Random access conflict resolution of preamble waiting list based Game-theory

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Abstract. With the development of mobile communication network, Internet of things and communication base station, super reliable transmission of communication signal and super anti-interference ability, mobile communication technology has been popularized in various industries, and a large number of products have emerged in communication technology and related applications. However, the increase in the number of products has caused a huge load to the mobile base station. The limited access resources of mobile base station also bring high access delay and high access conflict risk to access equipment. Random access is the first step of equipment access to mobile communication network. It can reasonably allocate access resources in the process of random access, which will effectively control the access conflict in the process of large-scale equipment access. Based on this, this paper proposes a solution to the random access conflict of packet preamble based on waiting queue list. The scheme introduces ACB (Access Class Barring) access factor for different types of access devices. At the same time, the preamble resources are grouped to reduce the load of single base station. The access probability of different demand types of equipment is continuously balanced by game model, which reduces the access probability of non-demand equipment and improves the access probability of demand equipment. Considering the conflict of retransmission waiting time and retransmission success probability in random access process, and the waste of access resources in mobile communication system, a preamble waiting queue list mechanism is proposed. This mechanism can reduce the repeated access and retransmission waiting of access devices by reasonably scheduling them to a high idle waiting queue. The resulting access delay improves the access efficiency of the device, reduces the resource idle degree of the mobile communication system, and improves the resource utilization rate.

1. Introduction
With the rapid development of 5G and Internet of things (IoT), mobile communication equipment is also developing rapidly, the number of related equipment is growing rapidly, and the related application services are emerging in an endless stream, which brings great challenges to the system capacity and load rate of 5G base station. In the situation of massive Machine Type Communication (mMTC) access, the first problem to be dealt with is the random access conflict. In order to reduce the conflict in the process of random access, reduce the device access failure rate and access delay caused by the conflict, and improve the access efficiency of the device, many experts have proposed effective random access conflict resolution methods. These methods can be divided into three aspects: random access traffic control, random access resource scheduling and cooperative random access design.
As for the random access traffic control, there are ACB that has been proposed by 3GPP[1] random backoff[2], timeslot access[3] and other schemes. The essence of random access traffic control is to disperse the massive access requests at the same time to a longer time window, and reduce the access traffic per unit time by sacrificing the access delay of the device, so as to reduce the probability of random access conflict. When this kind of method is applied to delay sensitive services such as location, it will produce great location error; and because this kind of method disperses multiple devices at the same time into a longer time window, it is not suitable for massive device access situation.

As for the random access resource scheduling, there are Resource Separation Scheme(RSS)[4], resource scheduling scheme based on priority[5] and so on. The essence of this kind of method is to schedule the access resources of different service types of equipment to meet the equipment access requirements in different business scenarios, so as to reduce the access conflicts in the access process of different business equipment. This kind of method can effectively reduce the access conflict according to the service priority for specific services, but it can not be applied to massive equipment access scenarios, only according to the service division can not effectively reduce the access load of the base station network, so the access conflict of the equipment can not be effectively reduced too.

As for the cooperative random access design has cooperative access scheme for multiple access devices[6][7][8] and multi base station cooperation scheme[9][10][11][12]. The essence of this kind of method is to reduce the access load of single base station network and reduce the access delay by managing different random access preamble resources. This kind of method can effectively reduce the access congestion of base station network and improve the access efficiency of equipment, but it can not access according to the priority of service, so it is not suitable for special scenarios and emergencies.

In order to improve the access success rate of equipment, reduce the load of base station, and adjust the priority of access equipment according to different services, combined with the above three methods, this paper proposes a solution to random access conflict of block preamble based on waiting queue list. This paper proposes a random access conflict resolution scheme for packet preamble based on waiting list. The scheme reduces the access load of single base station by grouping the preamble, and introduces ACB factor according to the requirements of different types of equipment, so as to improve the access priority of demand type equipment. Finally, the waiting queue list mechanism is proposed to adjust the utilization rate of each preamble through the idle state of the preamble resources, so as to realize the cooperation and dynamic adjustment among the preamble resources.

