NOMA-Based RFID Tag Identification Method

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Abstract. RFID (radio frequency identification technology) is a non-contact automatic identification technology. During the Tag identification process, an effective anti-collision method will make a significant contribution to the RFID system in accelerating the identification speed. This paper proposes a method to improved RFID anti-collision protocol that incorporates a NOMA (non-orthogonal multiple access) technique, which is based on ISO 18000-6C standard. This paper simulates the method and compares it with traditional scheme of 18000-6C18000-6C. Through our simulations, NOMA-based RFID Tag identification method outperforms Traditional schemes in both the average access slot efficiency and time efficiency. It can solve serious collision under massive Tags numbers and improve system efficiency. It also can be conveniently applied to engineering implementations.

Keywords: Anti-collision · NOMA · RFID · ISO 18000-6C · Efficiency improvement

1 Introduction

As the Internet of Things equipment grows with each passing day, the amount of data therefrom advances swiftly and vigorously every year, the relevant theoretical research on the Internet of Things steps into the rapid development stage. RFID, one of the most central key technologies on the processing layer of application network of wireless networks, identifies an entity object with the Tag and receives the data of entity object with RFID Interrogator. Facing with the massive access request nowadays and the operation characteristics different from human communications, there are higher requirements on the performance of the Access terminal of the Internet of Things.

Radio Frequency Identification (RFID) ("UHF-RFID" for short) on the basis of goods management, defines two types of protocols, namely Type A and Type B. Later, it defines the Type C of the communication between 860MHz-960MHz in the Version II of the follow-up protocol. ISO/IEC 18600-6C can simultaneously read hundreds of Tags, it has not only larger user data field, but also high transmission rate of 40Kbps-640Kbps, therefore it applies to the scenarios requiring larger flow; due to the characteristics of low power consumption, low cost and high efficiency, it gradually develops to maturation

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and occupies the main stream. Tag will be activated by the continuous wave (CW) RF signal transmitted by the Interrogator to it, and then reflect and scatter the signal to the Interrogator by modulating the reflection coefficient of its antenna; since the Interrogator and the Tag share the same wireless channel, there is channel contention, and ISO/IEC 18600-6C uses the ALOHA-based algorithm (Q- algorithm) on the basis of random number generator to reduce the probability of occurring collision, and then complete the Tag identification process.

In order to solve the collision when more than one RFID-Tag transmits their information to the Interrogator at the same time, the stack-like anti-collision algorithm, based on the ISO 18000-6C protocol, solves the fluctuation of Q value and thereby improves the system efficiency to some extent in [1]; In [2], the media access control algorithm adopted by ISO/IEC 18000-6C RFID on air interface protocol is analyzed and the process realizing the optimal identification efficiency is proposed. The above ones focus on the path optimization of Q-algorithm based on software and the realization of system's simple design, low cost and easy modification; however, the time delay is longer and the efficiency improvement is limited. In [3], an improved RFID anti-collision protocol is proposed, it is integrated with CDMA technology and does not cause bandwidth extension. It is an optimizing way combined by hardware and software, with less time delay and obvious improvement of efficiency, but it can increase the equipment complexity. Existing technologies are still facing with the issue that there is still severe collision under massive Tags numbers.

The 5th generation wireless systems are the latest generation of cellular mobile communication technology, the NOMA is one of the critical technologies of 5G. It can improve more network capacity, access user number and realize quicker access efficiency by stacking multiple users on the same time-frequency resource to achieve the doubled and redoubled user access.

For the severe identification conflict under massive Tags, this paper proposes a NOMA-based RFID Tag identification method. This method introduces NOMA technology to the Tag identification process, allowing the Tag at the different locations to reflect identification signal according to the different power, separate and identify multiple different Tags by receiving NOMA at the side of Interrogator. The method complying with ISO/IEC 18000–C6 protocol standard [4, 6] as designed therefrom is universal.

This article designs simulation and builds a NOMA-based RFID system, simulates and builds a traditional RFID system. Configures different simulation environments, and completes a large number of simulation results output. Its emulation proof is made on the NS3 software platform. According to the results of emulation proof, the NOMA-based RFID Tag identification method solves the identification conflict of massive Tags and thereby improves the identification efficiency of system.

