literature [8] studies the potential of artificial immune system in solving the problem of wireless communication channel allocation. Literature [9], based on the inspiration of artificial immunity, reduces the data transmission time and increases the data throughput of the trunked communication system. Literature [10] used the artificial immune algorithm based on clonal selection theory to maximize the total throughput of the radio system and reduce its interference to the main users.

In conclusion, the introduction of biological immune mechanism into the field of computer engineering and communication engineering has a broad application prospect [11]. The contributions of our work can be summarized as follows:

1. Study how to apply artificial immune algorithm to the engineering field of 5G message service.

2. Using the distributed characteristics of biological immune antibody cells, a semi-distributed dynamic adaptive architecture of 5G systems was constructed.

3. The 5G system messages are divided into two types of mapping relationships: clone message mapping (CMM) and gene editing message mapping (GEMM). The study uses immune algorithms to reduce the space consumption of the hash-map algorithm in route maps.

4. Define the biological immune environment of each element in the 5G message service system. On this basis, the application of artificial immune algorithm such as clonal selection and gene recombination is studied.

5. The simulation environment was set up, and the comparative pressure test of multiple scenes and loads was carried out.

The remaining parts of the article are organized as follows. The next section will discuss the architecture of 5G message service system based on artificial immunity. Then, the design idea and implementation details of message classification based on semi-distributed dynamic adaptive learning mechanism are discussed. In the following section, the realization of immune mechanism in IMDS is described, including: antibody antigen coding principle, affinity calculation, clonal selection, high-frequency mutation and immune memory. In the simulation, the differences between our work and the related research are summarized. The last section provides conclusions and points out future directions.

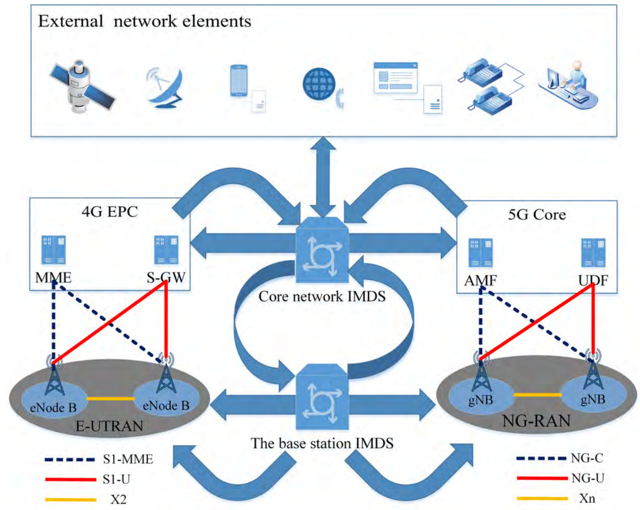

FIGURE 1. Deployment of IMDS in 5G systems.

II. 5G MESSAGE DYNAMIC ADAPTIVE UPDATE MECHANISM

A. SYSTEM SOFTWARE ARCHITECTURE

The 5G message service network architecture is constructed with reference to the bone marrow model produced by the antibody cells and the peripheral circulatory system model. Immune message distribution system (IMDS) can be used to handle internal and external messaging services from 5G systems. Since both 4G and 5G systems can adopt inter-process communication mode for message transmission, and the message format is composed of message header and message body, IMDS is compatible with 5G Non-Standalone (NSA) mode and can handle the message service of both 4G system and 5G system. We divide the IMDS into two layers, the IMDS in the core network simulates the bone marrow system, processes the messages of each network entity in the core network, and generates a set of initial antibodies. The messages of the external network entities are completed by the IMDS in the core network. The IMDS in the base station simulates a peripheral circulation system, processes messages of each network entity in the base station, and interacts with the core network IMDS to update the set of exchange antibodies. As shown in Fig. 1:

To realize the artificial immune mechanism, 5G communication system needs to rely on the efficient and reliable inter-process communication mechanism between base stations [12]. Therefore, in a heterogeneous and dynamic network environment, it is necessary to implement a reliable IPC mechanism in the Base station controller unit (BSCU) lightweight kernel [13]. Compared with middleware-based systems, the kernel-level IPC mechanism improves the diversity of system applications. The base station controller software system is divided into three layers: core control layer, virtual operating system and logic link layer [14], [15].

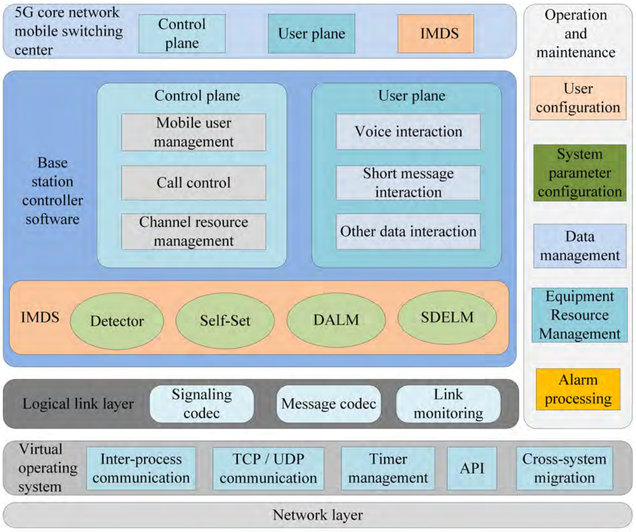

FIGURE 2. 5G message service base station controller software architecture including IMDS.

Referring to the routing framework of software-defined network (SDN) technology, the control plane and the user plane are separated in the core control layer [16]–[18]. The control plane signaling is collected and processed in the core network, so that the signaling messages between the base station and the core network can be effectively transmitted. There is no need to exchange routing information between the base stations, which reduces the system complexity and signaling cost [19]. The 5G message service base station controller software architecture including IMDS is shown in Fig. 2.

The base station controller software is responsible for the edge calculation, mainly to complete the base station side position information and call business processing. The core network is mainly responsible for message connection across base station services in the cloud. The IMDS module is responsible for handling the routing and distribution of 5G system context messages by using artificial immune technology, including: detector, self-set, dynamic adaptive learning module (DALM) and semi-distributed exchange learning module (SDELM).

Each base station in the 5G system is distributed and deployed, with high fault tolerance, which is the same as the biological immune system. This can avoid the situation where a problem at one point leads to a total collapse [20]. However, there is a logical need for a level of centralized management, functional division, and connection of user and control surfaces between base stations, which should be done by the core network. When the core network stops working, the subordinate base stations serve as the redundant backup of the core network and can be upgraded to the core network according to the priority. The base stations can copy, exchange and collect the information of other base stations. When the core network is restored, the base station will upload the incremental information in memory to the core network [21], [22]. We call the architecture described above 5G semi-distributed architecture, as shown in Fig. 3.

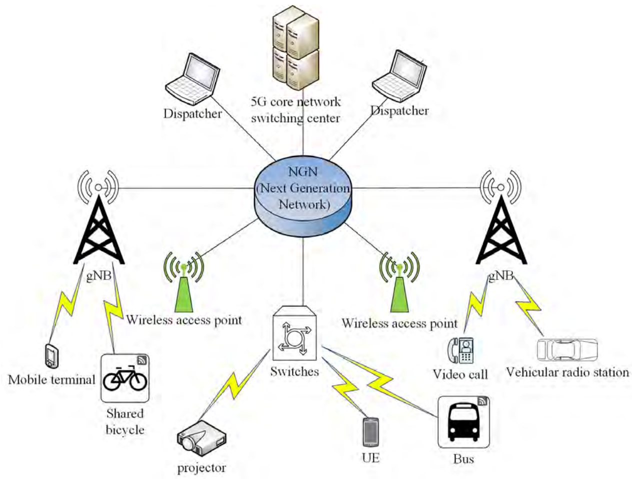

FIGURE 3. 5G semi-distributed architecture.

