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A Reader Anti-Collision Protocol Based on Density for Dense RFID Networks

Azam Razaghi[1], Mehdi Golsorkhtabaramiri[✉2]
1) University College of Rouzbahan,Sari, Iran
2)Department of Computer Engineering, Babol Branch, Islamic Azad University, Babol, Iran
a.razaghi@rouzbahan.ac.ir; golesorkh@baboliau.ac.ir

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Abstract

Radio Frequency Identification (RFID) Systems are wireless identification technology that provide communication and identification of tagged objects through wireless communications. In some applications, a single reader is not enough to cover a specific identification area, so several readers are placed very close to each other for optimal connectivity and coverage. This environment is called Dense Reader Environments (DREs). Such networks are susceptible to reader collision problems that cause decreases the performance of network. The reader-to-reader collision is an important challenge in dense reader RFID networks that lead to the reading throughput barrier and degrade the system performance. In this paper we propose a reader anti-collision algorithm based on the density of each reader in order to improve the network's throughput in dense RFID systems. Density Based Anti-Collision Algorithm (DBA) develops based on GDRA protocol but in this new algorithm each reader choice a time slot based on its density. Simulation results demonstrate the DBA algorithm provide 5.46% more throughput than GDRA.

Keywords: *RFID, Dense RFID Systems, Anti-Collision Protocol, Reader to Reader Collision, Throughput*

1. Introduction

Radio Frequency Identification (RFID) Systems are wireless identification technology that provide communication and identification of tagged objects through wireless communications. RFID enables wireless interaction over certain frequencies of RFID readers with a network system, to uniquely identify, track and capture the status of tagged objects within packages, animals or people at varying distances without the need of human intervention [1], [2].

Today RFID networks use concerns all the areas of the supply chain, transportation monitoring, inventory accuracy in warehouses, assembly assistance in manufacturing, and product availability in retail stores [3]. And Furthermore, RFID is considered as a crucial technology which has cheerful prospects in Internet of Things [4].

As shown in Figure 1, a RFID system is consisting of readers and tags. In most scenarios, passive tags are commonly preferred due to their low-cost, easy implementation, and durability [5].

Passive tags which are attached, do not incorporate battery and are powered by means of the electromagnetic waves energy emitted by the readers. Readers are more complex devices. They are installed in checking areas and they continuously transmit electromagnetic waves to feed tags. The tags that cross these areas send their information back to the readers [6], [2].

In some installations, a single reader is not enough to cover a specific identification area, or simply the final application requires the existence of multiple checking areas. These scenarios are forced to use RFID systems with several readers, so called Dense Reader Environments (DREs) [7]. A dense reader environment consists of several interrogators placed closely monitor passive tags/sensors [8]. An example of a RFID dense reader network has been shown in Figure 1.

In this RFID environments, hundreds of readers might be placed in the same area to scan a large number of tags for a desired coverage range. Such a dense network exhibits high number of collisions that lead to reduction in data collection throughput, increase in identification delay, and degradation in network efficiency and reliability [1].

However, due to reader's close proximity, when nearby readers simultaneously try to communicate with tags located within their interrogation range, serious interference problems may occur on tags. This is mainly due to the overlapping of readers' fields. Such interferences may cause signal collisions that lead to the reading throughput barrier and degrade the system performance [9].

