The Performance Analysis of RFID Anti-Collision in ISO/IEC 15693-3 Protocol

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Abstract - For multiple random accesses, a low throughput due to channel contention is the major limitation. The most latency occurs in the contention phase and, therefore, reducing the delay time thus becomes a relevant task. A collision occurs in real network access if two or more packets are simultaneously transmitted. Hence, the contention must be resolved when applying a protocol in the wireless data network. In this paper, we adopt the concept of elimination and dynamic tree expansion in RFID anti-collision of ISO/IEC 15693-3 to reduce the delay time and enhance the throughput. Analyses results indicate that if the number of tags does significantly exceed the number of the number of available slots from RFID reader, the performance is largely enhanced when the tree elimination algorithm is applied.

Key Words: RFID, anti-collision, throughput, mean delay time, tree elimination algorithm

1. INTRODUCTION

Scheduling problem is considered herein as a cost criterion which is the sum of flow time or completion times in a system with all packets receiving a service. A single server (i.e. the RFID reader in a RFID network) and some packets with associated processing times are modeled herein. The packets are generated by tags in a RFID network [1-4]. We consider a tag to be an active tag when it has some packets to be transmitted. In a queuing network, stochastic or dynamic process can be viewed as a problem of scheduling. Let us define the flow time of a system, i.e. an important measure of a system's performance, as the average time difference between the instance which a packet enters the system and the instance which the packet departs the system. When considering the sharing of bandwidth in random access network communication, system performance (including throughput performance and mean delay time) and the system stability are two critical factors. Therefore, the system network infrastructure must be developed with a limited bandwidth to achieve maximum throughput and minimize the mean delay time while considering stability. In addition, delay time is of significant concern with respect to a time constrained source and system's stability.

In a scheduling system, the system probabilistically generates the ordered sequence of packets. The RFID reader then processes these packets after accumulating and scheduling all information from all packets. In general, scheduling problem are specified in terms of access environments (protocol), packet characteristics and optimality criterion. A schedule allocates or shares a pre-existing resource to process these packets. In a random access network, all independent geographically distributed tags use a common channel to communicate with the reader.

To operate a multiple access network, active tags share a common access channel to transmit their packets. However, a collision occurs if two or more active tags are available to simultaneously transmit their packets. Regarding the quality of service or the time constraint requirement, the RFID reader must organize the retransmission of colliding packets and provide every packet to be eventually transmitted successfully with finite delay. Therefore, in addition to clearly determining the behavior of a transmission process, the collision resolution algorithm also affects the delay time of a packet until the packet is successfully transmitted. This algorithm must also maintain the efficiency of the multiple access schemes to obtain the maximum traffic rate.

A non-preemptive scheduling is defined as a task which can not be interrupted before justifying whether the transmitted packet is successfully received or fails to be received by the RFID reader once the task has begun execution. The scheduling of the RFID anti-collision of ISO/IEC 15693-3 here is a list scheduling because the sequence of served tasks is assigned to be in an ordered list by a repeated scan.

With respect to minimizing a system's flow time, it is in equilibrium to minimize the average starting times, waiting times or the service time. Therefore, the primary problem attempts to obtain an algorithm to optimize the desired performance measure, such as scheduled length or the mean time spent in the system for a packet. The measure of completing packet at a special point of time can be said to be the cost function of the packet. Restated, the scheduling problem attempts to identify a feasible schedule which minimizes the total cost function.

The rest of this paper is organized as follows. Section 2 describes the operation of RFID anti-collision of ISO/IEC 15693-3. Section 3 illustrates the relationship among the delay-throughput characteristics for RFID anti-collision of ISO/IEC 15693-3. Numerical results are presented in

Section 4. Concluding remarks are finally made in Section 5.