TABLE 1. Comparison of immune system and IMDS.

Immune System	IMDS
antigen	5G message
antibody	processed message
binding	Affinity string matching of messages
lymph node	detector
antigenic response	detecting events
self-tolerance	positive selection algorithm
co-stimulation	match that exceeds the activation threshold
variable region of antibody	message header
constant region of antibody	message body
cell clone	clonal selection algorithm
genetically modified	message coding
memory cell 1	CMM
memory cell 2	GEMM

The comparison between the immune system and IMDS is shown in TABLE 1.

B. SEMI-DISTRIBUTED IMMUNE DYNAMIC ADAPTIVE MECHANISM

IMDS in 5G can be defined as a finite set of nodes. The IMDS of each base station is equivalent to a single node, and the variable number of nodes constitutes a 5G communication system with a dynamic artificial immune mechanism. Each base station works independently. The detector in the base station is responsible for detecting self and non-self messages, and the base station is responsible for the automatic update and learning of its own detector and self sets. Independent self sets can reduce the occurrence of system-wide errors.

The important function of the immune system is to distinguish between the self and the non-self. The biological immune system distinguishes between self and non-self by the different forms of protein chains [28]. Similarly, IMDS first need to distinguish between messages is self message or non-self. As shown in formula (1), the finite set U composed of binary strings of fixed length represents all messages recognized by the system. U can be divided into two subsets: S for self message and N for non-self message.

$$U = N \cup S, \quad N \cap S = \emptyset \tag{1}$$

The initial S of IMDS in the base station includes: airport PDU signaling, common IPC messages in the base station, and common signaling messages that interact with the core network. The initial S of IMDS in the core network includes: airport PDU signaling, common interactive messages with all subordinate base stations. All messages in S require system initialization configuration. Collections in S remain unchanged unless a version upgrade is made. All non-self messages belong to the N set. The system considers a message to be self-message only when all the base stations recognize it as self-message. Minimize the error probability of receiving messages [29].

The detector in IMDS simulates lymphocytes in the biological immune system and is used to detect and recognize antigen messages. Each base station has its own independent detector set D. 5G messages refer to the 3GPP standard protocol, and the process of interactive messages in the system are all prophet conditions. In IMDS, the detector adopts the affirmative selection algorithm, which is responsible for detecting and collecting the messages of set N. For example, if a message contains any item of the core network ID, base station ID, message code and other information that cannot be recognized by the system, the message will be added to the initial detector set. The initial detector became mature after a certain period of immune tolerance. The detector in IMDS can be understood as the first layer of message filtering. Only the self-message that can be recognized by the system will enter the system, otherwise, the antigen message will be cloned and deleted. When a detection event occurs in a base station, the base station will broadcast the message to other areas through the core network, preventing the same detection event from being processed multiple times in a short time.

Base stations stimulate each other through their semi- distributed exchange learning modules and share learning data with each other dynamically. SDELM in the core network IMDS is responsible for collecting the learning content of the base station SDELM it manages, carrying out backup and upgrading, and using the thread communication mode to make a thread correspond to a base station. In order to reduce the amount of learning, base station SDELM regularly downloads the learning content from the core network IMDS in an incremental manner. When the link between the base station and the core network is interrupted, the base station SDELM can independently complete the connection processing and save the system data in the station. At this time, the off-line base station IMDS stops working. When the link is restored, the IMDS data of the core network will be synchronized and updated to the latest data.

Base station side DALM is responsible for coordinating and processing the data exchange of detector and self set with SDELM, filtering and filtering data, carrying out load balancing and tolerance processing, and maintaining the dynamic adaptive learning and update of detector and self set in the base station. And the incremental learning data is sent to SDELM, which is sent to SDELM of the core network. DALM of the core network is responsible for filtering and filtering the data of each semi-distributed switched learning thread on the side of the core network, and broadcasting incrementally to the semi-distributed switched learning threads corresponding to other base stations. 5G semi-distributed dynamic adaptive learning mechanism, as shown in Fig. 6.

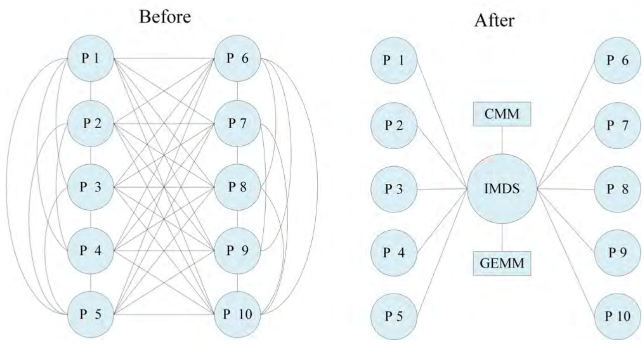

FIGURE 4. Design ideas.

According to the different application environment and protection purposes, IMDS is divided into a variety of architectures, mainly divided into network-based IMDS and host-based IMDS. SDELM in the base station IMDS is a configurable module. When the base station IMDS adopts the host mode, it can be deployed as a software module in the base station carrier board to communicate with other modules. When the base station IMDS adopts the network mode, it can be deployed in the same network environment as a single server and base station.

As shown in Fig. 4, the main design idea of IMDS is: data aggregation and elimination of redundant messages, effectively improving the transmission efficiency of the system [23], [24]. Using artificial immune method, system context signaling messages are automatically classified into two types of message map [25], [26]: clone message map (CMM) and gene editing message map (GEMM), processing flow chart as shown in Fig. 5. Where, the message in CMM is the message body unchanged, and the message header can be directly cloned, copied and forwarded after mutation, usually the user plane message. The message in GEMM refers to the message sent to the corresponding process module for processing, usually the control plane message [27].

Before designing IMDS, we first need to determine the main factors that affect the efficiency of 5G message service. Let the maximum number of messages loaded on the system IMDS be K. The maximum number of message propagation process modules is D_k, and messages need to be sent to L process modules. Let the distance between process i and j be $d_{ij}(i, j = 1, 2 \ldots, L)$, then the distance between IMDS and each module is d_0. The number of modules spread by message k is $n_k(n_k = 0$ means that the kth message is

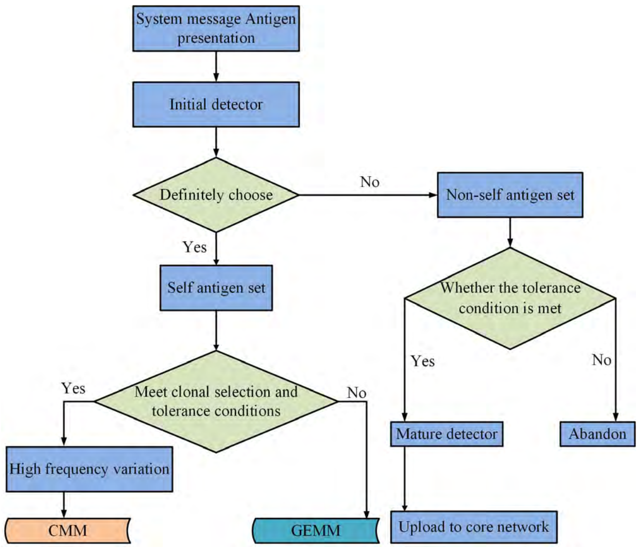

FIGURE 5. Design ideas flow chart.

