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High Adaptive MAC Protocol for Dense RFID reader-to-reader Networks

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Abstract. This paper proposes a *high adaptive contention-based medium access control (HAMAC)* protocol that considerably reduces RFID readers collision problems in a large-scale dynamic RFID system. HAMAC is based only on realistic assumptions that can be experimented and does not require any additional components on RFID reader in order to improve the performance in terms of throughput, fairness and coverage. The central idea of the HAMAC is for the RFID reader to use a WSN-like CSMA approach and to set its initial backoff counter to the maximum value that allows the system to mitigate collision. Then, according to the network congestion on physical channels the reader tries to dynamically control its contention window by *linear decreasing* on selected physical channel or *multiplicative decreasing* after scanning all available physical channels. Extensive simulations are proposed to highlight the performance of HAMAC compared to literature's work where both readers and tags are mobile. Simulation results show the effectiveness and robustness of the proposed anti-collision protocol in terms of network throughput, fairness and coverage.

Key words: RFID systems, Medium Access Control (MAC), Network protocol design, Anti-collision protocol, Capacity, Fairness

1 Introduction

Most radio frequency identification applications, such as supply markets, localization and objects tracking, activity monitoring and access control, etc., use passive RFID tags, which communicate with the RFID reader by modulating its reflection coefficient (backward link) to incoming modulated RF signal from the reader (forward link). However, unlike the traditional radio communication systems, in such systems, the RF signal does not provide reciprocity between forward and backward links because the reflected RF signal from a tag is inversely proportional to the fourth power of the distance between reader and tag [11]. This link unbalance requires in above large-scale applications of RFID systems to deploy a large number of RFID readers allowing the coverage of the interested environment. A direct consequence of this feature deployment is the operation within the closest proximity of several tens or hundreds of readers in order to overcome the shortcoming of the backward communication distance. However, due to readers 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. Furthermore, when mobility is also considered in RFID systems because it extends coverage, facilitates inventory or stock and avoids installation and maintenance costs, the performance drops significantly due to both the interference and classical *hidden node* problems that can frequently appear.

In the literature, collision problems can be broadly classified into two categories. The first category, called *tag-to-tag* collision [9] occurs when multiple tags try to respond simultaneously to a reader *query*. This category is considered to be solved and is part of patents developed by EPCglobal standard [1]. While the second category, called *reader-to-reader collision* (RRC) and *multiple reader-to-tag collision* (RTC), obtained few attention because previous applications of RFID systems considered only a reader with several tags, the design of an efficient reader anti-collision protocol has emerged as the most interesting research issues in recent years.

The state-of-the-art protocols can be broadly classified as CSMA-based [2–4] and activity scheduling based [5, 6, 8] through time division, frequency or by putting together both approaches. The former approach 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 (e.g. server) like in the latter approach. However, the existing protocols still suffer from traditional *backoff scheme* in dense RFID networks as it is recently observed in NFRA [6] and GDRA [5]. To the best of our knowledge, the design of an efficient anti-collision protocol with an efficient backoff algorithm is still missing and this is the focus of our paper.

This paper presents *High Adaptive MAC (HAMAC)* a distributed CSMA-based anti-collision protocol. HAMAC adapts the reader behavior according to the network congestion on multichannel dense RFID networks. It operates by dynamically controlling the reader contention window through *linear decreasing scheme* on selected physical channel or *multiplicative decreasing scheme* after scanning all available physical channels. To cope with the collision problem brought by mobility, HAMAC borrows the idea of *control channel* from [3]. HAMAC improves the performance such as throughput, fairness behavior during channel access in large-scale RFID system.

The rest of this paper is organized as follows. Section 2 formally defines our objective, the collision problem in RFID system and introduces the system model. Section 3 presents our new anti-collision protocol. In Section 4, we show simulation results to validate the accuracy of our model under various RFID environment scenarios and according to several criteria. Finally, Section 5 concludes by discussing future research direction.

2 Preliminaries

In this section, we formally define the collision problem in RFID systems, our objectives and introduce the underlying modeling assumptions.

