Energy Efficient Tag Identification Algorithms For RFID: Survey, Motivation And New Design

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***Abstract*—Radio-frequency identification (RFID) is widely applied in massive tag based applications, thus effective anti-collision algorithms to reduce communication overhead is of great importance to RFID in achieving energy and time efficiency. Existing medium access control (MAC) algorithms are primarily focusing on improving system throughput or reducing total identification time. However, with the advancement of embedded systems and mobile applications, the energy consumption aspect is increasingly important and should be considered in the new design. In this article, we start with a comprehensive review and analysis of the state-of-the-art anti-collision algorithms. Based on our existing works, we further discuss a novel design of anti-collision algorithm and show its effectiveness in achieving energy efficiency for the RFID system using EPCglobal C1 Gen2 UHF standard.**

***Index Terms*—RFID, anti-collision, sub-frame, energy efficiency.**

I. INTRODUCTION

The Internet of Things (IoT) is an emerging application of Internet and traditional telecommunication networks, which allows embedded objects to implement interconnection and interoperability. Radio frequency identification (RFID), which is a key technology to enable Internet of Things (IoT), can identify objects automatically by employing wireless communication. Typically, an RFID system includes tags, a reader and back-end systems. A tag is made up of antenna, coupling component, and microchip. Enclosed in an adhesive sticker, every tag is attached to an item with a unique identifier (UID). The reader initializes an identification process by broadcasting a query command. After receiving the query command, the tags in the vicinity respond to the reader with their IDs. Accordingly, RFID can identify multiple items without line of sight and easily map the physical world to the cyber world. According to power supply mode, RFID tag can be categorized into passive and active tag. Passive tag with small size and low cost has no onboard power supply, its operation energy is from the continuous wave transmitted by the reader. Thus the transmission distance is quite limited. As a contrary, active tag is with an internal battery to provide energy for the microchip and ensure communication between tag and reader. The potential transmission range can thus reach several hundred meters. However, the production cost is high, and the service lifetime is short given the battery needs to be periodically replaced.

RFID drives lots of IoT applications. For example, by accurately tracking a good expiry date or item leakage, RFID can help reduce waste and energy consumption in operations ranging from monitoring to packaging and refrigeration, which in turns enables more extensive deployment of RFID systems [1]. With a future trend to integrate RFID into IoT system, the format of reader may not necessarily be a fixed device. A mobile reader or even battery powered wireless sensor nodes can be enabled as reader devices. Thus energy efficiency is an important metric to evaluate the overall performance of RFID system [2-4]. Energy efficient RFID protocol can prolong the operating lifetimes of reader and tags (if they are active) and promote the growth of green RFID and its various applications that have been envisaged. In order to achieve that, the reader needs to adopt an energy-efficient anti-collision algorithm to optimize tag cardinality (the number of unread tags) estimation, adaptively modulate transmission power level, and reduce tag collision and eavesdropping, etc [4]. In this article, we survey the state-of-the-art anti-collision algorithms and demonstrate our effort in developing an energy efficient RFID anti-collision algorithm.

Existing RFID anti-collision solutions can be mainly divided into aloha-based [5-6] and tree-based. Tree-based [7] algorithm is especially operated by recursively dividing the contending tags into smaller groups until each group contains up to one tag. Aloha-based algorithm employs a frame structure which contains a certain number of time intervals (called time slots) per frame, and tags randomly pick up a time slot to respond to the reader using their IDs. These previous works pay more attentions to improving system throughout or reducing identification time rather than energy consumption. For a static or fixed reader with power supply, identification time is more important when a number of tagged items need to be identified in a continuous scanning manner. However, in many scenarios like inventory control where a portable or mobile reader with limited power is widely used, the energy consumption is critical especially when periodically scanning is needed. A lower energy consumption can maintain a longer service time and avoid the frequent recharging or replacement.