not used). The set R_k represents the propagation path of the message k, where r_{ki} represents a requirements process module, and the order of the demand process in the path k is i, $r_{k0} = 0$ means IMDS. The mathematical model of the signaling message routing optimization problem is established by taking the minimum value of the message propagation path as the optimal value of the objective function. As shown in formulas (2), (3), and (4):

$$\min F = \sum_{k=1}^{k} \left[\sum_{i=1}^{n_k} d_{rk(i-1)rki} + d_{rknkrk0}\, flag(n_k) \right] \tag{2}$$

$$flag(n_k) = \begin{cases} 1, & n_k \geq 1 \\ 0, & n_k < 1 \end{cases} \tag{3}$$

$$R_{k_1} \cap R_{k_2} = \emptyset, \quad \forall k_1 \neq k_2 \tag{4}$$

The time range of the message reaching the target module i is required to be $[a_i, b_i]$. The time when the message arrives at the target module i is S_i, the processing time of the message in the target module is T_i, and the time from the target module i to the target module j is T_{ij}. As shown in formulas (5) and (6):

$$S_{rki} = S_{rk(i-1)} + T_{rk(i-1)} + T_{rk(i-1)rki} \tag{5}$$

$$T_i = \max\{a_i - S_i, 0\} \tag{6}$$

To sum up, the main design principle of IMDS is to reduce the number of transmission modules of 5G messages and shorten the waiting time of 5G messages in the target module.

III. IMDS IMPLEMENTATION

The goal of IMDS is to ensure the shortest routing time, maximize the diversity of antibodies, and save as much space as possible. Ideally, the time required to hash-map to find value is O (1), because for computer memory, the time to access any address is the same, that is, very short, equivalent to all addresses can be accessed at the same time. The easy way to understand this is that, after finding the key, the hashed map iterates through the key-value pairs to find the value in O (1). What is more difficult to do is to find the key in order of time, which is also the key of hashed map design. In the traditional way, if the traversal time complexity of hashed map reaches O (1), a large memory space is required, and the length of its linked list determines its search efficiency. Therefore, if the routing efficiency of antibody messages is to be improved, the length of the hashed map linked list should be as short as possible, so that the time to find the key should be as short as possible, and the editing and transmission process of antibody messages should be shortened. Next, we use the immune algorithm to improve the hash map, through the immune affinity calculation, the clonal selection algorithm, and the dynamic adaptive mechanism of antibody concentration, to ensure the diversity of antibody messages, shorten the hash map list length, so as to reduce the computer memory overhead and shorten the routing time.

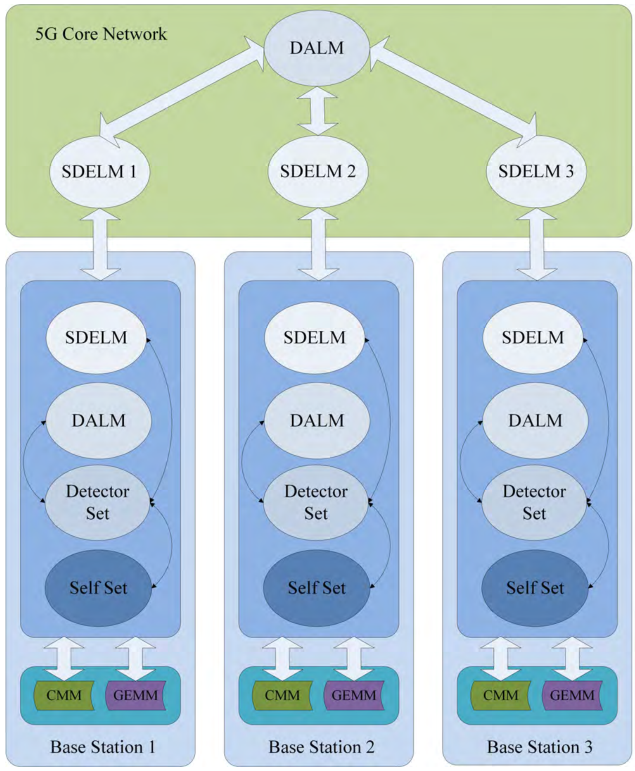

FIGURE 6. 5G semi-distributed dynamic adaptive learning mechanism.

A. ANTIGEN AND ANTIBODY CODING

The structure of immune antibody cells is divided into constant region (C region) and variable region (V region). The C region of the same type of antibody is the same, and the V region of antibody produced by different B cells is different, but the V area of antibody produced by the same type of B cells or cell cloning is the same [30]. Forrest proposed that the antibody/antigen is represented by a bit string of fixed length L, and the identification is performed by whether or not the bit string is matched. In the Celada-Seiden model,

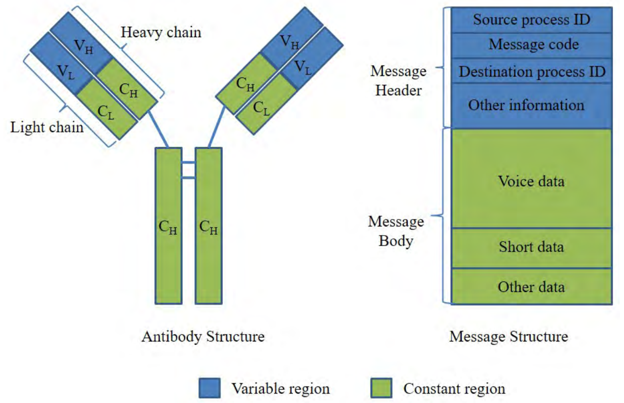

FIGURE 7. **IMDS message and antibody structure analogy.**

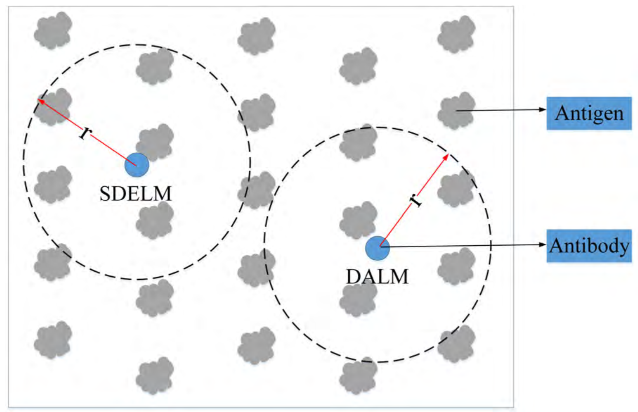

FIGURE 8. **Schematic diagram of IMDS antigen and antibody affinity.**

antibodies can recognize antigens as long as the antibody/ antigen bit strings are complementary matched [31]. In this paper, the antibody structure and antigen structure are the same as the message structure. The antibody is the message that can be sent to the target process module after being screened by the detector and processed in the CMM and GEMM, including the antibody message discarded by the system. The encoding mode of antibody/antigen combines the simplicity of Forrest and the high trigger of Celada-seiden model. Referring to the cell structure of antibody, the message packet in the context of 5G system is expressed as antigen. All antigens need to be processed by IMDS to be converted into the system's recognizable antibody message.