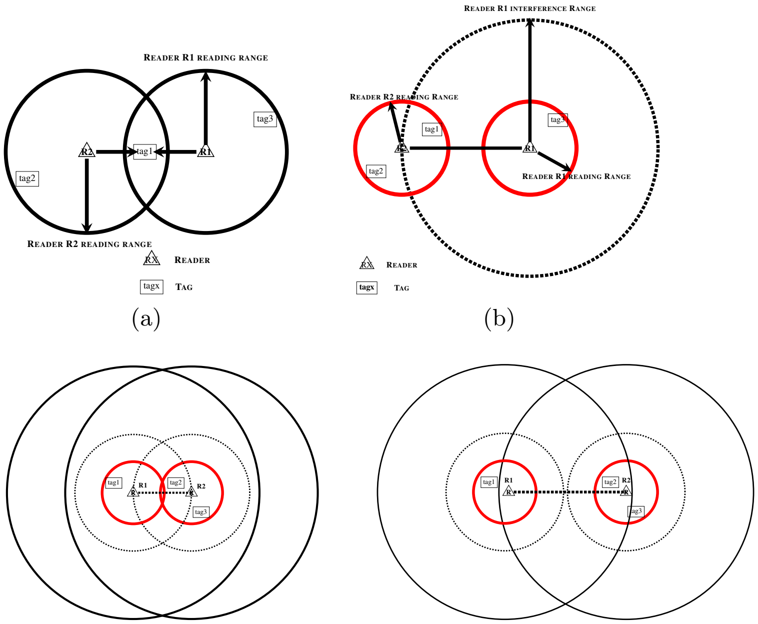
2.1 Problem Statement

Single radio channel In passive RFID, tags have no energy embedded. They are activated only when they pass through the electromagnetic field of a reader. When a wave bounces on a tag, the reader can read data stored in the tag [7]. However, when a tag enters an interference area, reader electromagnetic fields will overlap, transmitted signals will collide thus, tags will be unable to answer readers queries. This is called reader collision. The tag then becomes unresponsive and according to the kind of tags, may not be detected until it leaves all readers fields (and not just the interference area). It will be responsive again once it enters an area where there is no active field. So, on Figure 1a, if $R1$ and $R2$ are activated at the same time, $tag1$ will not be read. This is called *multiple Reader-to-Tag Collision (RTC)* and can occur only if the distance between operating readers is lower than $2 \times d_{RT}$ (e.g. d_{RT} is *reader-to-tag reading* range). It can be avoided by making them to operate onto different time-slots. Note that all tags are not impacted but only the ones in overlapping areas. For instance, $tag2$ and $tag3$ will still be successfully read by readers $R2$ and $R1$ respectively. However, in practice this does not hold true. Because, even when it has no overlapping areas and the distance is higher than $2 \times d_{RT}$, but less than or equal to the interference range (i.e. d_{RR}), if they operate at the same time, collison can occur at readers side. It is called *Reader-to-Reader Collision (RRC)* and can occur when $tag2$ (respectively $tag3$) answer interferes with the $R1$ (respectively $R2$) query. It is illustrated by the Figure 1b and can be avoided by using different channel frequencies or time-slots or by combining together both.

Multichannel radio network In a multichannel network scheme, readers could use different channels to read the tags but still this does not prevent all collisions [2]. To better illustrate it, let's consider Figure 1c. On this figure, dotted lines represent the communication links between readers, small circles display the reader's reading range, dotted circles show the interference range of adjacent channels and big circles illustrate the reader's interference range. Readers $R1$ and $R2$ can communicate in a wireless adhoc manner and they are in communication range of each other, i.e. $d_{R1R2} < d_{RR}$ where d_{R1R2} is the Euclidean distance between $R1$ and $R2$.

In a multichannel RFID network, if two readers use the same frequency to read tags, whatever the distance between them, tags laying on the overlapping area of their fields will not be read. (On Figure 1c-1d, $tag1$, $tag2$ and $tag3$ will not be read if $R1$ and $R1$ use the same frequency at the same time). But, if two readers use different reading channels, even if they are active at the same time, tags laying in the overlapping area of their fields will be successfully read if and only the distance between the readers is larger than $3.3 \times d_{RT}$. For instance, on

Figure 1c, even if $R1$ and $R2$ use different frequencies to interrogate tags, if they are activated at the same time, they will still collide since they are too close to each other. But, if $R1$ and $R2$ use different channels, as illustrated by Figure 1d, their tags will be successfully read.