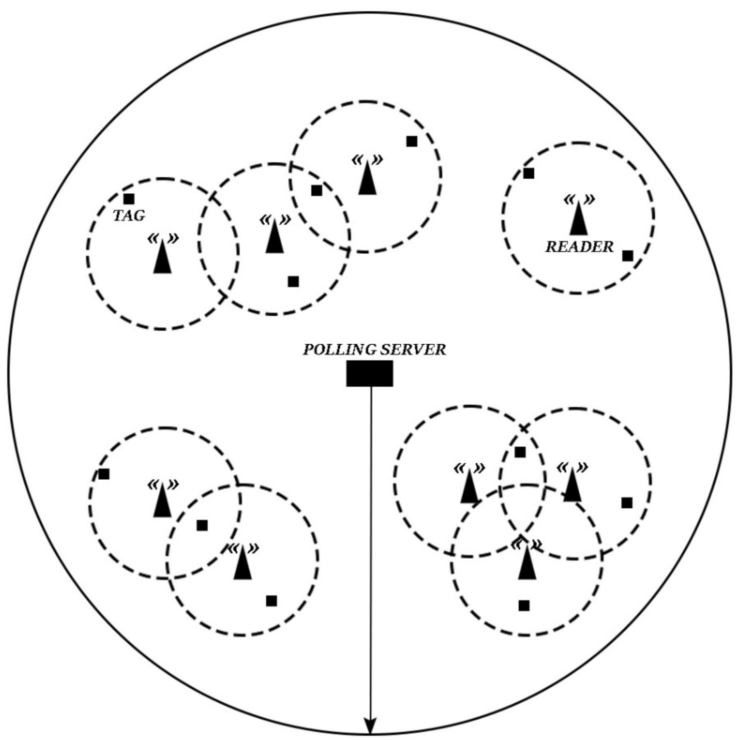

Figure 1. An example of RFID dense reader network

In recent years, due to the emergence of new applications that require multiple readers to work simultaneously," Reader Collision Problem" (RCP) receives more attention in researches. The RCP models the task of assigning radio frequency spectrum over time to a set of RFID readers. There are two primary types of RCP in RFID system: reader-to-reader interference and multiple reader-to-tag interference [10].

Reader-to-reader collision (RRC) which is also called frequency interference, happens when the signal generated by one reader interferes with the reception system of other readers. It occurs when the physical distance between two or more readers is lower than reader to reader interference range. RRC hinders the tag identification process; a reader can receive strong signals from neighboring readers, interfering with the weak response signal from the tag [7], [11].

For example, as we can see in Figure 2(a), *R* indicates interrogation range and *I* is interference range of r_2, tag t_1 lies in the interrogation zone of r_1 and also in the interference zone of r_2, the weak reflected signal reaching reader r_1 from tag t_1, interferes by signal from r_2.

Reader-to-Tag Collisions (RTC) occurs when two or more readers overlap their reader-to-tag read ranges and try to read the same tag simultaneously. This is a source of RTC, even if both readers are operating at different frequency. Since tag is a passive device, it has not the specify hardware to select a particular reader/frequency to transmit its data. [11]

For example, as we can see in Figure 2(b), tag t_1 is located in the interrogation zone of r_1 and r_2.whenr_1 and r_2 interrogate t_1 at the same time, it cannot select any signal. Thus, that results in failure of interrogation for both r_1 and r_2.

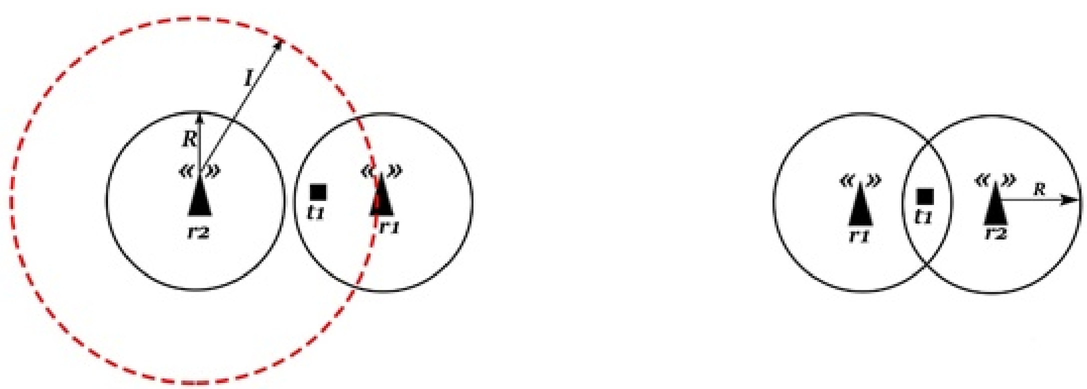

Figure 2. (a): Reader to Reader Collision. (b): Reader to Tag Collision.