The second section of this paper introduces Related Work and Motivation, the third section details the method of RFID Tag identification based on NOMA, the fourth section simulates and tests the method on the ns3 simulation platform, the fifth section summarizes the Results and Concluding Remarks, the last section is the Acknowledgement.

2 Related Work and Motivation

2.1 RFID Tag Identification Method Principle

The ISO/IEC 18000-6C protocol [4] adopts the Q-algorithm, its command set includes Query, QueryAdjust, QueryRep etc. The primary parameter is the slot counting parameter Q. The value Q in the protocol decides the slot number used by the anti-collision, the Interrogator completes the anti-collision job by issuing corresponding commands to the Tag to change the status of the Tag.

An inventory round starts when the Interrogator issues a Query command, the Query command contains the parameter Q, the Tag in the non-killed status receives the command and picks up a random value from the range $\left(2^{Q}-1\right)$ and load it into the slot counter. The Tag with the slot counter as "0" converts into the Reply status and makes a reply immediately. Afterwards the non-zero Tag can be selected to convert into the Arbitrate status and then wait for issuing the command QueryAdjust or QueryRep. The steps when a Tag completes the identification are shown by Fig. 1 as follows:

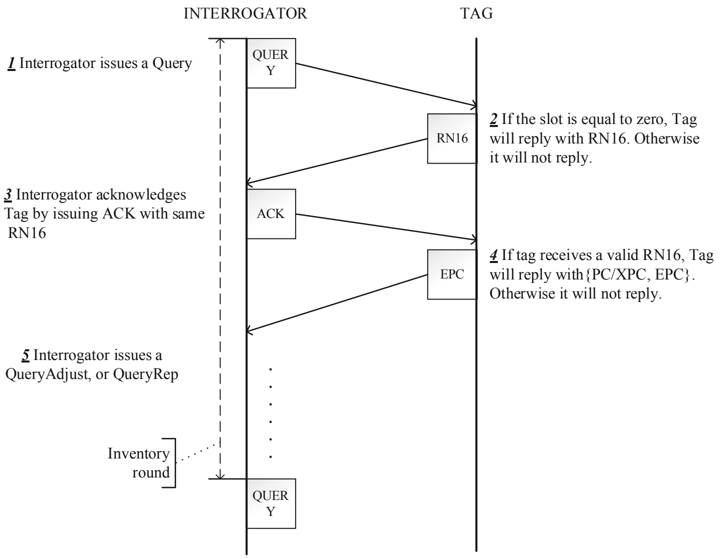

Fig. 1. Steps of an Interrogator inventories and access of a single Tag.

a) The tag issues a reply first, and then backscatters the RN16 (16-bit random number or pseudo-random number) signal;
b) The interrogator will acknowledge the Tag with an ACK containing the coincidence RN16;
c) The acknowledged Tag switches to the acknowledged state and backscatters PC/XPC, EPC;

d) The Interrogator issues a QueryAjust or QueryRep, whichcauses the identified Tag transition to ready and another Tag to start a query-response dialog with the Interrogator since the Step (a) above;

After issuing the command Query to start an inventory round, the Interrogator will generally issue one or more QueryAdjust or QueryRep command. The QueryAdjust command will repeat the previous Query command, it can make the Q value appreciate or decrease, but the new Tag will not be introduced to the inventory round. The QueryRep command will repeat the previous Query command, the parameter will remain unchanged, and the new Tag will not be introduced to the inventory round. The inventory round can comprise multiple QueryAdjust or QueryRep command. The Interrogator will issue new Query command at a moment, and a new inventory round will start therefrom.

Through detecting and solving collision at the waveform level, the RN16 from one of Tags could be resolved by the Interrogator, then the solved Tags could be further acknowledged, whereas the unsolved Tags will receive the wrong RN16 and return to Arbitrate state instead of backscattering the reply EPC.

2.2 Power Domain NOMA Principle

The NOMA (non-orthogonal multiple access) is defined as follows: the identical resource can carry multiple data, it supports massive connection and ultra-large capacity; there are many solutions via different resources, such as power domain NOMA, SCMA, MUSA, PDMA, IDMA, BDM etc.