(a) (b)

(c) (d)

Fig. 1: (a) Multiple Reader-to-Tag Collision, (b) Reader-to-Reader Collision, (c) Multichannel Reader-to-Reader interference, (d) Multichannel Reader Reading

HAMAC will address both RTC and RRC in a multichannel environment, taking advantage of all inherent physical properties and optimizing the system performances.

2.2 System model and assumptions

We consider a large-scale mobile RFID system with multiple readers and homogeneous local density of RFID tags within the interrogation area. We assume that both readers and tags are mobile according to random mobility model. Readers' communication range is assumed to be the same. We assume that readers have two wireless interfaces. Similar to ETSI EN 302 208-1 regulation [4], in this paper, we assume the use of multichannel network scheme. Thus, we assume the use of f_{max} data channels on the first radio interface. According to this regulation, we assume that a reader has output power of 2 Watt Effective

Radiated Power (ERP). This limits the *reader-to-tags* read range (d_{RT}) to a maximum distance of 10 meters while *reader-to-reader* interference range (d_{RR}) may reach 1000 meters [12]. Since mobility is considered in this paper, we assume that the second radio interface is used by all readers to send a *control channel*. To save energy, we assume that it is switched on only during the *reader-to-tags* reading process. This interface, which operates on a different channel, is used only during *reader-to-tags* communication. It consists in sending periodically an advertisement messages up to $3.3 \times d_{RT}$ as defined in [2]. Our aim is to cope with the *multiple reader-to-tag collision (RTC)*, from tag point of view, when closest readers are operating on different data channels. Since the advertisement channel is shared by all operating readers, they are able to detect their transmissions and thus, to re-schedule quickly their activities in order to minimize a collision impact. Therefore, in order to limit the occurrence of adjacent channel interference and to avoid undecodable radio frequency signals inside tags, the distance between two closest readers must be at least $3.3 \times d_{RT}$ further away.

2.3 Motivations and Objective

Motivations and state of the art
The issue of reader collision problem has been extensively studied in the context of RFID system [2–6, 8], where the main objective was to maximize network throughput while trying to mitigate MAC-level interference. These approaches can be broadly classified as CSMA-based [2–4] and activity scheduling [5, 6, 8] through time division (TDMA), frequency division (FDMA) or by putting together both approaches. To achieve this objective, the former approach is considered a more suitable solution and more adaptive approach for large-scale RFID networks because it is full-distributed algorithm and scalable, it does need neither synchronization nor additional resource such as centralized server which can address the synchronization problem or the use of bistatic antenna [5] in order to detect collision, in the latter approach. Although some activity scheduling approaches are also based on distributed TDMA algorithm [8], these protocols are based on an unrealistic radio channel assumption when collision appears. They basically assume that a reader is able to detect a collision, so that readers can randomly select different slots during the next round. Note that in this category, communication is organized in groups of timeslots called rounds. As a consequence, the latency of tags' coverage gradually increases. To the best of our knowledge, GDRA [5] is the only one that overcomes this unrealistic assumption by using a bistatic antenna. It is proposed to be compliant with the EPCglobal standard and ETSI EN 302 208-1 regulation and to minimize the reader collision by using SIFT [10] probability distribution function to choose the timeslot. However, as we have previously shown in [13], the use of the geometric distribution only does not totally eliminate collisions. Moreover, by reducing the contention window size at the minimum value (e.g. 32) order to minimize the delay, GDRA performs poorly in terms of collision. In contrast to minimizing this parameter, the achieved throughput also decreases due to the contention latency. So, there is a tradeoff in such conditions.