According to the description of these three types of collisions, the key to make the RFID system efficient is to schedule reader's activities so that neither interferences nor collisions may occur [12]. Therefore, the design of an efficient communication protocol or scheduler mechanism has emerged as the most interesting research issues in recent years. Various Anti-collision protocols have been proposed that perform limitedly and cannot satisfy the performance requirements fully, thus leaving some room for improvement.

In this paper, we proposed a reader Anti-collision algorithm based on GDRA protocol by accounting the density of each reader in order to increase the number of the active readers in system and improve the system throughput in a RFID networks with the dense readers.

The rest of this paper is organized as follows: in Section 2 we survey some of the related work. Section 3 introduce the principles of proposed algorithm. In Section 4 we describe about evaluation and simulation results of the proposed algorithm. And finally, the conclusion presented in Section 5.

2. Related Works

In this section some of the most related Anti-collision protocol for coordinating readers in passive RFID systems are reviewed. Many approaches were recently proposed to reduce the impact of collisions, minimize interference, and increase number of active readers and consequently maximize the transmission efficiency in RFID systems.

The state-of-the-art protocols can be broadly classified as CSMA-based and activity scheduling based through time division, frequency or by putting together both approaches.

CSMA-based is considered as an efficient and more adaptive approach in large-scale RFID reader networks because it is full-distributed algorithm and it does need neither synchronization nor additional resource like server. However, the existing protocols still suffer from traditional back off scheme in dense RFID networks. Therefore, the back off algorithm for CSMA-based may need to be investigated in depth in order to maximize the network throughput but also to minimize the collisions which still exist [12].

In distributed mechanisms, readers work independently of each other, or communicate with their neighbors usually by means of wireless links and do not rely on a centralized device to allocate the network resources [7].

The European standard ETSI EN 302 208 specifies a protocol, called Listen before Talk (LBT), based on CSMA scheme. Before transmitting, a reader selects a channel and it stands in listen mode for at least 5 mille second, measuring any signal on that channel. If a signal is detected, the channel is busy and reader monitors another channel. The reader switches to talk mode and starts the transmission if a free channel is found. The reader can transmit for no more than 4 seconds. After stopping communication, the reader must wait for at least 100 mille second before listening again the same channel. However, LBT's high collision probability and the delay embedded in CSMA handshake have been sensibly reduced by subsequent proposed protocols, like PULSE [13].

PULSE is a CSMA-based notification protocol that attempts to mitigate the reader collision problem using two channels in the RFID networks [4]. PULSE is a LBT based protocol that makes use of an auxiliary control channel. Readers can listen simultaneously the control and the reading channel, but only transmit in one of them. Before powering the tags, readers check if some neighbor reader is on. When a reader is activated it continuously transmits beacons in the control channel before the tag reading process takes place. After a guard period without transmissions in both channels, the reader occupies the control channel filling it with beacons, and shortly afterwards it starts the tag reading process [6]. PULSE is relatively flexible and simple, but its disorderly contention mechanism induces performance degradation in dense reader RFID system [4].

Resource scheduling based protocols aim to allocate system resource (usually time) according to network environment. Color wave is one of the first reader anti-collision algorithms. It is a distributed TDMA based algorithm, where each reader chooses a random time slot in which it doesn't collide with adjacent readers to transmit [4]. If the transmission collides, the transmission request is discarded and the reader randomly selects a new timeslot and sends a kick packet to all its neighbors to indicate selection of new time slot. If any neighbor has the same color, it chooses a new color and sends a kick (small control packet) and this continues. If the percentage of successful transmission goes below certain threshold, the max Colors is incremented. While if the percentage increases beyond certain threshold, the max Colors is decremented [1].

The final efficiency in these protocols depends on the number of colors, which algorithms adjust dynamically using different criteria, and on the way algorithms "solve" collisions, i.e. how they reassign colors after a collision event. State-of-the-art methods within this family is the algorithms NFRA. NFRA is a semi-centralized algorithm, since the readers interchange control messages with the coordinator [14].

In centralized mechanisms a centralized master is in charge of reader coordination. It communicates with the readers using a wired or wireless link, and synchronizes the readers. It checks the requirements of each reader, and distributes the available resources among them, that is, it schedules the operation of the readers [6].