2. ANTI-COLLISION PROCEDURE

A means of enhancing the system performance is to resolve the probability of contending packets. According to information theory, the more pertinent information which is available to describe the observed event allows us to more accurately estimate the event. In real network access, a collision may occur if two or more packets are simultaneously transmitted at the same slot. Hence, how to resolve the contention collision is a relevant issue when applying a protocol in the wireless data network. Restated, the primary goal of multi-access communication is to facilitate the sharing of a communication channel between multiplicities of tags where each tag has sporadic service requirements. To share the common communication slot among these tags, collision resolution is a feasible approach to such sharing. Therefore, we closely examine the feasibility of using more sophisticated collision resolution techniques that maintain stability without any complex estimation procedures and also increase the system's availability.

In this section, we concentrate mainly on the infrastructure of wireless networks. The RFID reader design is a controller which manages the operation of RFID anti-collision protocol. Since the released numbers of slots are fixed, the interval of an anti-collision phase is fixed. A dynamically-sized data interval, referred to herein as group transmission periods, is also maintained to transmit the packet among these stations after contention. A polling cycle is defined as the time duration between two successive intervals once the RFID reader allows all RFID tags to rejoin the channel contention. This phenomenon implies that a polling cycle consists of a contention interval and a group of transmission periods. The procedure of the RFID protocol can be briefly summarized as follows.

Step 1: When ready to collect up-link packets, the reader sends an inventory request, in a frame, terminated by an EOF, to all tags within its coverage. This message contains all information. The instance to send an inventory request is defined as the beginning of a polling cycle. Assume that the total number of available slots is *k*. The value of *p* equals 16 in the standard form of ISO/IEC 15693-3:2001(E).

Step 2: Tags randomly select one of the slots after receiving an inventory request from the reader. Tags independently generate and transmit their packets simultaneously from the *p* available slots. Due to these selected slots, group transmission periods occur. Each transmission period consists of one or more tags to transmit their packets.

Step 3: The reader polls the tags according to the ordered sequence of slots' number. Those active tags with this specially slot then transmit their packet to the base station simultaneously without any delay time in the group transmission periods.

Step 4a: When the tag has detected an EOF from a valid reader, it shall wait for a time t_1 before starting to transmit its response to the request from the reader or before switching to the next slot in an inventory process. t_1 is defined as a time interval which starts from the detection of the rising edge of the EOF received from the reader. Its nominal value in the requirement of ISO/IEC 15693-3 is 320.9 μs. The tag transmits its response in the especially polling slot. It is the only one to do so, therefore, no collision occurs and its UID is received and registered by the reader. If either successfully receiving the packet from any tags, the reader sends an EOF, meaning to switch to the next slot.

Step 4b: A collision occurs in a specially polling slot if the group transmission period consists of two or more active tags. The reader detects it and remembers that a collision was detected in the slot. If unsuccessfully receiving the packet from any tags, the reader sends an EOF, meaning to switch to the next slot.

Step 4c: If a slot is not selected among these tags, no tag transmits a response when the slot is polled. Therefore, the reader does not detect a tag SOF and decides to switch to the next slot by sending an EOF. During an inventory process, when the reader has received no tag response, it shall wait a time t_3 before sending a subsequent EOF to switch to the next slot.

Step 5: To ensure that the tags are ready to receive a subsequent request, a waiting time t_2 should be induced when the reader has received a tag response to a previous request. The minimum value of t_2 is 320.9 μs. The reader could have continued to send EOF's till slot *p*-1. The reader then decides to send an addressed request to these tags which their UID has been correctly received and registered by the reader. If these tags detect a SOF, then exit the anti-collision sequence. These tags process this request and transmit their response according to the polling from the reader.

Step 6: A collision resolution cycle is created by the reader to resolve all packets that collide with each other. After scheduled transmissions, the reader initiates a new renewal (polling cycle) again. After scheduled transmissions, the reader initiates a new polling cycle again (i.e. repeats Step 1-4) and all tags are ready to receive another request. If it is an inventory command, the slot numbering sequence restarts from 0.