Even if the former approach [2–4] has been proposed in order to cope with the activity scheduling protocols weakness, however, all these protocols still suffer from traditional *backoff scheme* when the number of readers increases in the system. Because the maximum contention window size is set to a time, which is proportional to twice the time to read a tag in the worse case scenario [4]. In the existing CSMA-based approach, how to set the backoff algorithm during channel access in order to make them efficient, however, is far less investigated. They use an arbitrary value without any discussion about its impact on the performance. Moreover, to improve the read tags size, [2] proposed to use a *forwarding mechanism* between readers. Thus, is not acceptable in real RFID system and can increase the design complexity. By inspiring from MANET CSMA-based protocols, that have already investigated this problem and have proved their efficiency, we have adapted and characterized them in RFID system in [13]. Our aim was to mitigate both reader-to-reader collision (RRC) and multiple reader-to-tags collision (RTC) by using together a multichannel mechanism and efficient backoff algorithm. Thus, according to these observations, we plan to propose, in this paper, a new CSMA-based protocol, that outperforms most of existing protocols such as GDRA [5]. It should perform efficiently regardless of the radio frequency (RF) resource because RF spectrum is a scarce and expensive resource that needs to be managed carefully.

Objective
Our objective is to propose an efficient, fair and scalable full-distributed CSMA-based protocol, called *high adaptive medium access control (HAMAC)*, in large-scale mobile RFID system. HAMAC takes advantages of the CSMA approach together with the multichannel characteristics. To the best of our knowledge, HAMAC is the first one to cope with the fact that multichannel use does not prevent from all collisions and takes advantage of the different properties and features.

3 Design of HAMAC protocol

3.1 Overview of HAMAC

With respect to the problem statement, in order to optimize the reading throughput, HAMAC is split into two parts that are detailed in this section. The idea is to first select a channel which is not used by neighboring readers in order to limit the number of collisions. This is the purpose of the first algorithm, HAMAC-channel. Then, once a channel is selected, HAMAC aims to prevent from colliding with close readers which can collide even if they use a different channel. This is the purpose of the second algorithm HAMAC-reading. Table 1 lists the notations used in the description of HAMAC protocol.

In CSMA-based protocol, every reader contends for its own medium access opportunity independently. We therefore describe below how a reader can gain

Table 1: Notations Used in HAMAC's algorithms

Symbols	**Notations**
r_x	Reader x
f^{adv}	Advertisement channel frequency
f_x^d	Data channel frequency of reader x
f_x^u	The set of occupied channel frequency during carry sensing (CS) of reader x
CW_x	Backoff counter value of reader x
CW_x^r	The remaining backoff counter value of the reader x
CW_{max}	The maximum backoff counter value
R_{adv}	Advertisement message transmission range
d_{RT}	Tags reading range
d_{RR}	Reader communication range

the data channel access in its vicinity. The basic idea operation of HAMAC can be subdivided in two parts.

3.2 Algorithm 1 - HAMAC-channel

Before beginning tags reading process, the reader first sets the initial parameters to default value (e.g. $W_{max} = 1024$), randomly selects its data channel frequency among the available channel lists $[1 : f_{max}]$ and its backoff counter over an interval $[0 : 1023]$ and sets the occupied channel frequency to an empty set (lines $1-6$). Then, it begins to listen the selected data channel by decreasing its backoff counter each timeslot (e.g. $500\mu s$). Two actions can occur:

- In the best case, the selected data channel remains *idle* during the listen process and the reader decreases each timeslot its backoff counter until it reaches zero (lines 9-10). Then, algorithm 2 is called in order to process the second part of the HAMAC operation (lines 23).
- The selected data channel is busy, this means that the condition of line 9 is *false*. In such case, the reader checks if its occupied channel frequency list was reached its maximum value (line 12). If this condition of line 12 is satisfied, the reader adds this frequency identifier in the list of occupied channel frequency and randomly selects a new channel frequency, which it is not in the occupied channel frequency list, and goes back to the line 8 to continue the listen process on the new selected channel (lines 11-16). Otherwise, the condition of line 12 is not satisfied. The reader reaches its maximum occupied channel frequency value, saves its backoff counter in its remaining backoff counter and divides by two its maximum backoff counter (lines 17-18).

  Then, the reader checks if the minimum backoff counter value is reached (line 19). If this condition is false, the reader jumps to the process of line 4 and repeats the same process again until it gains the channel by jumping to algorithm

2 or it loses by reaching the minimum backoff counter. For both conditions, line 19 is false and the reader lost by reaching the minimum backoff counter, it jumps to line 1 and repeats all the process of channel access until the channel becomes idle.