In NFRA, a polling server is designated to divide the communication time into identification rounds. Every round begins by an arrangement command AC (random numbers from1 to maximum number, MN) broadcasted to all the readers. Every reader generates its own random number after receiving the AC. The server then issues an ordering command (OC). The readers then compare their random numbers with the value in the OC. If both values are same, the readers broadcast their beacon signals to determine whether a collision happens or not. A reader which does not experience any collisions sends an overriding frame (OF) to its neighboring readers. The OF prevents the neighboring readers from receiving the next OC from the server. Communications between a Reader and Tags (CRT) is performed by successful readers only [8].

The main drawback of NFRA arises from the random hierarchy among the readers established by the selection of at the beginning of the round. Readers drawing the lowest value have the best opportunities to query tags; they experience a collision only if a neighbor has the same value. As increases, the probability of receiving an OF from readers with lower numbers grows. However, this probability depends on the size of the neighborhood, too. The fewer the neighbors are, the lower the probability of receiving a beacon is. The uniform distribution probability used in NFRA gives to all the readers the same probability of selecting a low value, without correlating it with the size of the neighborhood [3].

Although NFRA shows better performance than the other state-of-the-art proposals, its throughput could be improved if the contention procedure is modified. In [7] authors proposed GDRA is a protocol based on NFRA. In order to avoid RRC effects, GDRA coordinates the readers in a TDMA scheme, but it also combines the FDMA scheme of ETSI EN 302 208 [7].

In GDRA protocol, where several changes are addressed with the aim of improving the performance of RFID systems as well as to create a mechanism that could be implemented in real RFID systems. In GDRA, readers no longer work in a single UHF frequency, but randomly select (following a FDA scheme) one of the frequencies that are permitted by the standard and the country regulations where the readers operate. Unlike NFRA, The

CS does not communicate with readers at 433MHz because it is a dedicated band for active RFID systems. They will communicate each other using a wired (Ethernet) or wireless (Wi-Fi) infrastructure. And moreover the OC packet is removed because readers know the temporal length of every slot, and they can control when a new slot begins, using an internal clock. Readers use the truncated geometric distribution function to select the contending slot k [5].

Readers, after selecting slot k, wait for k-2 slots without listening the channel for saving energy. When slot starts, If the channel was busy in the k-1th slot (due to collisions or successful reader transmissions), those readers that selected slot k leave the contention, randomly select a new frequency and keep waiting a new AC packet. If the channel was idle (free channel) in the k-1th slot, those readers that selected slot k send a beacon packet at the beginning of slot k. In this way, these readers require the channel for reader-to-tag communication.

After sending beacon packets in slot k, if only a single reader transmits a packet in its set, it wins the contention and takes the channel in slot $k+1$, starting the reader-to-tag communication phase. If two or more neighboring readers transmit a beacon packet simultaneously, a collision occurs these readers leave the contention, select a new frequency and wait a new AC packet. The same actions are taken by readers that selected slot $k+1$, because they could be suffering collisions due to being in range of two sets. After transmitting in the reader-to-tag communication phase, the reader keeps the same frequency, waiting a new AC packet and the contention procedure [7].

In light of the principle of NFRA and GDRA protocols described above, if a reader succeeds in having the chance of transmission, it warns nearby readers by sending out a signal. Any reader receiving this signal has to stop competing and wait for the next transmission round. Clearly, if the density of readers is low, the number of readers affected by this signal is small. Instead, the number of readers affected is large, in case of high density of readers. The large number of readers affected and has to wait until the next frame, yielding low transmission efficiency [15].

Based on above mentioned premises, we proposed a reader Anti-collision algorithm based on GDRA protocol by accounting the density of each reader in order to increase the network throughput in a RFID networks with the dense readers. The proposed algorithm is explained in next section.

3. Proposed Algorithm

In this study, in order to increase the number of successful reading and thereby increase the throughput in a dense reader RFID network, the goal is to increase the number of active readers in each round. For this purpose, the algorithm that presented in GDRA protocol is improved so that the number of active readers in each round increased.

The main idea of this density based anti-collision (DBA) algorithm is that, if readers which are located in a sparse area have a higher priority of competing for transmission than readers which are located in a dense area. In this way fewer readers will affect by their control signal and therefore more readers can operate simultaneously.