The core concept of power domain NOMA downlink is the one of using the superposition coding SC (superposition coding) at the transmitting end, using the SIC (successive interference cancellation) at the receiving end, and realizing multiple access in the power domain via different power levels on the same time-domain and frequency-domain, this is the mainstream NOMA solution.

The principle of power domain NOMA is shown by Fig. 2 as follows: where Sender 1 and Sender 2 adopt the identical signal transmitting power; considering the factors of path loss, noise interference etc., the Receiver makes the successive demodulation on the received signal by using the capture effect of wireless network. The SIC technology is used to realize cache for composite signal, the other signals and noises at the receiving end are deemed as the interference; firstly the Sender 1 signal with higher power is demodulated, then the demodulation data of Sender 1 is used to re-construct its simulation waveform, following, the cached signal is used to subtract the re-constructed Sender 1 simulation waveform to obtain a relatively clear Sender2 signal, it is then demodulated accordingly.

2.3 Motivation

As shown by the Fig. 3, if two or more Tags reply RN16 simultaneously, the Interrogator under Type C protocol can only identify one thereof at most, but can't realize the total identification. When there are more numbers of Tags, the value Q remains unchanged, so the probability of replying RN16 at the same time will increase as the number of

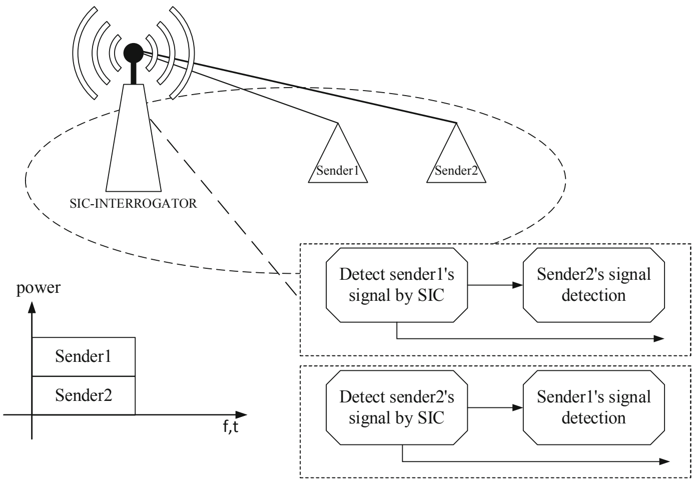

Fig. 2. Power domain NOMA Uplink Principle.

Tags increases, which will result in a severe collision. Moreover, it is not enough to only optimize the slot number (*i.e.*: the value Q) and the related algorithm since the number of slots has a slow dynamic regulation convergence, it takes a longer time for identification.

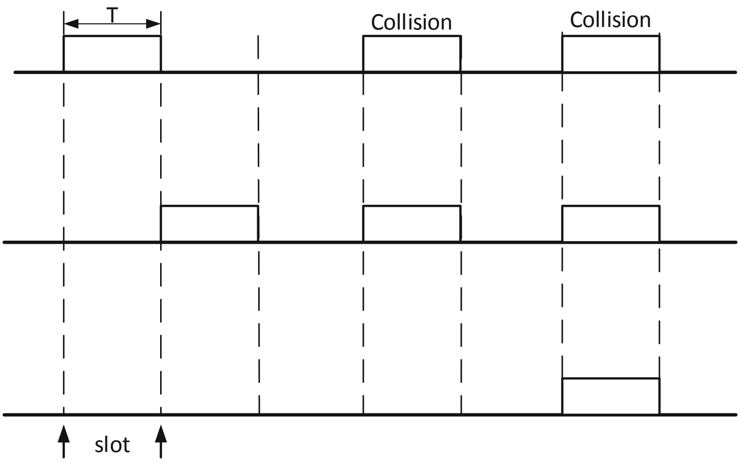

Fig. 3. Two or more Tags reply RN16.

3 NOMA-Based RFID Tag Identification Method

3.1 Introduction to the Basic Idea of the Method

RFID modulates the RF (radio-frequency) signal within the frequency range of 890 MHZ–960 MHZ, Interrogator transmits the information to Tag. A passive Tag signifies that it receives all operation energy from the RF signal of Interrogator.