Algorithm 1 High Adaptive MAC Anti-Collision Protocol operating for the reader r_i

```
 1: **Set** reader $r_i$'s **state** to IDLE
 2: $CW_{max} \leftarrow 1024$
 3: $CW_i^r \leftarrow 1024$
 4: $CW_i \leftarrow MIN\{CW_i^r, random(0, CW_{max})\}$
 5: $f_i^d \leftarrow (int)random(1, f_{max})$
 6: $f_i^u \longleftarrow \emptyset$
 7: **Data Channel Access Process:**
 8: **while** $CW_i \neq 0$ **do**
 9:     **if** (CS($f_i^d$) == IDLE) **then**
10:         $CW_i \longleftarrow CW_i - 1$
11:     **else**
12:         **while** $| f_i^u | \neq f_{max}$ **do**
13:             **Add** $f_i^d$ to $f_i^u$
14:             **while** $(f_i^d = (int)random(1, f_{max})) \in f_i^u$ **do**
15:                 $f_i^d = (int)random(1, f_{max}))$
16:             go to 8
17:         $CW_i^r \longleftarrow CW_i$
18:         $CW_{max} \longleftarrow \frac{CW_{max}}{2}$
19:         **if** ($CW_{max} > 32$) **then**
20:             go to 4
21:         **else**
22:             go to 1
23: CALL *Read tags subroutine($f_i^d$)*
```

3.3 Algorithm 2 HAMAC-reading

By calling algorithm 2 subroutine, this means that the reader have successfully gained its data channel frequency. Here, it first switches on the second radio interface, initializes its transmission power value so that the maximum transmission range is $3.3 \times d_{RT}$ [2], sets the new backoff counter to 20 timeslots that corresponds to twice the advertisement message period and begins to listen on the advertisement channel frequency (lines 1-8). Two actions can occur:

- In the best case, the reader finishes its backoff counter on advertisement channel and sends its first advertisement message in order to avoid the nearest readers to try gaining the channel, schedules periodically the advertisement message transmission with $5ms$ as period and begins the tags reading process.

The tags reading process depends on its tags' neighborhood size (lines 7-9 and lines 12-14).

- Otherwise, the channel is occupied by a nearest reader in its local environment, the reader jumps to line 4 and repeats the same process until the channel becomes idle.

Algorithm 2 Read tags subroutine(f_i^d)

```
1: Switch on the advertisement radio channel interface
2: Set $f^{adv}$'s transmission power to a value so that its communication range $R_{adv} \longleftarrow 3.3 \times d_{RT}$
3: $CW_i^r \leftarrow 20$                              ▷ Set the backoff counter twice
4: tag reading period
5: Advertisement Channel Access Process
6: while $CW_i \neq 0$ do
7:     if (CS($f_i^{adv}$) == IDLE) then
8:         $CW_i \longleftarrow CW_i - 1$
9:     else
10:        go to 3          ▷ Repeat this process until the selected channel becomes free
11: Send Advertisement message up to $3.3 \times d_{RT}$
12: Scheduler a periodic Advertisement Transmission each $5ms$
13: Read tags subroutine on data channel on $f_i^d$
```

4 Performance Evaluation

In order to highlight the benefit brought by the proposed protocol, we implemented *HAMAC* and *GDRA* [5] on WSNet [1], an event-driven simulator and fairly evaluate their performance under various network scenarios. For GDRA, the protocol specification and parameter settings follow the recommendation of [5]. We consider a dense and mobile RFID system where both readers and tags are randomly deployed with uniform distribution on a 1000 × 1000 square network. We use the *random waypoint model* as mobility model, where V_{max}^{reader} and V_{max}^{tag} are respectively reader and tag's speeds. V_{max}^{reader} is twice the tag's speed, which is $10km/h$. Readers and tags's pause time are respectively set to $2s$ and $10s$, because in the most RFID system, tags mobility is very rare, while reader can be moved more frequently in order to deal with uncovered area. We assume that the time necessary for reading one tag is about $5ms$ and $460ms$ is the maximum time that reader can spend to read tags in its reading range. Each simulation run lasts for 500 seconds, and each data point is an average of 50 simulation runs. Table 2 sums up all parameters.