3. SYSTEM PERFORMANCE

In this section, we establish a system model to obtain the performance of the system. Initially, we assume that the arrival process is a Poisson process with a mean λ for each tag. All tags are independent and identical sources, in which each tag has exactly one packet with a fixed packet length to be transmitted at any time. Here, a no-buffering assumption is made for each tag. In this way, a perfect physical transmission is assumed to receive these generated packets (response packets) from these tags.

For simplicity of analysis, we assume that no new tags are allowed any collision resolution cycle if the RFID reader has detected some collision packet periods at the previous collision resolution cycle. That is, assume that the operation of the RFID protocol is gated exhaustive. Herein, we define a collision packet period as the time interval in which the RFID reader serves these packets with a specifically transmitted slot. Similarly, we define a non-collision packet as the time interval in which the RFID reader servers the tag that only exists in a specially transmitted slot.

3.1 Probability Distribution Function

The condition probability distribution function, in which there are i non-collision packet periods (only one packet is transmitted during this period) and j collision packet periods (two or more packets are simultaneously transmitted during this period) given n active tags, can be expressed as

$$P(i,j)=\frac{1}{p^n}\binom{p}{i}\binom{p-i}{j}\sum_{all\ j\ pattern}\frac{n!}{\prod_{k=1}^{j}a_k!}\frac{j!}{\prod_m c_m}$$
$$\sum_{k=1}^{j}a_k=n-i,\ a_k>1$$
$$\sum_m c_m=j,\ c_m\geq 1 \quad (1)$$

The active tags select a_k times for each possible number of collision, where a_k is the number of recurring j collision numbers and c_m denotes how many different combinations between a_k to calculate their present frequency, i.e., $\{c_m\}_m$ are the presence frequency of $\{a_k\}_{k=1}^{j}$. Through this probability, we analyze the performance of the RFID protocol.

3.2 Throughput

In general, throughput and average packet delay time largely justify a protocol's robustness. To derive the system performance, initially assume that a total of N tags are within to the coverage of the RFID reader. Since the arrival process is a Poisson process with mean λ for each tag and all tags are independent and identical source, each tag takes an exponentially distributed time to generate a new packet only if a previous packet has completed service.

We can define the throughput as the ratio of expectant successful transmission duration to the total time for completely serving all tags with responses during multiple access contention process. Under a steady state, the average time ratio of non-collision packet periods in a mean polling cycle is called the throughput. The random available epoch $T(n)$ is defined herein as the mean interval between the instant that the RFID reader initiates a new polling cycle in which n active tags want to contend for the slots, and the ending instant at which all collided packets are resolved in this polling cycle. Allow $U(n)$ to be a random time variable to successfully transmit these active tags in the polling cycle. According to the definition of throughput, we have

$$throughput=\frac{E_n[U(n)]}{E_n[T(n)]} \quad (2)$$

Where $U(n)=nt$.

Let t_{over} be the packet duration of inventory including SOF and EOF parts. t_r denotes the response size (in time units) from each tags to contend a special slot. t_{EOF} represents the size of EOF packet (in time units). t_c denotes the packet collision period. τ is the propagation time. After contention, t_s represents the packet transmission to respond the request from RFID reader to each tag which has successfully contended the channel. The detailed representation of these time factors is illustrated in Fig-1.

For the randomly selected slots, if we have i successfully transmitted packets and j collision packet periods after contention, then the mean time to completely serve these n tags at the beginning of inventory request from the RFID reader is denoted as $T(i,j\,|\,n)$ and is given as

$$\begin{aligned}T(i,j\,|\,n)=&\,t_{over}+i(t_1+t_r+\tau+t_2+t_{EOF})+\\&j(t_1+t_c+\tau+t_2+t_{EOF})+\\&(k-i-j)(t_3+t_{EOF})+T(n-i)\end{aligned} \quad (3)$$