Antibody structure and message structure as shown in Fig. 7. The encoding method of an antibody and an antigen message is defined as a fixed-length binary string containing a message header and a message body. The message header includes the source address, destination address, source process ID, destination process ID, message code and other elements of the message. These elements are of fixed length, and the variation of the antigen is identified by the string change of the fragment in which the element is located. The message body is the body information content of the message, including the carried information, the voice data and other business data bearers, and the message body of some messages may be empty, such as a notification message. According to the design idea, the reference cell structure can also be divided into C region and V region. The message satisfying the cloning condition is that the message header fragment is the V region and the message body is the C region.

B. AFFINITY CALCULATION

Affinity is the ability to bind between an antibody and an antigen. The affinity of an IMDS in a digital cluster communication system can be defined as the degree of matching of an antibody message and an antigen message. The matching degree can utilize the r consecutive bit matching rule. If the antibody matches the character at each position in the header information of two fixed length binary strings in the antigen, this match is called an exact match. Let the message code of the antibody message be x, the length be i, the message code of the antigen message be y, the length be j, k be a corresponding position in x and y, and formula (7) describes the calculation method of IMDS affinity. *1* represents a match and *0* represents a mismatch.

$$f_{\text{affinity}}(\text{x,y,r}) = \begin{cases} 1, & \exists i,j, j-i \geq r, \quad x_k = y_k,\ i \leq k \leq j \\ 0, & otherwise \end{cases} \tag{7}$$

The optimal r value can minimize the number of detectors and obtain good recognition ability. In this paper, the message code is selected as the r value, which is similar to the recognition radius in the antibody shape space, as shown in Fig. 8. When an antigen message enters the system, IMDS determines the matching degree of antibody message code and antigen message code in CMM and GEMM, and then the affinity can be calculated. In order to make the detector recognize the antigen message code more quickly, the antigen message code can be divided into numerical ranges according to the business type in the system construction stage, for example, the decimal range of the call established message code is from 1 to 1000, the decimal range of the call maintained message code is from 1001 to 2000, and so on. After such processing, when the message enters the system again, the IMDS of the system first enters the CMM and GEMM for query, and gives priority to processing, so as to carry out rapid immune response and perform efficient and lasting message distribution function.

C. CLONAL SELECTION AND CLONAL AMPLIFICATION

The basic idea of clonal selection is that only those cells that recognize the antigen can be cloned and amplified. Clonal selection is used to explain how the immune response is formed when the B cell recognizes the font antigen pattern. Stimulated B cell proliferation activates somatic high frequency variation mechanisms: B cells compete for binding antigens, antigens (received messages) stimulate B cells with high affinity antibodies (messages in CMM), B cells (messages) reproduction (cloning). B cells with low affinity antibodies are eliminated or specifically processed (messages in GEMM). Repeating this process of mutation and selection (detector tolerance and immune memory), the immune system produces high-affinity antibodies [32], [33].

After immune classification, N_{CMM} antibodies are set in CMM and N_{GEMM} antibodies are set in GEMM. The *ith* antibody is broadcast to other wireless access networks according to formulas (8) and (9) of clonal scale respectively. Where, N_c is the total number of other wireless access networks in the 5G system, and η and ε are the clone coefficients.

$$\sum_{i=1}^{NCMM} \left[\eta \cdot NCMM / i\right] = Nc \tag{8}$$

$$\sum_{j=1}^{NGEMM} \left[\varepsilon \cdot NGEMM / j\right] = Nc \tag{9}$$

D. HIGH FREQUENCY VARIATION

High-frequency variation of somatic cells refers to the differentiation and amplification of antibodies at higher frequencies after binding to antigens. The progeny have a different receptor structure than the paternal, have different antigenic determinants affinity, and enhance cell diversity. The basic changes are distributed throughout the V region, but the location of the mutations is not random, but occurs in some areas of the variation hotspot. The overall result is that the average affinity of the progeny B cells and the antibodies produced by them to the antigen is improved.

With reference to the high-frequency variability of the antibody, IMDS can change the variable region (message header) in the antigen message according to the system user's needs when the antigen message is processed, while the constant region (message body) is unchanged [34]. The destination process ID and the destination message code send the mutated antibody message to the destination process module. When the clone is amplified, the message occurs in the IMDS in a high frequency variation.

E. IMMUNOLOGICAL MEMORY

When re-immunized with the same antigen, it can cause more antibody production than the initial response, resulting in a larger and faster response, called immune memory. Immunological memory is formed by multiple immunizations of the same antigen. Antibodies have two directions in their survival: whether they become memory cells or plasma cells [35].

The IMDS does the same for antibody messages: a timer and threshold are set for the detector, when an antibody message enters the system multiple times within the specified time of the timer, and the constant region of the message remains unchanged. Only the information such as the source address and the destination address in the variable region changes, and the clonal selection condition is satisfied. The antigen message is added to the CMM, otherwise the antibody message is added to the GEMM, and finally becomes the memory antibody cell, and the memory antibody only needs to be retained. The message code of the antigen message minimizes system memory space.

F. ADAPTIVE PROLIFERATION AND INHIBITION OF ANTIBODIES

In 5G system, IMDS select antibodies with high antigen-affinity and memory cells in the antibody population to participate in clonal amplification and mutation, while antibodies with low affinity still exist in the system and die out gradually.

Whenever a new antibody is produced or SDELM learns new antibody knowledge increments, in DALM, Euclidean space distance calculation formula is used to compare the affinity of the new antibody with the antibody in CMM and GEMM. As shown in formula (10), the coordinates of antibody m are $\{am_1, am_2, \ldots, am_i\}$, the coordinates of the antibody n are $\{an1, an_2, \ldots, an_i\}$. Define δ as the inhibition threshold. When D_{mn} is less than δ, the antibody is eliminated. By comparison, antibodies with high similarity but low affinity were eliminated. Maintain the diversity of antibodies in the system.

$$Dmn = \sqrt{\sum_{i=1}^{L} (am_i - an_i)^2} \tag{10}$$

N_{Ag} is the number of antigen messages, N_{Ab} is the number of antibody messages, N_{CMM} is the number of antibodies in CMM, and N_{GEMM} is the number of antibodies in GEMM, as shown in formulas (11) and (12):

$$N_{\mathrm{Ab}} = N_{CMM} + N_{GEMM} \tag{11}$$

$$N_{CMM} \cap N_{GEMM} = \emptyset \tag{12}$$

Let N_{Ab} antibodies be expressed as $\{x_1, x_2, \ldots, x_{Nab}\}$, N_{Ag} antigens are expressed as $\{y_1, y_2, \ldots, y_{NAg}\}$. Referring to the Farmer model [36], the dynamic equation of 5G IMDS system can be expressed as formula (13):

$$\begin{aligned} S = c\,[&\sum_{j=1}^{N_{\mathrm{CMM}}} M_{CMM_{\mathrm{ji}}}(xi, xj) + \sum_{j=1}^{N_{GEMM}} M_{GEMM_{ji}}(xi, xj) \\ &- \mathrm{k}_1 \sum_{j=1}^{N_{\mathrm{CMM}}} M_{CMM_{ij}}(xi, xj) - k_1 \sum_{j=1}^{N_{GEMM}} M_{GEMM_{ij}}(xi, xj) \\ &+ \sum_{j=1}^{N_{Ag}} M_{CMM_{\mathrm{ji}}}(xi, xj) + \sum_{j=1}^{N_{Ag}} M_{GEMM_{ji}}(xi, xj)\ ] - k_{2xi} \end{aligned} \tag{13}$$