In the Q-algorithm and under the same time-domain resource, if the slot counter of multiple Tags is 0, replying RN16 will result in collision and Interrogator will not identify the information of multiple Tags correctly, the current slot failure blocks the identification efficiency.

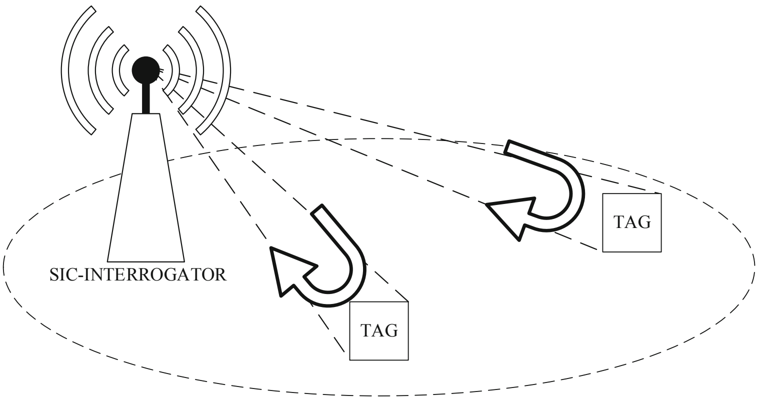

Fig. 4. SIC-Interrogator/Tag operations.

As shown by Fig. 4 as follows, Interrogator issues the continuous-wave (CW) RF signal to Tags and thereby receives the information issued by such Tag. Tags will respond by modulating the reflecting system of antenna and then reflect and scatter passively the information signal to Interrogator. Thus, within a RFID system, sender and receiver of signal can be deemed as the Interrogator itself; when using SIC-Interrogator, signal will be issued by SIC-Interrogator by using the identical transmitting power, and then be scattered to the Tags within the RF field, in such case Tags will respond the signal, whereas the SIC-Interrogator having NOMA uplink receiving capacity is capable of receiving multiple reply signals. As shown by Fig. 5 as follows, the distinguishable power levels of system can be divided according to the change of gray-scale color:

The signals returned by the Tag are at different power levels, and all signals are successfully identified. For instance, Tag1, Tag 2, Tag 3 and Tag 5 join in identification, so Tag 1, Tag 2, Tag 3 and Tag 4 at the slot are identified successfully.

If two or more Tags at same power level join in identification, all will fail to identify. For instance, Tag1, Tag 2, Tag 3 and Tag 5 join in identification, so Tag 1, Tag 2, Tag 3 and Tag 4 at the slot get identification failure. For certain related scenarios, see Table 1 as follows:

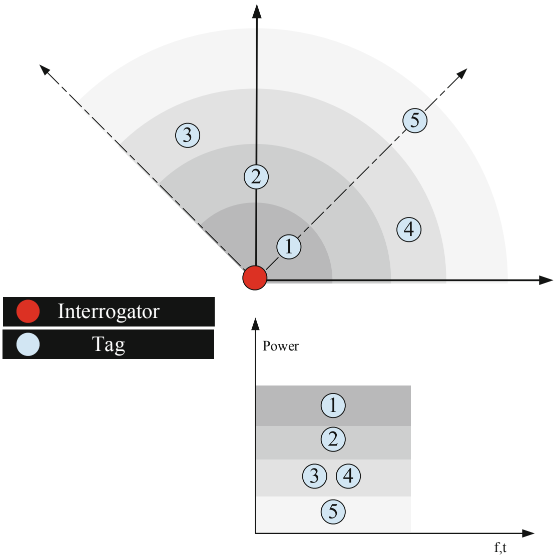

Fig. 5. Power level distinction.

Table 1. Identification results of different power levels.