In the following sections, we start with a review of various types of anti-collision mechanism. Furthermore, in order to achieve energy efficient and reduce the computational com-

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plexity, we present an anti-collision solution called Energy-Aware Frame Adjustment Strategy (EAFAS) based algorithm. The proposed algorithm integrates the low-cost estimation method, adaptive frame size calculation strategy and efficient frame size adjustment policy. To be specific, the presented algorithm ascertains the optimal frame size based on both estimated tag cardinality and energy efficiency of RFID system. Moreover, the proposed in-frame mechanism can also end the improper frame in advance. The remainder of the article is organized as follows. Section II reviews and analyzes the mainstream anti-collision strategies for RFID system. Sections III discusses the existing energy-efficient RFID algorithms. A newly energy-efficient anti-collision algorithm is described in Section IV. Section V illustrates the performance results. Finally, Section VI concludes this article.

II. SUMMARY OF ANTI-COLLISION ALGORITHMS IN RFID

With consideration of cost and implementation complexity, the time-division multiple access (TDMA) solutions have been mainly used in RFID systems. That is, each tag occupies the channel in a separated time interval and communicates to the reader. The TDMA based solutions can be divided into Aloha-based and tree-based algorithms which can be further divided into binary splitting and query tree. A comparison of various solutions is shown in Table I.

A. Aloha-based Algorithms

Aloha-based algorithms can be divided into three types, namely Pure Aloha (PA), Slotted Aloha (SA) and Framed Slotted Aloha (FSA). Among them, Dynamic FSA (DFSA) has been widely used in UHF RFID. DFSA algorithm is characterized by the strategy to adapt the frame size along identification process [6]. The principle of the DFSA algorithm is to divide time into several frame segments, each of which consists of a number of time slots. A tag responds to the reader with its ID when it receives a query command specifying the parameter F (F corresponds to the number of slots per frame). There are three possible states in a time slot: single response (singleton slot), no response (empty slot), and multiple responses (collision slot). After reading a frame, the reader needs to make full use of probabilistic or statistical methods to estimate the cardinality. Therefore, the Aloha-based algorithms can be also named as probabilistic algorithms.

The performance of DFSA depends on both the cardinality (the number of remaining tags) estimation and the setting of frame size. For a particular frame, the system throughput is calculated as the number of identified tags over the frame size. Specifically, the maximum system throughput 0.368 is attained asymptotically when the frame size is equal to the number of tags to be identified [5]. In order to improve the performance of DFSA, most previous solutions [5-6] require vast computational costs so that the accuracy of estimation can be ensured. However, most handheld RFID readers in practice are computation constrained due to their low-cost hardware structure such as single-core microprocessor. Consequently, anti-collision algorithms with complex estimation are inefficient in terms of time or energy efficiency. Recently, a number of energy-efficient DFSA algorithms have been proposed for the purpose of reducing computational overhead. The literature [9] presented an anti-collision protocol which depends on one examination of frame size at a specific time slot during each identification round. The authors in [10] introduced an Improved Linearized Combinatorial Model (ILCM) to estimate the cardinality with modest calculation cost. However, its performance fluctuates sharply with the number of tags. In [11], the authors presented a FuzzyQ method which integrates fuzzy logic with a DFSA algorithm. A fuzzy rule based system is defined to model the frame size and the collision rate with fuzzy sets to adaptively calculate frame size. However, the performance of FuzzyQ needs to be further improved.

The overall feature of the Aloha-based algorithms is easy to implement. The reader can statistically analyze the distribution of tags within the frame thereby estimating the number of unread tags. The disadvantages are tag starvation problem and high complexity in tag cardinality estimation. The tag cardinality estimation methods with high complexity cause higher energy consumption at the reader side.