The time $(k-i-j)(t_3+t_{EOF})$ in Equation (3) represents the waiting time which no tags select these $k-i-j$ slots. The additional time $T(n-i)$ is the time to resolve these unsuccessfully transmitted packets. The time $T(n)$ also refers to a situation in which the maximum delay time of the finally received packet which has left the system. This is an important time factor to ensure that all sources with the requirement of bounded time can be completely served during their required maximum delay bound. And

$$T(n) = \sum_{i,j} T(i, j \mid n) P(i, j) \quad (4)$$

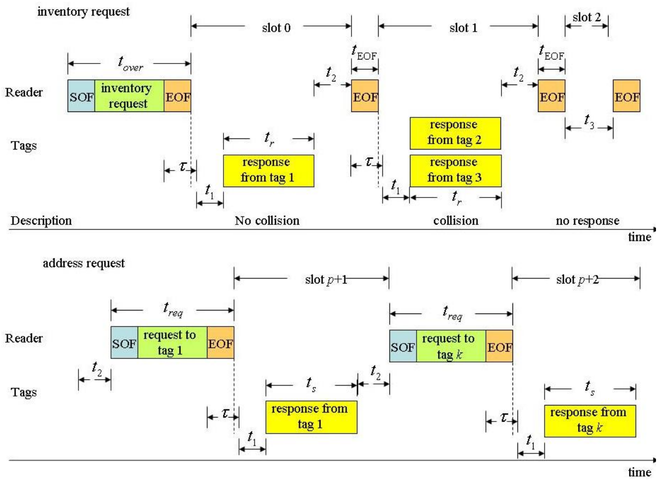

Fig-1: The timing diagram of possible anti-collision sequence

3.3 Delay Time Performance

A perfect channel is refered to a transmitted packet which is correctly received by the RFID reader when there is the only one packet is transmitted in the channel. This definition implies that a tag can successfully transmit its packet if no collision incurs with another packet at the same channel. Under the condition, we have i slots with successfully transmitted packets which are correctively received by the RFID reader. Thus, the residual $n-i$ tags must rejoin the next collision resolution cycle in order to transmit their packets. If $X(i, j \mid n)$ denoted as the delay time given i successfully transmitted packets, and j collision packet periods that have been detected by the RFID reader among these n active tags, we have

$$X(i, j \mid n) = i \left[\begin{array}{l} \frac{i-1}{2}\left[(t_1 + t_r + \tau + t_2 + t_{EOF}) + (t_{req} + t_1 + t_s + \tau + t_2 - t_{EOF}) \right] + \\ \frac{j}{2}(t_1 + t_c + \tau + t_2 + t_{EOF}) + \frac{k-i-j}{2}(t_3 + t_{EOF}) \end{array} \right] + (n-i) \left[\begin{array}{l} i(t_1 + t_r + \tau + t_2 + t_{EOF}) + j(t_1 + t_c + \tau + t_2 + t_{EOF}) + \\ (k-i-j)(t_3 + t_{EOF}) + i(t_{req} + t_1 + t_s + \tau + t_2 - t_{EOF}) \end{array} \right] + X(n-i) \quad (5)$$

And

$$X(n) = \sum_{i,j} X(i, j \mid n) P(i, j) \quad (6)$$

$$\begin{aligned} V(i, j \mid n) = t_{over} &+ i(t_1 + t_r + \tau + t_2 + t_{EOF}) + \\ & j(t_1 + t_c + \tau + t_2 + t_{EOF}) + \\ & (k-i-j)(t_3 + t_{EOF}) + \\ & i(t_1 + t_{req} + t_s + \tau + t_2 - t_{EOF}) + V(n-i) \end{aligned} \quad (7)$$

Where

$$V(n) = \sum_{i,j} V(i, j \mid n) P(i, j) \quad (8)$$

The average delay time $E_n[X(n)] = E_n\left[\frac{X(n) t_s}{U(n)} \mid n \right]$.