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[1] WSNet:http://wsnet.gforge.inria.fr/

Table 2: Simulation models parameters

HAMAC Parameters	
Parameters	Value
f_{max}	4
Advertisement packet Trans. range (R_{adv})	34 m
Timeslot size (T_{slot})	500μs

GDRA [5] Parameters	
Parameters	Value
AC Packet	2.83 ms
Beacon Packet	0.3 ms
Contention Window Size	32
Timeslot size (T_{slot})	5ms

4.1 Results

The section presents the simulation results. It first introduces the performance evaluation of HAMAC and GDRA in regardless the number of tags deployed in the network. Our aim is to show how efficient is the proposed protocol compared to GDRA according to some traditionnal performance evaluation metrics. In this scenario, 100 to 500 readers are deployed. We then present the reading performance metrics' results where 100 to 400 readers and 100 tags are deployed. The throughputs for HAMAC and GDRA [5] are depicted in Figure (2a) for different network density. We defined the throughput as the ratio of the average number of successful queries to read tags per reader over the simulation dura-

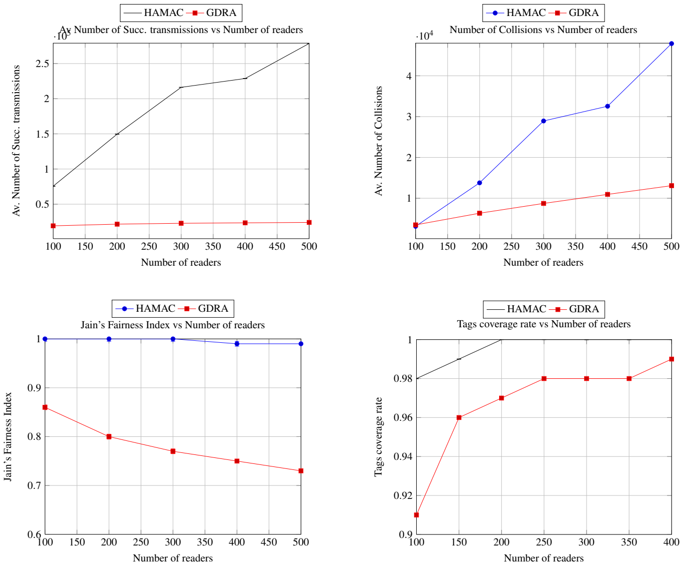

Fig. 2: Performance of HAMAC and GDRA protocols. (2a) Throughput, (2b) Number of collisions, (2c) Jain's Fairness Index and (2d) Number of covered tags vs The number of readers

tion. The higher system throughput, the more efficient protocol. As the results shown, HAMAC has a throughput that is nearly independent of the number of readers with HAMAC achieving much better performance than GDRA [5] protocol. Moreover, as the density increases, the throughput of HAMAC gradually increases, while GDRA presents a performance which slightly increases by 3%. The gap observed in this work can be mainly explained by the use of a high adaptive maximum backoff algorithm combined with the beaconing mechanism, which is used to cope with the mobility impact and interference inside tag when nearest readers operate on adjacent channel. Fig. (2b) shows the number of collisions based on the number of readers. Whatever the network density, the results show that GDRA outperforms HAMAC. However, as we have previously observed with the throughput, HAMAC has twelve times more throughput than GDRA. Thus, by basing our analysis only on this amount of successful queries to read tags sent by of HAMAC, we can intuitively conclude that HAMAC outerpforms GDRA. Fig. (2c) exhibits the Jain's fairness Index based on the number of readers in the system. This index allows to show how fair is the access to the transmission medium among readers. Because HAMAC uses an adaptive algorithm for accessing the channel, which tries to dynamically control its contention window, by *linear decreasing* on selected physical channel or *multiplicative decreasing* after scanning all available physical channels, according to the network congestion on channels, it presents a powerful results in term of fairness compared to GDRA which uses an unfair SIFT distribution as it is already shown in [10,13]. HAMAC has a gain that is 25% greater than GDRA's gain. Fig. (2d) illustrates the average number of covered tags according to the number of readers in the system. The high performances observed with HAMAC is obviously confirmed by these results. It displays growing performance that reach 100% of covered tags when the number of reader reaches 200. While GDRA presents a performance that is 98% slightly more.