In formula (10), c is a rate constant, which is related to the number of antibody encounters per unit time and the rate at which antibodies are produced after a single encounter. The first and second terms respectively represent the stimulation of antibody j to antibody i in CMM and GEMM. The third and fourth terms respectively represent the inhibition of antibody i in CMM and GEMM by antibody j, and the constant k_1 represents the unequal relationship between the stimulation and inhibition of the same antibody. The fifth and sixth items

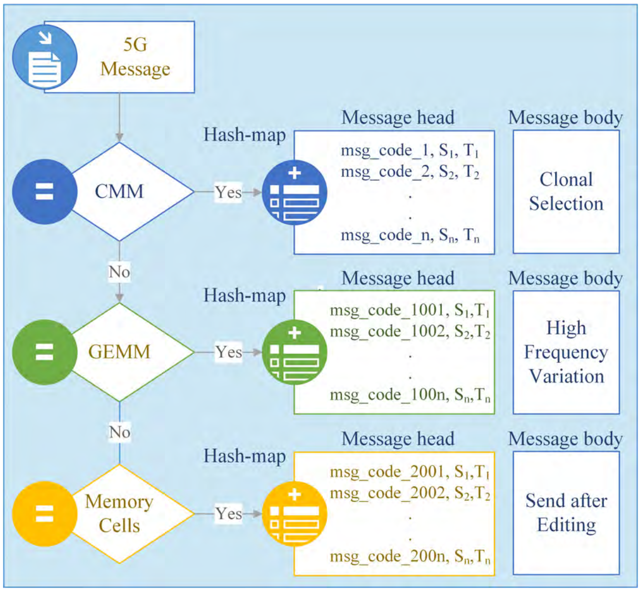

FIGURE 9. Processing of CMM and GEMM in IMDS.

respectively represent the stimulation degree of antigen to antibody i in CMM and GEMM. The last one is cell death, k_2 is the natural death rate.

The matching specificity matrix function M_{ij} is shown in formula (14). Where, *source(n)* represents the *nth* bit of the source address of the message, *target(n)* represents the nth bit of the destination address of the message, *code(n)* represents the message code, k is the number of shifts, m is the matching threshold, and xor operation is adopted. The function $R(x)$ is defined as formula (15):

$$M_{ij} = \sum_k R\Big(\sum_n \big[source_i(n+k) \wedge source_j(n)\big] + \sum_n \big[target_i(n+k) \wedge target_j(n)\big] + \sum_n \big[code_i(n+k) \wedge code_j(n)\big] - m + 1 \Big) \quad (14)$$

$$\mathrm{R}(x) = \begin{cases} x, & x > 0 \\ 0, & otherwise \end{cases} \quad (15)$$

The processing process of 5G messages in each module of IMDS is shown in Fig. 9.

IV. PERFORMANCE EVALUATION AND DISCUSSION

A. SIMULATION ENVIRONMENT

The simulation environment includes the real environment and the simulated simulation environment. The real environment is used to verify the real feasibility of IMDS in the actual system. The simulation environment is mainly used for pressure testing of IMDS.

Two core network servers and two base stations were used in the real environment. Each base station has two carrier boards, each carrier board uses time division multiple access, a total of four logic channels, including a control channel, three service channels. Twelve mobile terminals were used. As shown in TABLE 2.

TABLE 2. Simulation environment description.

Simulation Environment	*Parameter*
code operating system	Windows 10
code development environment	Visual Studio 2017
code compilation tool	GCC 7.4
core network operating system	Windows Server 2008
base station standard protocol	Police Digital Trunking
base station operating system	Linux Ubuntu 16.04
database	MySQL Community Server
channel coding technique	TDMA
number of core network servers	2
number of base stations	2
number of carrier boards in base station	2
carrier board slot number	2
total number of channels	8
number of logical control channels	2
number of logical traffic channel	6
number of wireless terminals	12
number of simulated base stations	100
number of simulated users	50000
number of affiliations of a group member	1×10^6

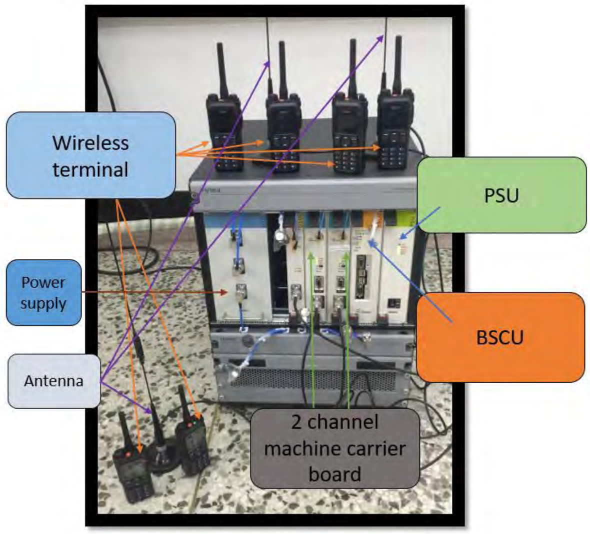

FIGURE 10. The real simulation equipment.

In the pressure test, three core network systems and 100 base stations were simulated. The simulated carrier board initiates the service and puts pressure on the base station. Simulate base stations to initiate concurrent traffic, which puts pressure on the core network. This includes 50,000 mobile users, 7,000 groups, and 1 million affiliate groups.

In order to ensure that the code can be used across operating systems, we use the virtual operating system platform to implement multiple operating system interfaces. Compile the Windows version code in Visual Studio 2017, use gcc to edit the Linux version code, and directly embed the executable program into the base station through the serial port. The real simulation equipment is shown in Fig. 10.

IMDS simulation belongs to interprocess communication and simulates protocol business process, which is less affected by simulation environment. Therefore, due to limited conditions, we carried out simulation experiments in the laboratory's private network base station. The base station controller is based on the PDT (Police Digital Trunking) standard protocol. The virtual operating system platform uses the interprocess communication API function of C++ development environment, and the map iterator provided by STL is used to implement CMM and GEMM.

Given the set D containing m samples, $D = \{(x_1, y_1), (x_2, y_2), \ldots, (x_m, y_m)\}$, where y_i is the real token for example x_i. Its mean square error is shown in formulas (16) and (16):

$$E(f; \mathrm{D}) = \sum_{i=1}^{m} (f(x_i) - y_i)^2 / m \tag{16}$$

$$y = \begin{cases} 0, & y \in CMM \\ 1, & y \in GEMM \\ 2, & otherwise \end{cases} \tag{17}$$

Pseudo code for the IMDS as shown in Algorithm 1.

Algorithm 1 IMDS.

```
procedure input: (5G antigen message)
Step 1: Initialization CMM and GEMM.
Step 2: Get the process ID and message code.
process_ID ← decod (5G antigen message)
message_code ← decod (5G antigen message)
Step 3: The detector checks the message.
for n ∈ ND do
    if Msg ← Find_Detector(process ID, message
    code) then
    add_Detector(Msg)
    break
    end if
end for
Step 4: Find the message in the CMM.
for n ∈ NCMM do
    if Msg ← Find_CMM (process ID, message code)
    then
    clone(Msg)
    Send_message(5G antibody message)
    break
    end if
end for
Step 5: Find the message in the GEMM.
for n ∈ NGEMM do
    if Msg ← Find_GEMM (process ID, message
    code) then
    gene_editing(Msg)
    Send_message(5G antibody message)
    break
    end if
end for
Step 6: Add messages not found to DALM.
new_map ← insert_map(process_ID,
message_code)
Step 7: Experience the process of immune tolerance
Broadcast_other_stations(Msg)
Update
end procedure
```

B. SIMULATION RESULTS

The communication modes between source process and destination process discussed in this paper can be divided into two types: 1. Direct communication (DC) mode. 2. Through IMDS communication (TIC) mode. Since there is no interference from other processes and factors, DC takes less time than TIC. We take the inter-process communication time in DC mode as the TIC comparison data.