According to the renewal theorem [5, 6], the mean waiting time $E_n[W(n)]$ can be expressed as

$$E_n[W(n)] = \frac{E_n[V^2(n)]}{2E_n[V(n)]} \quad (9)$$

Therefore, the average delay time $E_n[D(n)]$ becomes

$$E_n[D(n)] = E_n[W(n)] + E_n[X(n)] = E_n\left[\frac{X(n)}{n} \mid n \right] + \frac{E_n[V^2(n)]}{2E_n[V(n)]} \quad (10)$$

4. NUMERICAL RESULT

This paper presents a significant protocol, RFID anti-collision of ISO/IEC 15693-3, to analyze the system performance. From the above discussions and analyses in detail, to obtain the more system performance has to reduce the time duration of these following time factors: t_1, t_2, t_3, t_c, t_{SOF}, and t_{EOF}. In addition, according to our following results, we change the only one parameter and maintain the others unchanged to clarify the effect of changed parameter as much as possible for each comparison.

Altering the values of the number of available slots *p* makes the first comparison. According to Fig-2, we see that the throughput performance significantly increases with the increment of *p* at the same arrival rate. However, from Fig-3, the mean delay time performance significantly decreases with the increment of *p* at the same arrival rate. This phenomenon is incurred because the larger the value of *p*, the larger the number of unused slots is.

Varying the value of parameter *N*, the maximum number of tags within the coverage which the RFID reader can be served, makes second comparison. According to Fig-4, we see that the throughput performance is obviously different among these values of *N* at the same arrival rate. But, when the total offered traffic exceeds that of the maximum throughput performance, we see that the throughput performance approaches to be a constant when arrival rate becomes larger. This phenomenon can be easily explained because the buffer size to store arrived packets of any tag's response has been assumed to be one.

Therefore, all arrived packets are discarded when the buffer is filled.

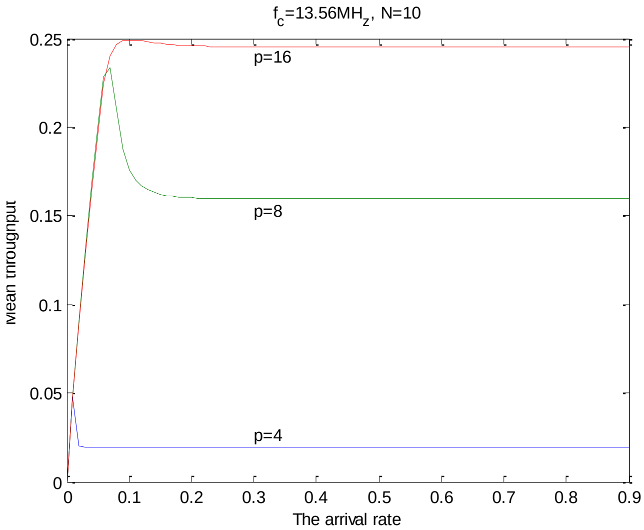

Fig-2: The mean throughput for ISO 15693 for different *p*

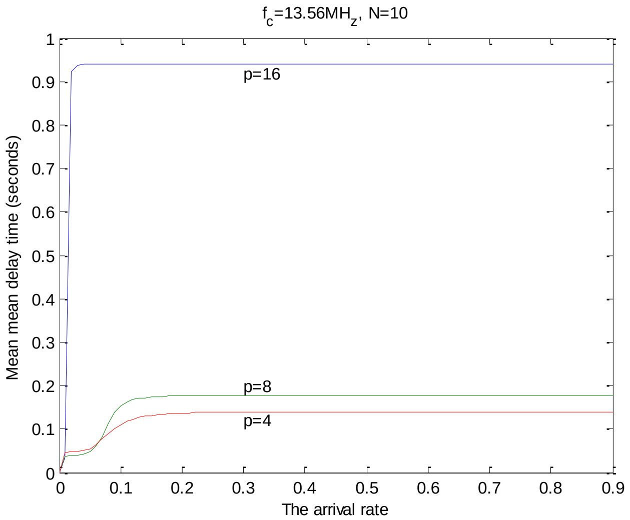

Fig-3: The mean delay time for ISO 15693 for different p

Fig-5 also depicts that the mean delay time of an ordinary packet increases with the increment of *N* at the same arrival rate. From Fig-2 to Fig-5, these figures reveal that the system performance is strongly dependent on the value of *p* and the value of *N*. The effect of arrival rate seems to be not a critic parameter to the throughput performance and the mean delay time of an ordinary packet.