Unlike GDRA, in DBA algorithm instead of using the truncated geometric distribution function to select the contending slot k, each reader generates a random number based on its density to transmit beacon packet.

In order to measure the relative densities of different readers, parameter pair (Nb, f) is set at each reader, where Nb with initial value Nb = 0 counts the number of distinguishable beacon packets that a reader receives from neighboring readers during the round, and f is a binary flag with initial value f = 0 that accounts for if there is at least a colliding time slot, i.e., a slot with multiple incoming beacon signals [15].

In this way, readers with less density or in other words readers with fewer neighbor, will choose smaller contending slot number and accordingly starts the reader-to-tag communication phase sooner. The pseudo-code for the DBA algorithm is presented in the following:

Algorithm 1 Pseudo code of The DBA Algorithm for each reader r_i

```
Initialization: set the value of frequency, Nb = 0 and f = 0;
loop
listens to the CS connection
while AC packet is not received do
no operation
end while
extracts the MN value from AC packet
Compute the values of the number of distinguishable beacon signals (Nb) and of the flag variable (f);
if Nb < MN-1 and f = false then
k = Nb + 1;
else if Nb < MN-1 and f = true then
k = Nb + 1 + randi (1, MN-Nb-1);
else
k = randi (1, MN);
end if
Broadcast a beacon signal in the k-th time slot in selected frequency;
if selected frequency is Idle start reader-to-tag communication;
else if receive any control signal then
No operation until the next AC;
end if
end loop
```

For instance, the readers without any colliding neighbor choose the k=1 and have the highest priority to transmit. If Nb < MN-1 and f=1, the priority of readers is degraded by adding a random number ranging between 1 and MN-Nb-1. And finally, if Nb= MN-1 and f = 1, DBA behave as GDRA.

In this regard, at the beginning of each transmission round, the polling server broadcasts an arrangement command (AC), consisting of the synchronization information and an integer number (MN) indicate the maximum range of random numbers allowable at readers. Once receiving the AC message, each reader extracts the value of MN and also determine the values of Nb and f. And then generates an integer number based on its density measured parameters.

The reader that wins the contention in a set, is the only one able to transmit in that frequency, in the reader-to-tag communication phase. Readers, after selecting slot, listen to the selected channel. If the channel was busy in the k-1th slot (due to collisions or successful reader transmissions), those readers that selected slot k leave the contention, randomly select a new frequency and keep waiting a new packet. Else send a beacon packet at the beginning of slot k. If only a single reader transmits a beacon packet in its set, it wins the contention and starting the reader-to-tag communication phase. Else it should leave the contention, select a new frequency and wait a new AC packet.

4. Simulation and Evaluation

In This section, in order to present the improvement brought by DBA algorithm, we simulated DBA algorithm using R2RIS simulator, which has been specifically designed to evaluate the performance of reader-to-reader anti-collision protocols [16].

We consider a dense RFID system that is composed by a set of bistatic RFID readers randomly placed in square areas of 100 meters. The reader output power is set at the maximum value permitted in Europe, equal to 3.2 watts. This value limits the reader-to-tag read range and the reader interference range to a maximum of 10 and 1000 meters, respectively. Note that at EIRP, RTC occurs when readers are placed at less than 20 meters to each other and RRC at less than 1000 meters to each other. Other parameters of the simulation approaches are according to the values defined in [7] and summarized in Table 1.

Table 1. Simulation Parameters

Parameter	Value
AC Packet	2.83 ms
Beacon Packet	0.3 ms
Reader-to-Reader Communication Length	0.46
T_{slot}	5 ms
Maximum Number	32

Since a good DRE mechanism should guarantee a high number of successful transmissions, regardless of the collisions. Hence, the throughput is an appropriate parameter for measuring the performance [6]. We define the throughput as the ratio of the average number of successful query sections per reader over the simulation duration. The higher system throughput, the more efficient protocol [12].

So to evaluate the performance of proposed algorithm we comparing its throughput with some of the anti-collision protocol. In this simulation 25, 50, 75 and 100 readers are deployed in an area of 100×100 m. Figure 3, illustrate compression of the throughput respect to the number of readers in the system, As we can see in Figure 3, DBA shows the highest throughput.