Identify members	Success/fail
Tag1/Tag2/Tag3/Tag4/Tag5	Success
Tag1, Tag2, Tag3, Tag5	Success
Tag1, Tag2, Tag4, Tag5	Success
Tag3, Tag4	Fail
Tag1, Tag2, Tag3, Tag4, Tag5	Fail

3.2 Design of RFID-Type C Tag Identification Frame Based on NOMA

In the RFID -Type C system as shown by Fig. 6(a), multiple Tags backscatter its RN16 simultaneously to Interrogator, if the Interrogator can identify one RN16 signal thereof, such Tag will be acknowledged. As shown by Fig. 6(b), multiple Tags backscatter its RN16 signal simultaneously to Interrogator. In the NOMA-based circumstances, Interrogator can successfully detect multiple RN16 signals coming from different Tags via SIC and then scatter the ACK frame of multiple different corresponding Tags. The Tag monitor channels; when detecting certain ACK frame field containing the own RN16, the Tag will backscatter its EPC to Interrogator to complete its own identification process.

Within RFID system, RN16 of multiple Tags can be successfully received under the same time domain sometimes when Tag capacity is ultra-large, therefore making ACK reply to every Tag will affect the entire system performance and increase the burden of Interrogator. Tag needs to catch the ACK belonging to themselves from many similar

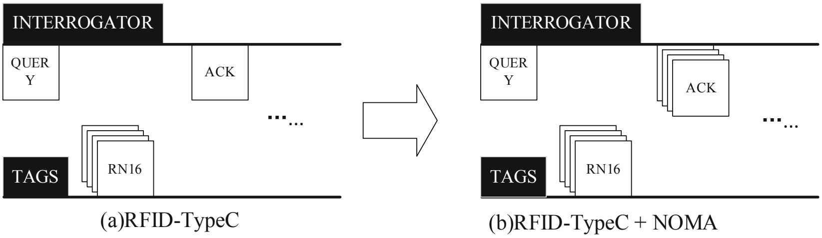

Fig. 6. Design of RFID-Type C identification frame based on NOMA.

ACK signals, so there are certain requirements on Tag performance, and thereby a design of ACK frame more suitable to NOMA is proposed, see Fig. 7.

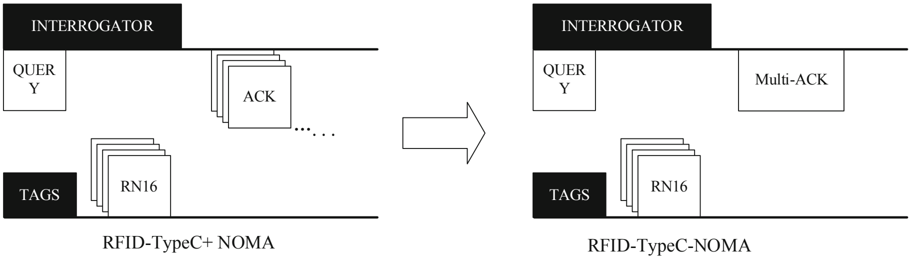

Fig. 7. Design of RFID-Type C Multi-ACK frame based on NOMA.

In the NOMA-based RFID-Type C Tag identification system, a Multi-ACK frame based on the number of RN16 to be received currently will be constructed, it contains all successfully received RN16 information; Tags will seek for the RN16 belonging to themselves from Multi-ACK and reply EPC.

3.3 SINR-Based Threshold and Power Control Method

If using SIC to carry out interference elimination, we need to know the signal meeting the given or required conditions is the usable signal. As we know, $SINR_{db} = Signal_{dbm} - Noise_{dbm}$, the larger SINR is, the better the quality of signal is; so we can deem the signal at the Lower power as the noise and assume the size of received power of Tag 1 ~ Tag N at the moment as follows, see Fig. 8:

Following, we can deem Tag2 ~ Tag N and noise as the interference of Tag 1, and select one threshold complying with the given conditions; when meeting $Power_{dbm}^{tag1} - Power_{dbm}^{tag2} > Threshold_{db}$, the Tag 1 and Tag 2 are identifiable under NOMA, the rest can be deduced by analogy like this.

$$Power_{dbm}^{tag1} - Power_{dbm}^{tag2} > Threshold_{db}$$

$$Power_{dbm}^{tag2} - Power_{dbm}^{tag3} > Threshold_{db}$$

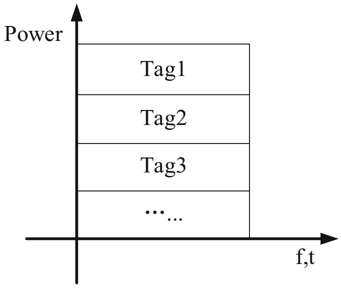

Fig. 8. Signal power received by the Interrogator at a certain moment.