Considering Step 4c in Section 2, if a slot is not selected among these tags, all tags want to spend a redundant waiting time to decides to switch to the next slot by sending an EOF from the reader. If this redundant waiting time can be eliminated, then the mean time to completely serve these *n* tags at the beginning of inventory request from the RFID reader is denoted as $T(i, j \mid n)$ and is given as

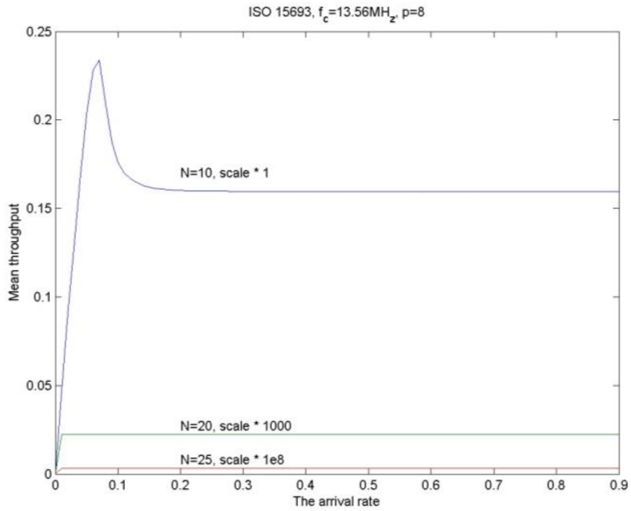

Fig-4: The mean throughput for ISO 15693 for different *N*

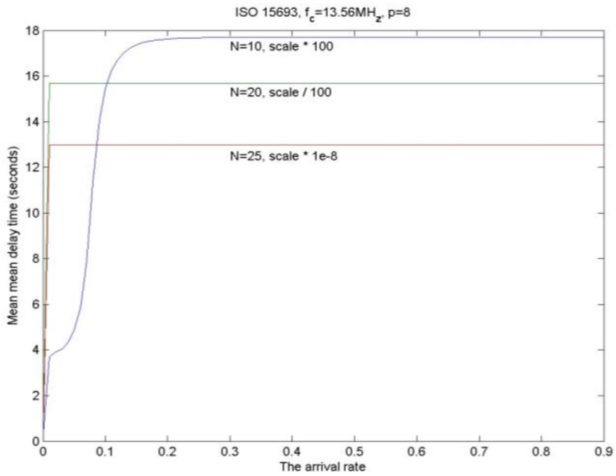

Fig-5: The mean delay time for ISO 15693 for different *N*

$$T(i, j \mid n) = t_{over} + i(t_1 + t_r + \tau + t_2 + t_{EOF}) + j(t_1 + t_c + \tau + t_2 + t_{EOF}) + T(n-i) \quad (11)$$

and the delay time given i successfully transmitted packets, and j collision packet periods that have been detected by the RFID reader among these n active tags, we have

$$X(i,j\,|\,n)=i\begin{bmatrix}\dfrac{i-1}{2}\begin{bmatrix}(t_1+t_r+\tau+t_2+t_{EOF})+\\(t_{req}+t_1+t_s+\tau+t_2-t_{EOF})\end{bmatrix}+\\ \dfrac{j}{2}(t_1+t_c+\tau+t_2+t_{EOF})\end{bmatrix}+$$
$$(n-i)\begin{bmatrix}i(t_1+t_r+\tau+t_2+t_{EOF})+\\ j(t_1+t_c+\tau+t_2+t_{EOF})+\\ +i(t_{req}+t_1+t_s+\tau+t_2-t_{EOF})\end{bmatrix}+X(n-i) \quad (12)$$