5 Discussion and Conclusions

This paper presents *high adaptive MAC* (HAMAC), a distributed CSMA-based MAC protocol for mitigating reader collision problems in dense RFID systems. HAMAC is a simple and effective approach that outperforms the state-of-art proposals regarding to the main performance criterias such as the throughput, the fairness and the reading performance such as the percentage of successful reading tags. Unlike the existing approaches, HAMAC incurs no extra cost in terms of additional resources or unrealistic assumptions, and is compliant with the EPCglobal and ETSI EN 302 208 standards. Therefore, HAMAC takes advantage of the multichannel characteristics by maximizing the network throughput and mitigating a part of happened collision. HAMAC adapts the reader behavior according to the network congestion on multichannels dense RFID network. It operates by dynamically controlling the reader contention window through *linear decreasing scheme* on selected physical channel or *multiplicative decreasing* *scheme* after scanning all available physical channels. To cope with the collision problem brought by mobility during the reading process, HAMAC periodically sends an *advertisement message* over the *control channel*. Our extensive simulations on WSNet highlights significant performance gain of HAMAC over GDRA [5], which is presented as the most powerful reader-to-reader anti-collision protocol.

The next steps of this work will include its performance evaluation in real RFID testbed in order to really confirm the simulations performance in terms of the throughput, fairness, collision mitigating efficiency and reading performance.

Acknowledgments

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References

1. EPCglobal Standard specification. EPC TM radio-frequency identity protocols class-1 generation-2 UHF RFID protocol for communications at 860 Mhz - 960 Mhz version 1.2.0, 2007.
2. J. Yu and W. Lee. *GENTLE: Reducing Reader Collision in Mobile RFID Networks*, in the 4th Intern. Conf. on MSN, 2008.
3. S. Birari, S. Iyer. *PULSE: a MAC protocol for RFID networks*, in Proc. of EUC 2005 Workshops, 2005.
4. ETSI EN 302 208-1 Version 1.4.1 2011,Available online at: `www.etsi.org`.
5. M.V. Bueno-Delgado and R. Ferrero and F. Gandino and P. Pavon-Marino and M. Rebaudengo. A Geometric Distribution Reader Anti-Collision Protocol for RFID Dense Reader Environments in IEEE Trans. AUTOM SCI ENG, Vol.10:(2), pp.296-306, 2013.
6. J.-B. Eom, S.-B. Yim, T.-J. Lee. *An Efficient Reader Anticollision Algorithm in Dense RFID Networks With Mobile RFID Readers*, in Trans. Ind Electron, Vol. 56 (7): 2326–2336, 2009.
7. K. Finkenzeller. *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification.*, chapter 3, John Wiley & Sons, 2003.
8. F. Gandino, R. Ferrero, B. Montrucchio, M. Rebaudengo. *DCNS: an Adaptable High Throughput RFID Reader-to-Reader Anti-collision Protocol*, in IEEE Trans. PARALL DISTR SYST, Vol. 99:1045–9219, 2012.
9. D. Simplot-Ryl, I. Stojmenovic, A. Micic, A. Nayak. *A hybrid randomized protocol for RFID tag identification*, in Sensor Review, Vol.26(2):147–154, 2006.
10. K. Jamieson, H. Balakrishnan, and Y.C. Tay. *Sift: a MAC protocol for event-driven wireless sensor networks*, in Proc. 3rd EWSN, 2006.
11. D.-Y. Kim, H.-G. Yoon, B.-J. Jang, and J.-G. Yook. *Interference analysis of UHF RFID systems*, Progress in Electromagnetics Research B, Vol.4:115-126, 2008.
12. K. S. Leong and M. Leng Ng and P. H. Cole. *The reader collision problem in RFID systems*, in Proc. IEEE MAPE, 2005.
13. I. Amadou, A. A. Mbacké and N. Mitton. How to improve CSMA-based MAC protocol for dense RFID reader-to-reader Networks, in Proc. 13th ADHOC-NOW, 2014.