$$Power_{dbm}^{tag3} - Power_{dbm}^{tag4} > Threshold_{db}$$

$$\cdots\cdots$$

$$Power_{dbm}^{tagN} - Power_{dbm}^{tag(N+1)} > Threshold_{db} \quad (1)$$

The signal meeting the relationships aforesaid is the usable signal. For different modulation styles and exterior environments, the setting values of power threshold are different, moreover the larger $Power_{dbm}^{tagN} - Power_{dbm}^{tag(N+1)}$ is, namely the larger SINA is, the better the receive signal is; the quality of signal may affect the parameters such as packet loss probability etc. The smaller the threshold is, the higher the performance requirement of SIC-Interrogator is, the better the NOMA identification efficiency is, and the larger the system overhead is. Therefore, the different thresholds are configured in different scenarios.

4 Simulation Platform Design and Implementation

NS3 and MATLAB 2018 is used for our simulations. NS3 is an open source, discrete event-based simulator. We use ns3 to build a NOMA-based simulation environment on LINUX, and then use MATLAB to process the simulation data.

Considering that in the simulation of RFID Tag identification based on NOMA, it is necessary to construct a similar situation in reality. Therefore, when using ns3 build a simulation environment, a radio propagation model with the propagation delay set to the speed of light is used, and use the shadowing Mode as wireless propagation loss model.

In this section of the simulation, we mainly focus on the number of tags connected in a unit time and the number of tags connected in a unit slot in different situations. Because time efficiency and slot efficiency can reflect the access efficiency of the system, this is our main consideration. Before the simulation, we set Interrogator to communicate with all tags with a constant transmission power of 17.0206dbm. Perform several simulations and take the average value as the simulation result.

4.1 NOMA Gain at Lower Slots

a) **Simulation configuration** (Table 2)

Table 2. Efficiency (lower slots).

Parameter	Configuration
Q (slots)	4 (16slots)/6 (64slots)
Interrogator communication radius	15m
Number of Tags	6–256
Threshold	6.9 db
Contrast variable	With or without NOMA
Cycles	5000
Output	Slot efficiency = All successful Tags/ Total number of slots Time efficiency = All successful Tags/ Total time (s)

b) **Simulation results**

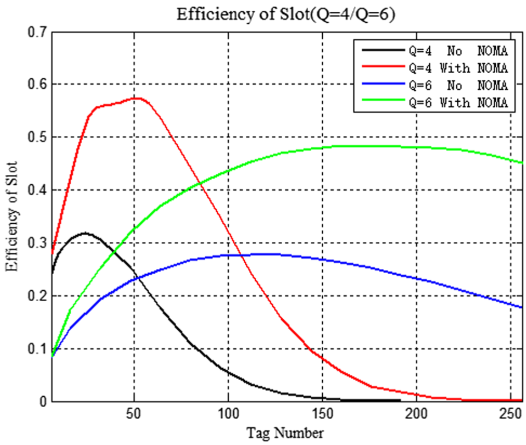

Fig. 9. Efficiency of Slot (Q = 4/Q = 6).

As shown by Fig. 9, it can be seen from the slot efficiency graphs with Q values of 4 and 6, that Type C with non-orthogonal multiple access function is more efficient than Type C in the whole process.

When the number of Tags is 24, the slot efficiency of Type C with a Q value of 4 reaches a peak of 0.320289. Compared with Type C with NOMA function, it can be seen that the slot efficiency reaches the peak when the number of Tags is 52, and its time slot efficiency value is 0.594048, the gain is about 185%.

As with Q = 4, it can be seen from the slot efficiency graph with Q = 6 that the efficiency of Type C with non-orthogonal multiple access function compared to Type C is gain in the whole process.

Type C reaches its peak at 112 Tags, and its slot efficiency is about 0.278183. Type C based on NOMA reaches its peak at 180 Tags, and its slot efficiency is about 0.484365. The slot efficiency peak gain is 0.484365/0.271183 about 178%.