B. Query tree algorithms

In query tree (QT) algorithms, every tag is assigned with a unique ID. The QT algorithm is working as a virtual traversal tree. The depth is defined as the number of branches from the root node to the leaf node. Each branch is marked with the method of "left 0 right 1". The reader first sends a probe command with a prefix 0, tags with prefix ID 0 will transmit their IDs to the reader. When a collision occurs, the reader iteratively divides the collided tags into two subsets according the position of collided bits of tags. The subsets become smaller until each subset contains only one tag. Such algorithms require a stack inside the reader to store the query prefix information. The reader constantly updates the query prefix based on the collision bits and pushes the query prefix onto the stack until the stack is empty. The current research on the QT algorithm focuses on how to use the collision information to update the query prefix. The literature [7] presented a collision tree (CT) algorithm which generates prefix and splits collided tags according to the first collided bit. M-ary Query Tree (MQT) has been proposed in [13], by forming a M-ary traversal tree instead of a binary traversal tree for collided tags. Although the number of probed slots is reduced, the communication overhead is increased by containing both mapped M-bits string and ID sequence.

Compared to Aloha-based algorithms, QT algorithms use the tag ID to separate the collided tags. Hence, they are deterministic in nature and not suffered from tag starvation problem. However, QT algorithms require a large number of reader query and tag response, and rely on collided responses to determine subsequent queries, which causes a higher energy consumption at both the reader and tags (if the active tags are used). Besides, QT algorithms require strict synchronization of the date responded by multiple tags. Therefore, its application is limited and it is difficult to apply to UHF RFID system.

TABLE I
THE CHARACTERISTICS OF VARIOUS ANTI-COLLISION ALGORITHMS

Categories	Methods	No Tag starvation	Good stability	High throughput	Low complexity	Energy efficient	Compatible to UHF standard
DFSA	MAP [5]			√			√
	ILCM [10]				√		√
	EACAEA [9]				√		√
	FuzzyQ [11]		√			√	√
	SUBF-DFSA [12]		√		√	√	√
	ds-DFSA [14]		√	√	√	√	
	EAFSA		√	√	√	√	√
QT	CT [7]	√	√	√	√		
	MQT [13]	√	√	√			
BS	BS [15]	√	√		√		√
	ISE-BS [15]	√	√	√		√	

C. *Binary splitting algorithms*

Binary splitting (BS) algorithms were originally developed for random access networks. The BS algorithm continuously divides a collided tag set into smaller subsets by using random binary number. Essentially, BS algorithm also belongs to a probabilistic algorithm because it has a strong randomness. It has been widely used in ISO/IEC 18000-6B standard. Different to the Aloha-based algorithm, contending tags in the BS will be repeatedly divided into groups until each group owns only one tag. Compared to Aloha-based algorithms, BS algorithms are insensitive to tag cardinality because when the tag number is increased, the system throughput is almost converged to a constant value. Although the BS approach can tackle tag starvation, it has relatively long identification latency due to the splitting procedure starting from a single set with all tags. Moreover, such algorithm always uses tag ID to perform collision arbitration, and hence reduces the time efficiency.

III. EXISTING ENERGY-EFFICIENT ANTI-COLLISION ALGORITHMS

A. *DFSA algorithms with low cost estimation and sub-frame observation*

In most RFID application scenarios, the reader needs to estimate the cardinality accurately to maximize the system throughput. Previous works focus on how to improve the estimation accuracy at the end of the frame, then update the frame size accordingly [5-6, 10]. If the foregoing frame size is improper, the accumulated estimation error will degrade the whole performance. Moreover, the estimation with high complexity will consume more energy. In [12], we proposed a sub-frame based algorithm (SUBF-DFSA) to overcome the accumulated estimation error. Specifically, the tag cardinality is estimated based on linear relation between empty and collision slot statistically counted in a sub-frame. Since the computational complexity of the estimation is reduced, the energy efficiency of SUBF-DFSA can be improved compared to the estimation methods with high complexity. However, since the usage of empirical correlation is not based on theoretical calculation, the accuracy of estimation is not sufficient. In [14], we further proposed a two-phase anti-collision algorithm named detected sector based DFSA (ds-DFSA) to enhance the identification performance. The ds-DFSA algorithm effectively uses empty, singleton and collision statistics in an early observation phase to recursively determine an optimal frame size. After that, the simple calculation is used to estimate the number of concurrent tags contained in each collision slot n_{ave}. Then, the frame size for each collision slot is obtained as the closest power-of-two value to n_{ave}. Benefiting from such dived-and-conquer frame size assignment and low-cost estimation strategy, both time and energy efficiency have been improved. Moreover, due to the requirement of new command, modification to the existing UHF RFID standard is needed for the proposed algorithm, thus making it difficult to be implemented in off-the-shelf RFID system.