$$\begin{aligned}V(i,j\,|\,n)=t_{over}+i(t_1+t_r+\tau+t_2+t_{EOF})+\\ j(t_1+t_c+\tau+t_2+t_{EOF})+\\ i(t_1+t_{req}+t_s+\tau+t_2-t_{EOF})+V(n-i)\end{aligned} \quad (13)$$

According to the renewal theorem, the mean throughput and mean delay time of a packet related to each arrival rate are depicted in Fig-6 and Fig-7, respectively. Fig-6 reveals that the enhanced throughput performance of no considering these unused slots is roughly 6.2% than that of original RFID anti-collision protocol based on *N*=20. This figure also reveals that the enhanced throughput performance of no considering these unused slots is roughly 22.8% than that of original RFID anti-collision protocol based on *N*=10.

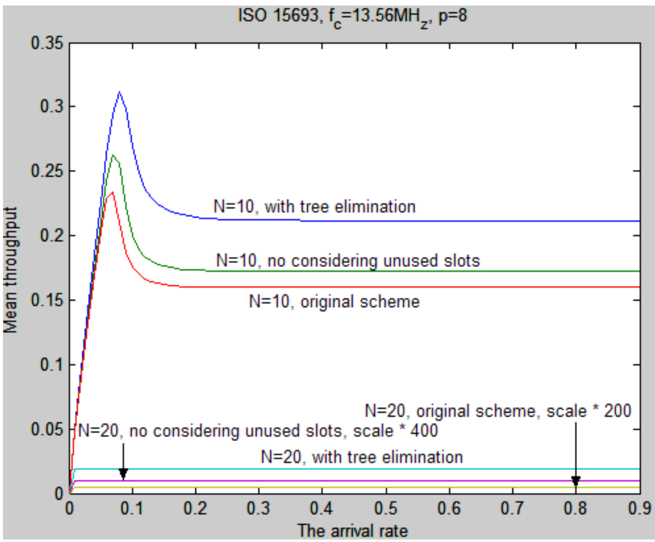

Fig-6: The mean throughput for ISO 15693 for different schemes

Fig-7 reveals that the enhanced mean delay time performance of no considering these unused slots is roughly 3.1% and 3% than that of original RFID anti-collision protocol based on *N*=10, and *N*=20, respectively. From Fig-7, we see that the amounts to enhance the man delay time performance is not obvious. However, the throughput performance is enhanced.

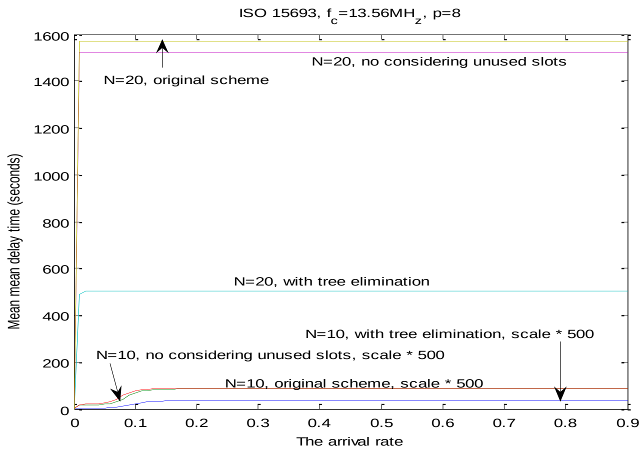

Fig-7: The mean delay time for ISO 15693 for different schemes

For multiple random accesses, a low throughput due to channel contention is the major limitation. The most latency occurs in the contention phase, reducing the delay time thus becomes a relevant task. A tree algorithm [7-9] is a more efficient method to resolve the colliding packets by using the binary splitting searching steps in the communication networks. By the natural characteristic of anti-collision protocol in ISO 15693-3 standard, the RFID reader knows how many collided packet slots occur and when some collision resolution cycles are created. This occurrence implies that the RFID reader knows the actual branches in a tree node. According to these collided packet slots, no time is wasted when the collided packets are split into some subgroups according to their new transmitted contentions immediately after collision (refer to the operation of the anti-collision protocol in ISO 15693-3 standard on Step 4b in Section 2).