As the Q value increases, the peak slot efficiency of RFID decreases from 0.320289 with a Q of 4 to 0.278183 with a Q of 6. The peak slot efficiency of NOMA-based RFID has decreased from 0.594048 with a Q of 4 to 0.484365 with a Q of 6.

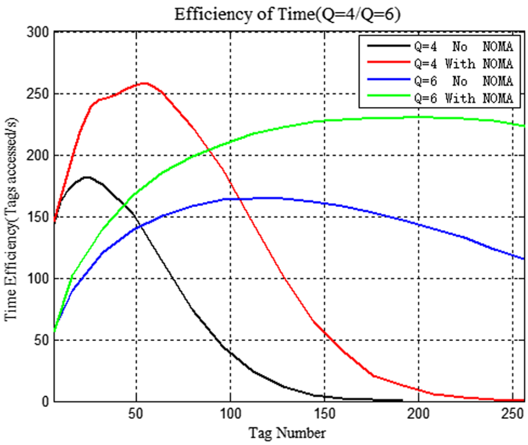

Fig. 10. Efficiency of Time (Q = 4/Q = 6).

As shown by Fig. 10, the number of Tags accessed per unit time with a Q value of 4 also reached peaks at 24 and 52, with values of 182.031 and 263.788, respectively, with a gain of 145%.

Type C with a Q value of 6 reaches a peak of 164.835 at 112 Tags, and a NOMA-based Type C with a Q value of 6 reaches a peak of 230.063 at 180 Tags. Its gain is about 140%.

As the Q value increases, the peak time efficiency of RFID decreases from 182.031 with a Q of 4 to 164.835 with a Q of 6. The peak time efficiency of NOMA-based RFID has been reduced from 263.788 with a Q of 4 to 230.063 with a Q of 6.

As the Q value increases, its peak gain will decrease slightly. For example, when Q is 6, the time slot efficiency peak gain is 178%, when Q is 4, the time slot efficiency peak gain is 185%, and the time slot efficiency gain is reduced by about 7%. When Q is 6, the time efficiency peak gain is 140%, and when Q is 4, the time efficiency peak gain is 145%, and the time efficiency gain is reduced by about 5%.

The peak access efficiency of RFID system is related to the number of slots and Tags. In each inventory round, when the number of slots is equal to the number of Tags, the access efficiency of the inventory round is the highest. Since a certain number of Tags will be stored in each inventory round, the access efficiency is a dynamic value for each different inventory round, So the number of Tags corresponding to the peak of the total RFID access efficiency is always greater than a value, which is the number of Tags equal the number of slots.

4.2 NOMA Gain at Higher Slots

a) **Simulation configuration** (Table 3)

Table 3. Efficiency (higher slots).

Parameter	Configuration
Q (slots)	8 (256 slots)
Interrogator communication radius	15 m
Number of Tags	6–354
Threshold	6.9 db
Contrast variable	With or without NOMA
Cycles	5000
Output	Slot efficiency = All successful Tags/Total number of slots Time efficiency = All successful Tags/Total time (s)

b) **Simulation results**

As the number of slots increases, the number of Tags that the RFID system can accommodate also increases. With the addition of the NOMA function, the slot efficiency and time efficiency of the system has been further improved on this basis. (Figs. 11 and 12)

4.3 Different Thresholds

a) **Simulation configuration** (Table 4)

b) **Simulation results**

Threshold is a problem that needs to be considered for NOMA-based RDIF Tag identification. According to Fig. 13, comparing the curves with thresholds of 10.3 db

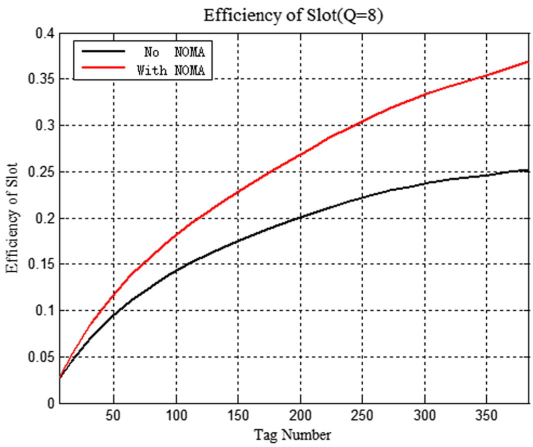

Fig. 11. Efficiency of Slot (Q = 8).