B. *BS algorithm with idle slots elimination*

In BS-based algorithms, a single set is usually formed in concurrent tags. If a collision is detected, the reader will repeatedly divide the collided tag set into multiple subsets and resolve them one by one. Although BS-based solutions is robust to tag starvation, its latency is high due to the large number of concurrent tags involved in each collision response. Moreover, the tag ID is used for collision arbitration in BS-based solutions, which increases the total collision arbitration time and wastes the energy consumption. In [15], by eliminating the empty slots, we presented a binary splitting protocol (ISE-BS) to enhance the performance of RFID system. ISE-BS algorithm is a variant of binary splitting by means of introducing 1-bit Q signal to pre-split contending tags set. Since the empty slots in the splitting process and the time duration used for collision arbitration are eliminated, the performance of ISE-BS can be improved on the basis of time and energy efficiency.

Although the above discussed algorithms can improve the energy efficiency to some extent, they are unable to optimize the frame size setting according to the energy consumption. In the following, an improved anti-collision algorithm is proposed to overcome these drawbacks. The proposed algorithm aims at achieving both robust estimation with low-cost and energy efficient frame size setting.

IV. A NEW DESIGN OF ENERGY EFFICIENT IDENTIFICATION STRATEGY

A. *Tag Cardinality Estimation*

In order to guarantee the estimation accuracy, here we also refer to the maximum a posteriori probability (MAP)

[5] method to calculate the tag cardinality based on feedback from a sub-frame. Although MAP can achieve an accurate estimation, its high computational overhead hinders its application in low-cost RFID platforms such as a handheld reader. In the proposed estimation method, we design look-up tables (LUT) to pre-store intermediate variable of estimation results. Restricted by the sub-frame size and the item quantity in the tables, the proposed estimation strategy is space-efficient and implementable. Considering n tags allocated in F slots, the probability that empty slot occurs e times, singleton slot occurs s times, and collision slot occurs c times in a sub-frame F_{sub} can be expressed as $P\left(n|e,\ s,\ c\right)$ by using multinomial distribution, that is

$$P\left(n\left|e,\ s,\ c\right.\right)=\frac{F_{sub}!}{e!s!c!}P_{i}^{e}P_{s}^{s}P_{c}^{c} \tag{1}$$

The tag cardinality involved in a sub-frame is determined when the value of $P\left(n|e,\ s,\ c\right)$ is maximized. So, the estimation result in a sub-frame is $\hat{n}_{sub}$. Then the estimated cardinality involved in the full frame is calculated as

$$\hat{n}_{est}=\hat{n}_{sub}\cdot\left(F/F_{sub}\right) \tag{2}$$

The recommendation setting of F_{sub} can be referred to [14].

B. Adaptive Frame Size Calculation

Traditionally, most existing DFSA algorithms set the frame size as the proximal value of the estimated tag cardinality with the aim of maximizing the system throughput [8-9, 12-14]. However, such frame size setting strategy is only applied when equal time duration for each slot type is assumed. The EPCglobal C1 Gen2 UHF RFID standard specifies different duration for empty, singleton, and collision slots, defined as T_e, T_s, and T_c, respectively. Therefore, the traditional system throughput is a not appropriate metric to evaluate the performance of RFID anti-collision algorithm. Moreover, such metric does not consider the energy consumption. Unlike the previous DFSA algorithms, the proposed algorithm calculates the frame size by maximizing the energy efficiency, which can be defined as

$$\eta_{effi}=\frac{S\cdot\left[\left(P_{Rt}+P_{Rr}\right)\cdot T_{EPC}\right]}{T_{total}\cdot P_{Rt}+T_{received}\cdot P_{Rr}+E_{est}} \tag{3}$$