The core problem of this paper is random access conflict resolution, so the first step is to introduce random access. Random access is the first step of mobile device access and conflict generation. In 5g protocol, random access is divided into competitive random access and non competitive random access. The random access preamble used by the latter access device is specified by the mobile base station and will not conflict with other devices. At the same time, the non competitive random access preamble only accounts for a small part of the random access preamble set, so this paper only considers the random access in the competitive mode, and the specific process is shown in Figure 1.

![Figure 1. Contention based Random Access Procedure](image)
Competitive random access process:

1.1. MSG1: terminal type sends preamble to base station.
Before random access, the mobile phone obtains the basic information and time-frequency resources of random access preempt code through the system message broadcast by the base station to complete the initialization of random access. The preamble code is composed of 64 ZC sequences and their shift sequences generated by the physical layer. The mobile device can only initiate random access once at a time, then start to monitor msg2, if not, start retransmission.

1.2. Msg2: base station sends random access response(RAR) information to terminal.
The base station will always blind check the mobile phone access signal in the random access channel. After the mobile phone sends MSG1, the base station can detect the preamble code sent by the mobile phone and report it to the MAC layer. Then the base station will feedback RAR to the mobile phone in the PDSCH channel. When multiple mobile phones apply for access to the base station at the same time frequency, these mobile phones will receive the same RAR information. If the mobile phone receives the RAR before the end of monitoring, it will not retransmit MSG1.

1.3. Msg3: RRC connection established.
After receiving the RAR, the mobile phone can get uplink synchronization through TA adjustment in RAR, and transmit msg3 in uplink resources allocated by base station for subsequent data transmission. Msg3 carries its own identity and RRC connection request or RRC connection reestablishment request, depending on the mobile access scenario.

1.4. Msg4: RRC connection established successfully.
After receiving the msg3 sent by the mobile phone, the base station will generate msg4, in which msg4 will carry the contention resolution ID and then send it to the mobile phone. After sending msg3, the mobile phone is waiting to receive msg4. When the received msg4 message contains its own identity, the random access is successful.

As the uplink signal receiver of mobile terminal, the base station continuously broadcasts system information after power on, including 64 preambles contained in the base station. The mobile device will randomly select one of these preamble codes as the preamble sequence code for random access. If multiple mobile devices select the same preamble code at the same time and frequency, it will generate random competition Access conflict. The failed party will need to wait for the next time slot, and then reselect the preempt code for random access again, which will increase the access delay.

This paper proposes a access conflict resolution method based the game-theory model. The first step is to set different priorities for different terminals according to the service requirements, and then the preamble resources are grouped according to the service requirements. Finally, the access probability of the non demand equipment is balanced based on the revenue function of the game model, so that the access probability of the demand equipment is increased and the access interference of the non demand equipment is reduced. The second step is to create a preamble waiting list according to the idle state of each preamble, according to this table, the idle rate of each preamble resource is adjusted to reduce the waste of preamble resource, shorten the access delay of access equipment and improve the throughput of base station.

2. Preamble packet access scheme based on Game Theory

2.1. Game Theory
Game theory is a new branch of modern mathematics and an important subject of operational research. It refers to that when restricted by certain conditions, individuals make corresponding strategies referring to the strategies of other parties participating in the game, and find a stable solution from a balanced point of view[13].
Game theory studies the theories and methods of competition or struggle. The basic elements of game include three: participants, strategies and utility. The result of the balance of game theory at the same time is generally called Nash equilibrium. In order to improve the access success rate of demand-based devices and reduce the interference of other devices, this paper groups the competitive access preamble, and builds a game model based on the access success rate of non-demand devices as a profit function.

2.2. Building Game-Theory Model

The first step divides the types of access devices into two types according to business requirements. The second step divides the competitive random access preambles into A, B and C groups. Group A has a preamble for access of demand devices, Group C has C preambles for access of non-demand devices, and Group B has b preambles for access of all terminal devices.

As shown in the figure below, Preamble represents a preamble resource, UE represents a demand-class device, and MTC represents a non-demand-class device.