Figure 3. Compression of throughputs of anti-collision protocols

Moreover, to better evaluation two different scenarios have been investigated, to compare the performance of the DBA algorithm with the GDRA protocol. One for a sparse reader environment (i.e., small number of readers) and other for dense reader environment (i.e., large scale number of readers). In scenario 25, 50, 75 and 100 readers are deployed in an area of 100×100 m. In the second scenario, the size of the area is the same but the number of readers is increased as 100, 150… 500. Therefore, the average number of neighbors is higher than the previous scenario.

Figure 4 and Figure 5, illustrate compression of the throughput respect to the number of readers in the system, of both DBA algorithms and GDRA. All simulation results are averaged over 20 repeated trials.

As we can observe in Figure 3 and Figure 4, the DBA algorithm provides higher throughput than GDRA. The DBA algorithm has a 5.46% increased throughput as compared to GDRA in first scenario and 2.57% in second scenario. This is because the DBA algorithm considers the density of each reader in order to choose contending time slot.

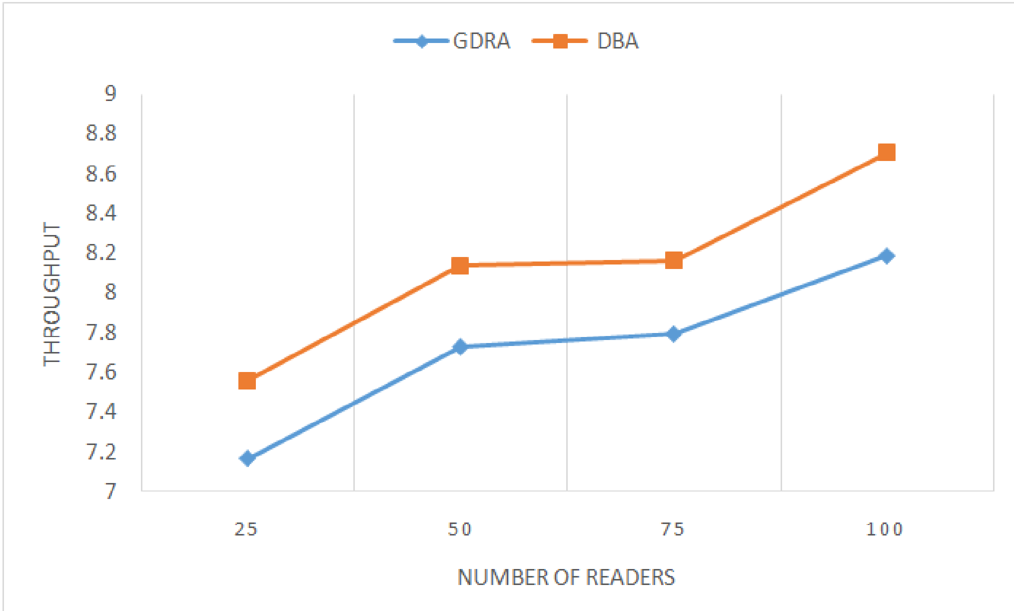

Figure 4. System throughput respect to the number of readers in the sparse reader environment