herein S and C denote the number of singleton slots and collision slots, respectively. T_S, T_{RN16}, and T_{EPC} denote the time duration of a singleton slot, a 16-bits random number and a EPC (UID). T_{total} denotes the required time for a whole identification process. $T_{received}$ denotes the receiving time duration of the reader for identifying all tags. P_{Rt} and P_{Rr} represent the transmitting and receiving power of the reader when it communicates with tags, respectively. E_{est} is the energy consumption during the tag cardinality estimation process. If the frame size F is assumed large enough, the probability distribution of r tags allocated in a slot can be approximated as Poisson distribution with mean $\lambda = n/F$. Then S, C, $T_{received}$ and T_{total} can be approximated as the functions of the tag number n and frame size F. By maximizing the Eq. (1), the value of λ corresponding to the different time parameters can be derived. The optimal frame size can be determined by the estimated tag cardinality n_{est} and λ.

C. Frame Size Adjustment Strategy

The general frame size adjustment strategy can be divided into three categories. First is Frame-by-Frame (FbF) [5, 10] in which the reader calculates a new frame size in the last slot of the current frame. The FbF strategy is not efficient when the frame size (the number of slots within the frame) is far away from the number of tags. Second is Slot-by-Slot (SbS) in which the reader calculates the new frame size at every slot in the current frame. The SbS strategy is suffered from a rather high complexity. Finally, the sub-frame solution provides the flexibility of ending the current frame in advance to maintain the performance stability with a reduced computational complexity. Third is Point-by-Point (PbP) in which the reader chooses some particular slots within the frame, referred as the point in the presented works [9, 12, 14]. The reader updates the frame size at the point which is usually set as a fraction of the current frame. In our proposed algorithm, we adopt a hybrid strategy combining sub-frame observation and SbS. At every slot, the reader keeps track of the relation between E and C. And then the reader will reset the sub-frame size if the difference value between E and C is above the threshold value. After the reading of F_{sub} slots, the reader estimates the tag cardinality and updates the new frame size for the next identification round. Then the reader computes the energy efficiency η_{effi1} and η_{effi2} with the current frame size and the new frame size, respectively. The reader ends the current frame and enables the new frame only if $\eta_{effi1} < \eta_{effi2}$. Otherwise, the reader will continue reading the next slot in the current frame. The identification process ends until no collision occurs. According to the hybrid frame size adjustment strategy, the algorithm can achieve a better and stable performance.

By combining tag cardinality estimation, adaptive frame size calculation, the Energy-Aware Frame Adjustment Strategy (EAFAS) based algorithm is proposed. The flowchart of the EAFAS is described in Figure 2.

V. EVALUATION DISCUSSION

This section evaluates the performance of EAFAS algorithm in metrics, system throughput and energy efficiency, and compares it with state-of-the-art methods including MAP [5], ILCM [10], EACAEA [9], FuzzyQ [11], and SUBF-DFSA [12]. Simulation scenarios with a reader and a various number of tags have been evaluated using MATLAB, where the tags are uniformly distributed in the reader vicinity so that all tags can receive the reader's command. In our simulations, the tag number is chosen between 100 and 1000. This article mainly focuses on the MAC layer, whereas the physical layer effects are not considered [9-12, 14-15]. To reduce the randomness and ensure the convergence, the simulation results are averaged over 1000 iterations. The parameters used in MATLAB simulation are listed in Table II, which are aligned with the EPCglobal C1 Gen2 UHF RFID and commercial Impinj solution specifications.