![Figure 2. Preamble grouping based demand.](image)

The ACB access factors[14] for each group were also set to $\delta_A$, $\delta_B$ and $\delta_C$, respectively.

$$M_i = \frac{1}{\delta_i} \tag{1}$$

$M_i$ is the number of preamble access devices for selecting packet $i \in (A,B,C)$, the preamble packet situation and access factor $\delta$ will be transmitted to the terminal through the base station system. The non demand equipment will receive the system message and know that it can access the preamble packet, and an access factor $\delta_{Mi}$ is generated at the local site, when $\delta_{Mi} < \delta$, then the terminal can access randomly, at the same time, the access probability of group B preamble selected by demand equipment will not be affected by access factor, which will effectively improve the access probability of demand equipment. The game theory model is as follows:

Participants: Group C non-demand equipment, group B all access equipment.

Strategy: each non-demand device can choose group B preamble access or group C preamble access.

Revenue: the probability of successful access of each non-required equipment.

Suppose that N devices select m preamble for random access, and the probability of successful access of a device is $P(N,M)$, then:

$$P(N,M) = \binom{M-1}{N-1} \tag{2}$$

When the number of demand equipment accessing group B is $n_g$ and the number of non-demand equipment accessing group B is $m_g$, then the access factor of group B is

$$\delta_y = \frac{1}{n_g + m_g} \tag{3}$$

Then the access success probability of group B non-required equipment is $P_y$
\[ P_b = \delta_b \times \left( \frac{h-1}{h} \right)^{m_b-1} \]  

(4)

When the number of non-required devices accessing group C is \( m_c \), then the access factor of group C is

\[ \delta_c = \frac{1}{m_c} \]  

(5)

Then the access success probability of group C non-required equipment is \( P_c \):

\[ P_c = \delta_c \times \left( \frac{c-1}{c} \right)^{m_c-1} \]  

(6)

When \( P_c = P_b \), then the game model enters Nash equilibrium.

Assuming \( n_b \) remains unchanged, when \( P_c < P_b \), the number of non-demand devices accessing group B \( m_b \) increases, group B access factor \( \delta_b \) decreases, and \( P_b \) decreases. When \( P_c = P_b \), the number of non-demand devices selected for group B and group C tends to be stable; When \( P_c > P_b \), \( m_c \) increases, \( \delta_c \) decreases, so \( P_c \) decreases, and when \( P_c = P_b \), it tends to be stable.

When \( P_c = P_b \), due to the demand class devices are not affected by group B access factor, \( n_b \) increases; then group B access factor \( \delta_b \) decreased, so \( P_b \) decreased, \( P_c > P_b \), the \( \delta_c \) decreases with the increase of \( m_c \) in the non-demand devices that access group C, so the \( P_c \) decreases until the \( P_c = P_b \) enters a new balance. In this continuous balance, the access probability of demand-type devices will be greatly increased, and the access conflicts with demand-type devices will be reduced during the access process of non-demand-type devices.

2.3. Game Theory Model Simulation Results

In this simulation process, the number of preamble codes grouped B and C in this paper is initialized to 20, and the number of devices initially accessed is a random number, from which the results of subsequent iterations are derived. In figure 3, the blue line represents the access probability \( P_c \) of non-demand devices in group C, and the red line represents the access probability \( P_b \) of non-demand devices in group B. Since the access devices in group B include demand devices, the initial access probability \( P_b \) is less than \( P_c \), but as the number of iterations increases, \( P_b \) gradually equals \( P_c \) and enters a balanced state.

![Figure 3. Pb and Pc converge with the increase of the number of iterations](image1)

![Figure 4. Pb and Pc equilibrium after convergence](image2)

Fig.5 The horizontal coordinate represents the number of iterations, and the vertical axis represents the number of non-demand devices that access Group B. It can be seen that with the increase of
iterations, the number of non-demand devices that access Group B decreases significantly. Therefore, this game theory model can effectively reduce the impact of non-demand devices on demand devices, improve the access rate of demand devices, and reduce access conflicts.

From the simulation results, it can be seen that the grouping preamble game model proposed in this paper can effectively reduce the access probability of non-demand-type devices, thus improving the access success rate of demand-type devices. Therefore, access conflicts can be applied in different scenarios according to different business devices, and grouping of preambles can effectively reduce the load of single base station network and avoid the load reduction due to network side. Access conflict for low devices.