We conducted simulation tests in TIC and DC modes respectively. Firstly, the service pressure test of each single industry is carried out. In 1), the database write operation test is described. In 2) to 4), three kinds of single service pressure tests are described, including: voice group call, voice single call, short message group call. Next, the pressure was gradually pressurized and the multi-service mixed pressure test was carried out. In 5) to 7), the pressure test of three kinds of service combination synchronization service is described respectively, including: voice group call, registration, short message group call. In 8) to 9), the pressure test of two kinds of service combination registration service is described respectively, including: voice group call and short message group call. Finally, the multi-service mixed load pressure test was carried out for a long time. In 10), the average execution time, the number of executions, and the average single execution time of each service under the pressure load for a long time are respectively counted.

1) CONTRAST WITH DIRECT COMMUNICATION MODE

In order to observe the efficiency of IMDS in the most intuitive way, we select user information statistics service. The user information statistics business process is relatively simple, and its process in IMDS (TIC mode) can be described as follows: the mobile user management (MM) module process writes the user information data to the database (DB) process after passing through IMDS. Compared with DC mode, the DC process can be described as: MM process writes user information data directly to DB. In DC mode and TIC mode, the service is triggered for 10000 times respectively. According to the logging tool, the message recall rate is 100% and the accuracy rate is 100%. In the comparison data between the two, 20 times of them are randomly selected for comparison, as shown in Fig. 11:

The average time of running the user statistics service in DC mode for 10,000 times is about 0.05423ms. The average TIC run time of 10,000 times is about 0.20641 milliseconds. The difference is about 0.15218ms. In 5G communications services, the huge amounts of the demand of the terminal connected, all terminals are need to understand the received 5 g message service process of source and target process is not realistic, so the DC mode as reference data, only through the application in the business user information statistics, it can be seen that the reliability of the IMDS is very good, efficiency is high.

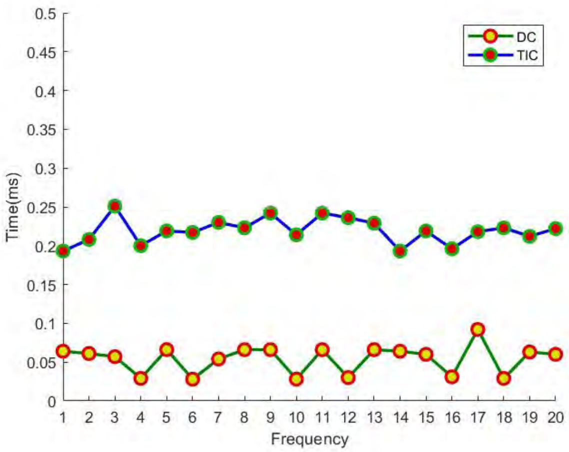

FIGURE 11. Time-consuming comparison of PRPC and PPDC for user information statistics service.

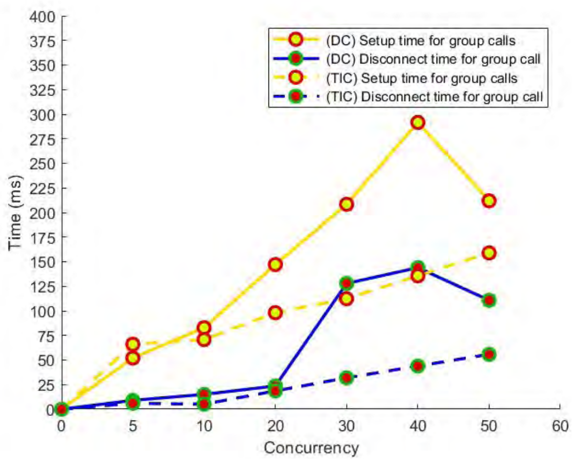

FIGURE 12. Group call changes with the number of concurrent.

2) VOICE GROUP CALL PRESSURE TEST

The call setup statistics time of the voice group call is the time when the base station sends the call setup request message to the core network response message, and the disconnection statistics time is the time when the base station sends the disconnection request message to the core network response message. As shown in Fig. 12:

The test model is multi-way concurrency. After the pressure is stabilized, the DC method accumulates many old services in the message queue before processing each new service, resulting in an increase in response time as the number of concurrent routes increases. When 40 channels are concurrently, the average response time is higher than 50 channels, and the processing capacity must fluctuate up and down. In the TIC mode, the service is relatively stable and takes less time than the DC mode.

3) VOICE SINGLE CALL PRESSURE TEST

The call setup statistics time of the voice single call is the time when the base station sends the service setup request message to the core network response message; the disconnection statistics time is the time when the base station sends the disconnection request message to the core network response message. The test model is multi-way concurrent. As shown in Fig. 13:

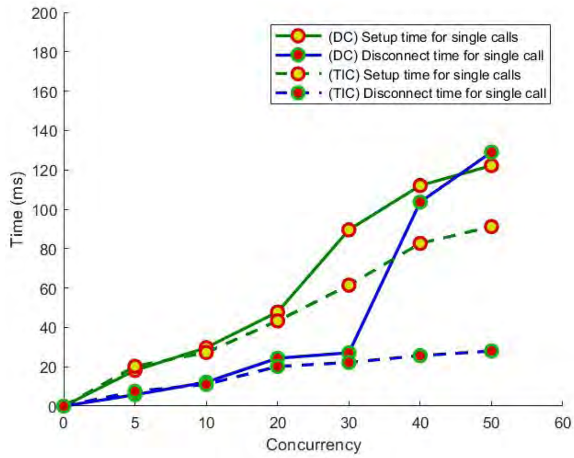

FIGURE 13. Single call changes with the number of concurrent.

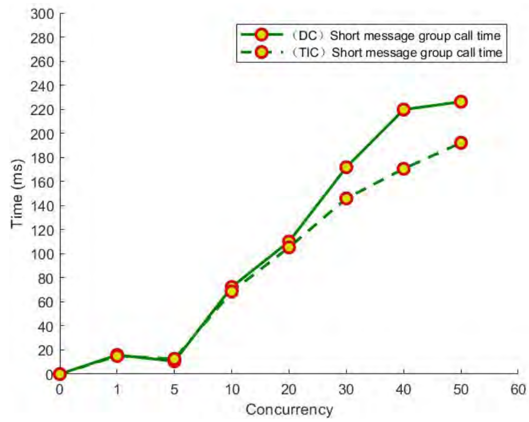

FIGURE 14. Short message group call changes with the number of concurrent.

4) SHORT MESSAGE GROUP CALL PRESSURE TEST

The establishment time of the short message group call is the time when the base station sends the short message service setup request message to the core network response message. The test model is multi-way concurrent. As shown in Fig. 14:

5) VOICE GROUP CALL COMBINED SYNCHRONOUS PRESSURE TEST

Under the condition that the group call business pressure is unchanged, the pressure level of the synchronous service is gradually adjusted to verify the influence process between the threads when the core network MM module processes different services in multiple threads. As shown in Fig. 15:

With the pressure adjustment of the synchronous service, the setup time and the disconnection time of the group call in the DC mode have no significant effect. However, the statistical time of group calls still fluctuates.