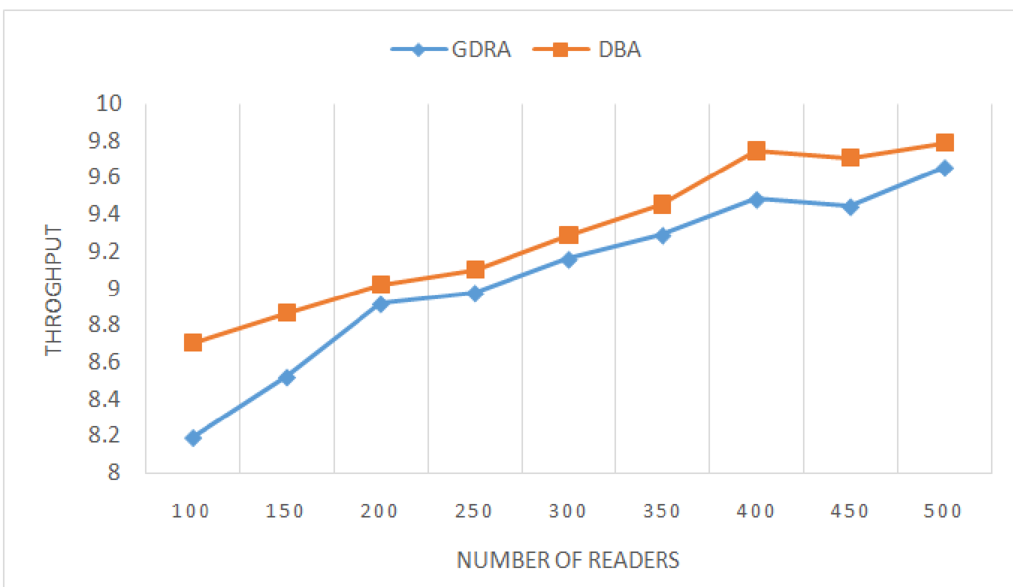

Figure 5. System throughput respect to the number of readers in the dense reader environment

Although the main purpose of this study been considered to increase system throughput but during the simulation has been observed that, average waiting time of proposed algorithm is lower than GDRA. Figure 6, shows the average waiting time of network respect to the number of readers in sparse scenario. The DBA algorithm has a 4.93%

decreased average waiting time as compared to GDRA in first scenario and 2.11% in second scenario.

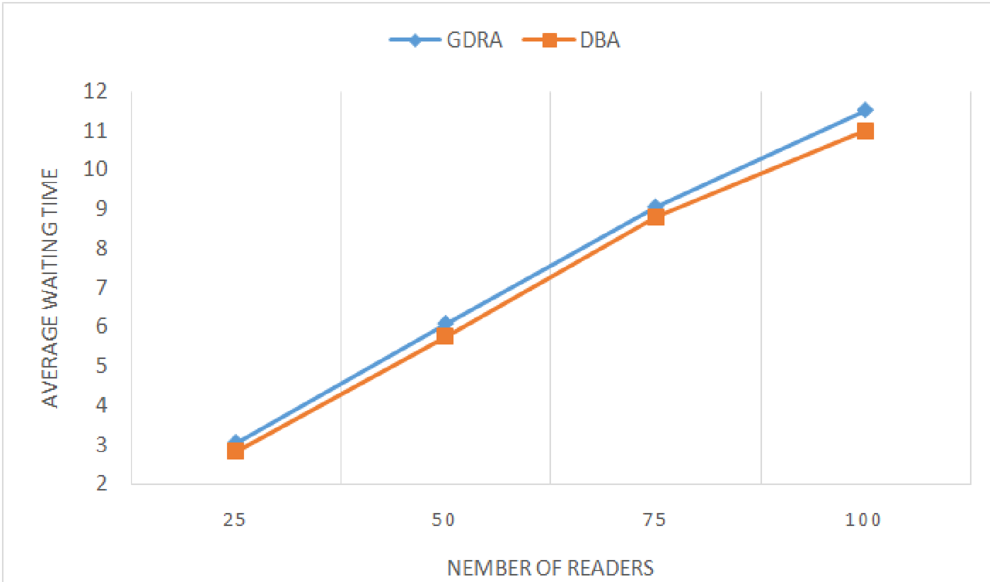

Figure 6. Average waiting time respect to the number of readers in the sparse reader environment

5. Conclusion

Hence, the reader-to-reader collision is an important challenge in dense reader RFID networks that lead to the reading throughput barrier and degrade the system performance. In this work, an improvement version of the Geometric Distribution Reader Anti-collision protocol (GDRA) has been proposed. This new algorithm is suitable for RFID networks with dense mobile readers, by accounting the densities of different readers. In particular, relative density of each reader evaluate by counting number of distinguishable beacon packets that received from neighboring readers during the round.

In this way, readers with less density will choose smaller contending slot number and accordingly starts the reader-to-tag communication phase sooner. So the number of affected neighbors by them decrease and more readers can operate simultaneously. Simulation results demonstrate 5.46% enhancement of the DBA algorithm over the GDRA with respect to the system throughput.

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