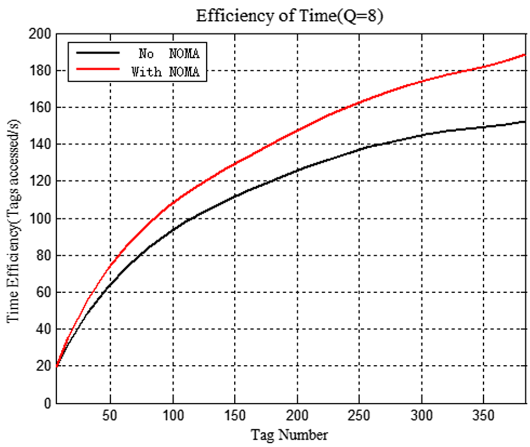

Fig. 12. Efficiency of Time (Q = 8).

and 6.9 db, as the threshold increases, the efficiency of the system also decreases. The gain of NOMA-based Tag identification system depends on the threshold setting, and different SINR thresholds can achieve different gain effects. In order to be more adaptable to engineering implementations, diverse SINR thresholds are configured according to the actual scene.

5 Results and Concluding Remarks

This article proposes the NOMA-based RFID Tag identification algorithm with the purpose of versatility increment and efficiency improvement for RFID systems. Through numerous simulations, we detect that the radio frequency identification system based on NOMA has a great performance improvement, which is undoubtedly very suitable for

Table 4. Efficiency (Different thresholds)

Parameter	Configuration
Q (slots)	8 (256 slots)
Interrogator communication radius	15 m
Number of Tags	6–354
Contrast variable	Threshold = 6.9 db/10.3 db
Cycles	5000
Output	Slot efficiency = All successful Tags/Total number of slots

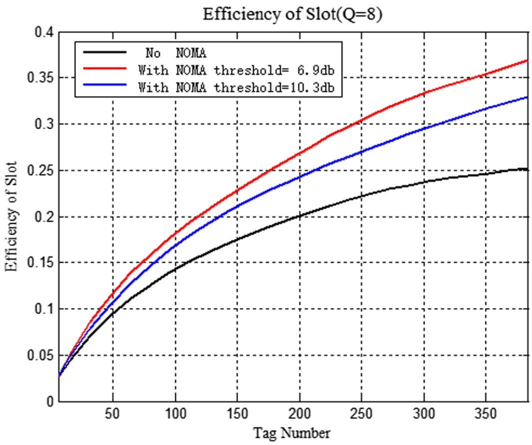

Fig. 13. Efficiency of Time (Q = 8). Efficiency of Time (Q = 8/Different threshold)

the upcoming 5G. In the actual implementation, this method only needs to consider the modification and update of the Interrogator device without considering the Tag device. Therefore, the method also has excellent versatility. The algorithm has higher access efficiency, larger system capacity, and higher peak Tag count Compared with traditional RFID system.

The peak Tag count of RFID system is related to the slots and Tags [5]. In each inventory round, when the number of slots is equal to the number of Tags, the access efficiency of the inventory round is the highest. H. Wang [1] and Y. Maguire [2] used two different algorithms to improve the system performance by changing the Q-value under different inventory round. Through simulation comparison, it is found that the algorithm complexity of our NOMA-based method is smaller and the performance gain is higher. And compared with T. Demeecha's algorithm [3], our method has better system overhead while ensuring the complexity of the algorithm. In summary, NOMA-based RFID Tag identification method has the best comprehensive performance.

Reader can grasp through the protocol design of Sect. 3.3 and the simulation of Sect. 4.3 in this article that a smaller SINR-threshold will bring better performance gains, but will increase the overhead of the system. How to select a threshold in combination with different actual conditions is also What we need to do in the future. we will try different SINR-threshold algorithms to obtain the best SINR-threshold under the current system overhead.

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