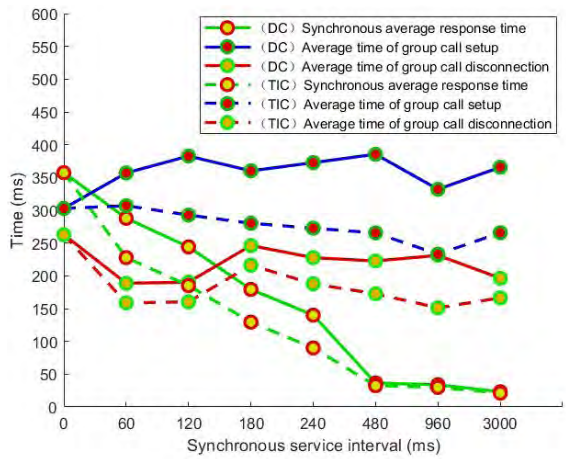

FIGURE 15. Voice group call combined synchronous pressure test.

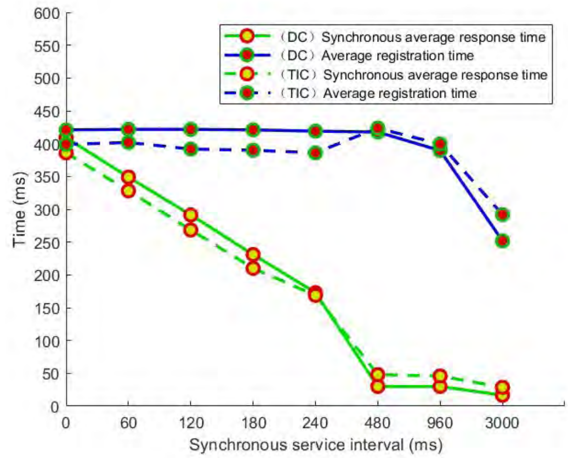

FIGURE 16. Registration combined synchronous pressure test.

6) REGISTRATION COMBINED SYNCHRONOUS PRESSURE TEST

Under the condition that the registration business pressure is unchanged, the pressure level of the synchronous service is gradually adjusted to verify the degree of influence between the thread when the core network MM module processes different services in multiple threads. As shown in Fig. 16:

With the pressure adjustment of the synchronous service, the response time of the registration service under the DC mode has no significant effect. When the synchronization interval time increases, the message queue of DC mode does not have too much pressure, which is gradually close to the processing time of TIC mode, and slightly better than TIC mode after the pressure level becomes stable.

7) SHORT MESSAGE GROUP CALL COMBINED SYNCHRONOUS PRESSURE TEST

Under the condition that the short message group has the same pressure, the pressure level of the synchronous service is gradually adjusted to verify the degree of influence between the thread when the core network MM module processes different services in multiple threads. As shown in Fig. 17:

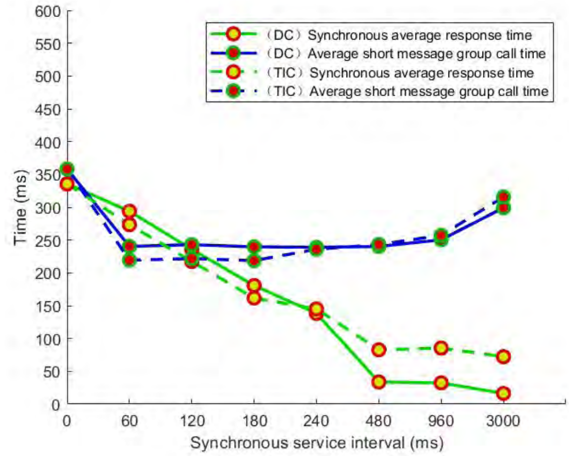

FIGURE 17. Short message group call combined synchronous pressure test.

With the pressure adjustment of the synchronous service, the short message group call response time in the DC mode has no significant influence. When the synchronization interval time increases, the message queue of DC mode does not have too much pressure, which is gradually close to the processing time of TIC mode, and slightly better than TIC mode after the pressure level becomes stable.

8) VOICE GROUP CALL COMBINED REGISTRATION PRESSURE TEST

Under the condition that the group call business pressure is unchanged, the pressure level of the registration service is gradually adjusted to verify the degree of influence between the thread when the core network MM module processes different services in multiple threads. As shown in Fig. 18:

With the pressure adjustment of the registration service, the establishment time and the disconnection time of the group call under the DC mode have no significant influence. However, the statistical time of group calls still fluctuates.

9) SHORT MESSAGE GROUP CALL COMBINED REGISTRATION PRESSURE TEST

Under the condition that the short message group has the same pressure, the pressure level of the registration service is gradually adjusted to verify the degree of influence between the thread when the core network MM module processes different services in multiple threads. As shown in Fig. 19:

With the pressure adjustment of the registration service, the response time of the short message group call in the DC mode has no significant influence. However, the statistical time of the short message group calls still fluctuates.

10) MULTI-SERVICE LOAD TEST

Under long time load pressure, test the processing speed and change trend of each service in the system.

As shown in Fig. 20 and Fig. 21, in the mixed test of multiple services, the response time of each service in TIC mode is stable and does not increase with the execution time, and the number of times of business processing per unit time

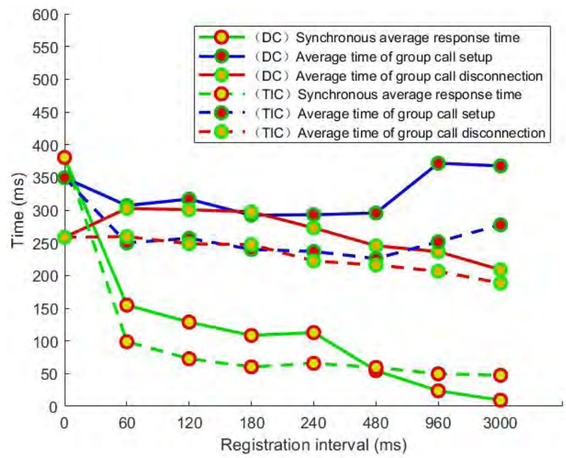

FIGURE 18. Voice group call combined registration pressure test.

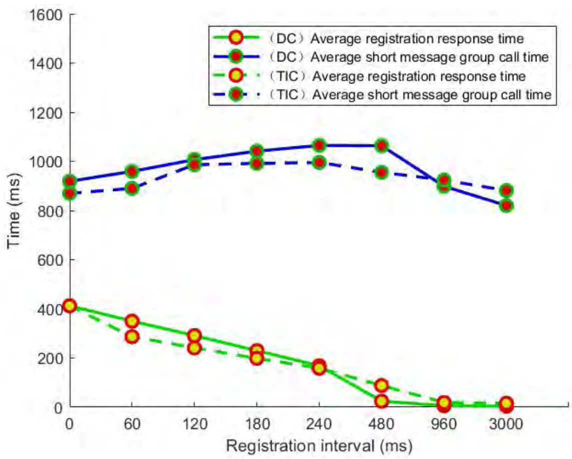

FIGURE 19. Short message group call combined registration pressure test.

is significantly greater than that in DC mode. In the first hour, the response time of each business in DC mode is relatively slow, especially in the single-call dismantling line. In addition, the response time of each business will fluctuate during operation, and the response time will increase. As shown in Fig. 22, the average time of single execution of each service in TIC mode and DC mode is very close under mixed loads of multiple services for a long time.