When tree elimination algorithm is applied, the mean time to completely serve these n tags at the beginning of inventory request from the RFID reader is denoted as $T(i,j\,|\,n)$ and is given as

$$\begin{aligned}T(i,j\,|\,n)=t_{over}+i(t_1+t_r+\tau+t_2+t_{EOF})+\\ j(t_1+t_c+\tau+t_2+t_{EOF})+\sum_{r=0}^{p-1}T\left(1_{\{n_r>1\}}n_r\right)\end{aligned} \quad (14)$$

Where $T(n_r)$ denotes the average waiting time of n_r tags which want to re-contend the channel with slot *r* after collision. Based on that the delay time given *i* successfully transmitted packets, and *j* collision packet periods that have been detected by the RFID reader among these *n* active tags, we have

$$X(i,j\,|\,n)=i\left[\frac{i-1}{2}\left[\begin{matrix}(t_1+t_r+\tau+t_2+t_{EOF})+\\(t_{req}+t_1+t_s+\tau+t_2-t_{EOF})\end{matrix}\right]+\frac{j}{2}(t_1+t_c+\tau+t_2+t_{EOF})\right]+$$
$$(n-i)\left[\begin{matrix}i(t_1+t_r+\tau+t_2+t_{EOF})+\\j(t_1+t_c+\tau+t_2+t_{EOF})+\\+i(t_{req}+t_1+t_s+\tau+t_2-t_{EOF})\end{matrix}\right]+\sum_{r=1}^{p}X\left(1_{\{n_r>1\}}n_r\right) \quad (15)$$

$$V(i,j\,|\,n)=t_{over}+i(t_1+t_r+\tau+t_2+t_{EOF})+j(t_1+t_c+\tau+t_2+t_{EOF})+i(t_1+t_{req}+t_s+\tau+t_2-t_{EOF})+\sum_{r=0}^{p-1}V\left(1_{\{n_r>1\}}n_r\right) \quad (16)$$

According to the renewal theorem, the mean throughput and mean delay time of a packet related to each arrival rate are also depicted in Fig-6 and Fig-7, respectively. Fig-6 reveals that the enhanced throughput performance of tree elimination algorithm is roughly 32.62% than that of original RFID anti-collision protocol based on N=10. This figure also reveals that the enhanced throughput performance of tree elimination algorithm is roughly 4.12 times that of original RFID anti-collision protocol based on N=20.

Fig-7 reveals that the enhanced mean delay time performance of tree elimination algorithm is roughly 60.39% than that of original RFID anti-collision protocol based on N=10, and the enhanced mean delay time performance of tree elimination algorithm is roughly 3.13 times that of original RFID anti-collision protocol based on N=20. From Fig-6 and Fig-7, we see that if the number of tags does significantly exceed the number of the number of available slots from RFID reader, the performance is largely enhanced when the tree elimination algorithm is applied.

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5. CONCLUSIONS

In this paper, we point out the critical design's parameters which significantly influence the system performance. We also propose and discuss some collision resolution schemes which are more appropriate for application for the protocol to yield a more efficient performance.

When the tree elimination algorithm is involved, a more enhanced performance is achieved. From figures, we see that if the number of tags does significantly exceed the number of the number of available slots from RFID reader, the performance is largely enhanced when the tree elimination algorithm is applied.

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BIOGRAPHIES

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