3. waiting queue list based idle state of preamble

At the same time frequency, when multiple access devices choose the same preamble resource for random access, a competing random access conflict will occur. If these conflicting objects do not receive MSG4 messages with IMSI, they will re-select a new preamble resource access, increase the access delay and increase the energy consumption of the access devices. At the same time, the idleness of multiple preamble resources participating in competing random access will result in low overall utilization of the preamble resources, thus causing a waste of resources. Therefore, this paper presents a waiting queue list based on the idle state of the preamble. This table dynamically adjusts the number of access devices for the preamble resources by comparing the idle state of different preamble resources, so that the usage of each preamble tends to be consistent.

3.1. Waiting queue list building process

Step 1: The waiting queue list builds a waiting queue for each competing preamble. The queue is made up of a list of list nodes, each node of which contains its own device information, waiting time T information, and pointer information to the next node. In the waiting queue, all nodes except the header node are sorted from large to small according to the waiting time T, while the long time ranks first, and the header node has the highest priority, so no sorting is needed. You can directly select the corresponding preamble of the waiting queue to access the base station.

Step 2: Create an array based on all the competing access preambles. Each element of the array consists of the preamble information and the number of elements in the preamble waiting queue, as well as a pointer to the corresponding waiting queue header node. The base station looks at the number of waiting queue devices corresponding to each preamble through each time slot, and dynamically adjusts them so that the length of each waiting queue tends to be the same. Avoid the problem of low access efficiency caused by idle and busy preambles.
The waiting queue list of preamble can effectively reduce the access time of the whole device of the base station, and reduce the total time for all devices to be positioned in the search and rescue positioning process.

3.2. Flow chart of waiting queue list of preamble
Waiting queue list build’s function. As below.

Figure 7. Algorithm structure of waiting queue list.

The above algorithm structure initializes the parameters and data structure, and then subtracts the devices to be accessed by the queue head from each time slot, adds new devices, adjusts the waiting queue, and then adjusts the access order according to the priority. Finally, when the number of devices in the waiting queue list is 0, the cycle ends.

3.3. Waiting queue list Simulation result
This simulation will be divided into three groups, each group will test five times, and take the average value of five groups of data. The experimental values are shown in the table below.

| Number of equipment | Use waiting queue(times) | No waiting queue(times) |
|---------------------|--------------------------|-------------------------|
| 1000                | 50                       | 62                      |
| 5000                | 250                      | 475                     |
| 10000               | 500                      | 1137                    |

In the above simulation results, the number of initialization preamble packets is 20. It can be seen from the table that using the preamble waiting list can significantly reduce the access time and improve the access efficiency. The more devices are connected, the more obvious it is.

| Preamble | Num0 | Num1 |
|----------|------|------|
| 0        | 25   | 20   |
| 1        | 24   | 20   |
In Table 2, the number of simulation preamble is selected as 5, the total number of access devices in each time slot is set to 100, the number of devices accessed by each preamble in the first slot is Num0 and the number of access devices after using the waiting queue list equalization function is num1. From the balance function of each queue, we can see how effective it is to use the preamble.

From the simulation results, it can be seen that the preamble waiting queue list mechanism proposed in this paper can effectively reduce the high delay caused by retransmission and collision in the process of device random access, and effectively reduce the idle rate of preamble resources and balance the idle state of preamble resources.

4. Concluding remarks
Combining the advantages of the current advanced random access methods, this paper proposes a random access conflict resolution scheme based on game model for preamble waiting list, which reduces the network load of base station, equipment access delay, device access conflict rate and preamble resource idle rate. It improves the response ability of different services, the access priority of demand equipment and the access success rate of equipment. But at present, there is no actual data experiment, only the simulation of the scheme is carried out on the pseudo base station, and the subsequent experiments will continue; at the same time, the preamble packet strategy proposed in this paper can not be applied to the access scenario of multi priority services, and the subsequent research will continue to study the preamble packet strategy of multi services with the same priority.

Acknowledgments
This research was supported in part by the Beijing Natural Science Foundation under Grant L221003 and the National Natural Science Foundation of China under Grant 61801041 and the State Key Laboratory of Information Photonics and Optical Communications (BUPT) under Grant IPOC2022ZT09, P. R. China.

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