C. RESULTS ANALYSIS

It can be seen from the above simulation that in the case of a small amount of traffic and a relatively small number of interactive processes, in the DC mode, since there is no pressure on the message queue, in this case, the average time of each service in the TIC mode is slightly more. The main reason is that in the inter-process communication process of each module under TIC mode, IMDS, a process module, is often experienced in message routing and delivery, and the invocation of message body is less.

In the concurrent test, after the pressure reaches a stable level, when the DC mode is processing each new business,

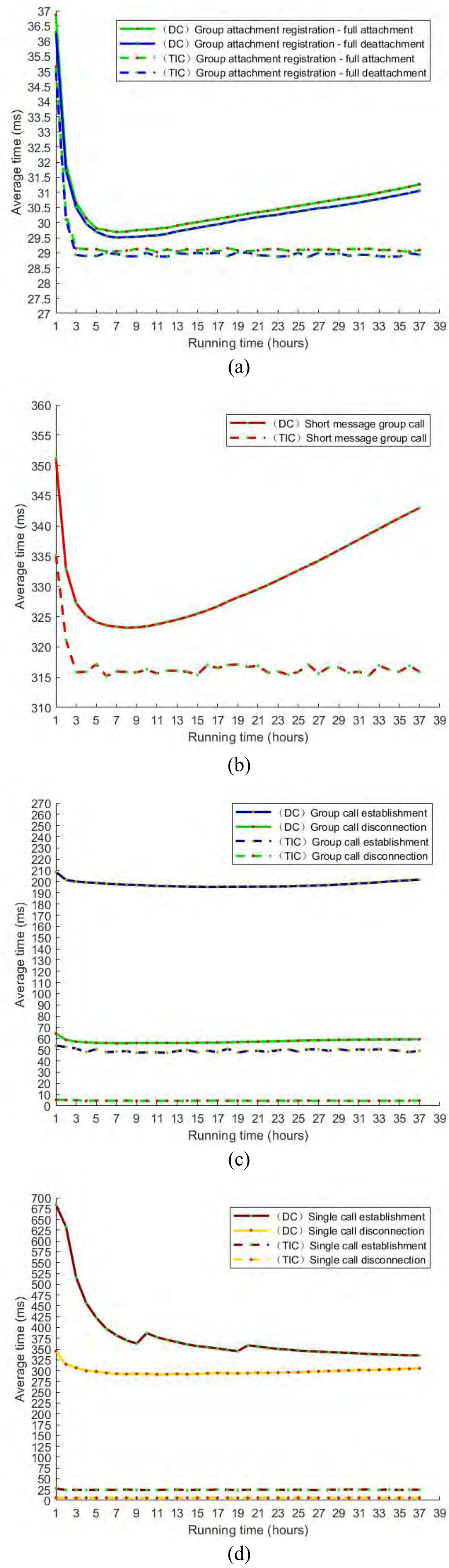

FIGURE 20. Average execution time of each business over time under pressure load.

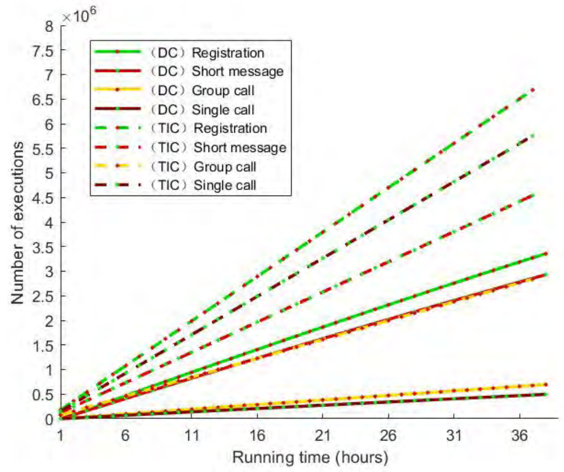

FIGURE 21. Average execution time of each business over time under pressure load.

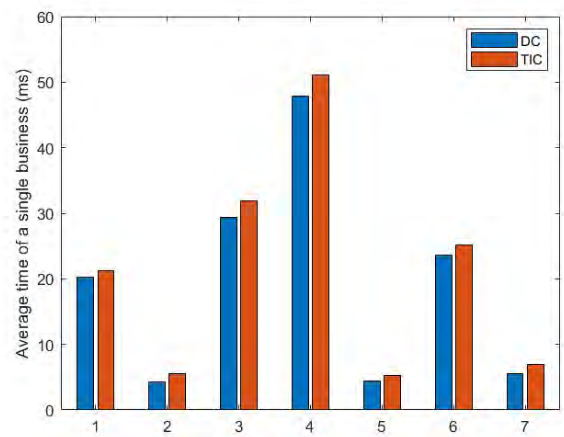

FIGURE 22. Average time of a single business. In the horizontal axis, 1 to 7 respectively represent the following businesses: 1. Group attachment registration - full attachment; 2. Group attachment registration - full deattachment; 3. Short message group call; 4. Group call establishment; 5. Group call disconnection; 6. Single call establishment; 7. Single call disconnection.

due to the accumulation of multiple old businesses in the message queue, the response time increases with the increase of the number of concurrent routes. In DC mode, the main reason for the accumulation of old businesses is that there are too many messages stored and the message body is too large, resulting in a long time for the message to be stored, edited and forwarded. In the TIC mode, redundant antibody messages are eliminated. At the same time, in the CMM, the message that can be directly forwarded is cloned, stored and forwarded to the message body in the process of message editing, which reduces the storage and forwarding time of the message body. In GEMM, high frequency mutation operation is carried out on the message body that needs to be mutated, which saves the editing processing time and memory space of the message. After editing, the message is directly forwarded according to the message header information stored in the hash-map. At the same time, the detector and memory cells in IMDS eliminate redundant antibodies through affinity and antibody concentration calculation, maintain the diversity of antibodies, save the storage space of hash-map, reduce message traversal search time, and improve the efficiency of message delivery.

V. CONCLUSION

5G will bring various new demands on message communication. In this paper, our innovative contributions mainly include:

1. Combining with the distributed characteristics of biological immune cells, a 5G message service system framework based on the semi-distributed immune dynamic adaptive mechanism is proposed. The semi-distributed architecture of the system is simple, which enhances the edge computing ability of 5G base station and realizes the efficient scheduling of 5G message service.

2. The concept and design idea of IMDS were proposed by comparing the molecular structure of immune cells with the structure of messages. The message classification processing mechanism based on CMM and GEMM is used to clarify the message classification and reduce the traversal and lookup time of message routing. Clone selection and high frequency mutation algorithm were used to edit and distribute the message body, which effectively reduced the storage space of hash-map and improved the efficiency of message storage and forwarding. Antibody concentration and affinity calculation are used to ensure the diversity of antibody messages.

Through a large number of simulations, we verify the feasibility and practicability of the proposed scheme. The simulation results of single and multi-service mixed pressure show that the semi-distributed immune dynamic learning mechanism increases the adaptability of the system, IMDS has a good ability to recognize antigen messages, and antibodies have diversity and high detection rate. Under the pressure of high load for a long time, TIC mode has better execution efficiency than DC mode, faster processing speed and good message throughput of the system. Moreover, the TIC mode runs smoothly, which improves the information processing capacity of 5G system.

This paper provides an effective solution and idea for the message routing of 5G message service system, which reflects the great application potential of artificial immunity theory in the field of 5G communication. In the future, 5G message service is basically designed for internet of things (IoT) device communication. The emerging communication of IoT devices will put forward higher requirements for message services in terms of service capability, performance and security. In the future work, we should always master the latest 5G demand dynamics and apply the artificial immunity theory to 5G in a deeper and more comprehensive way.

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