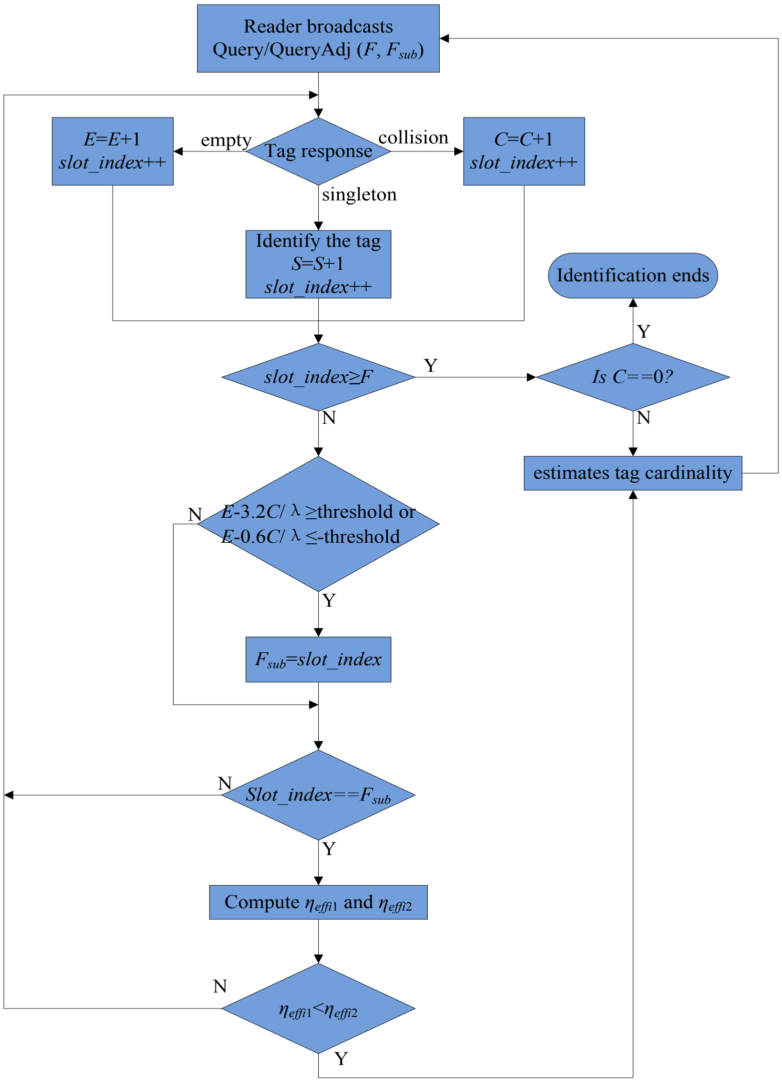
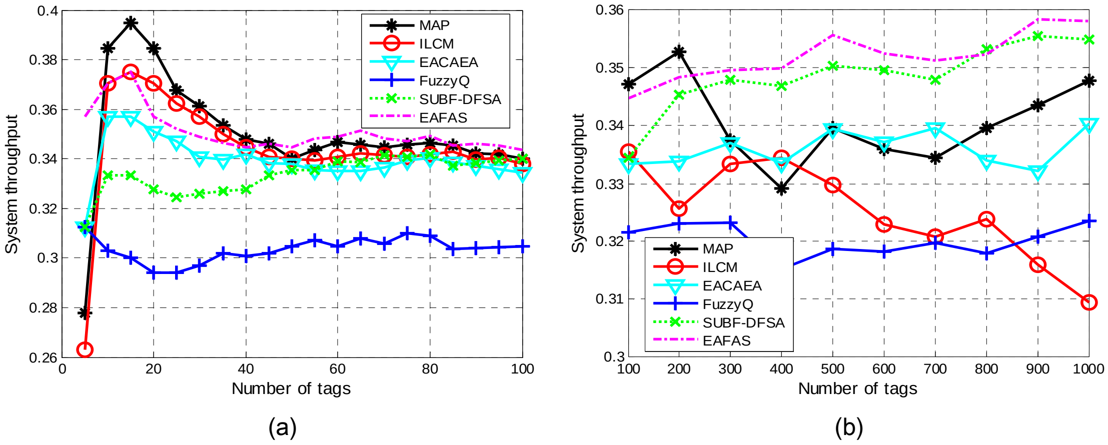
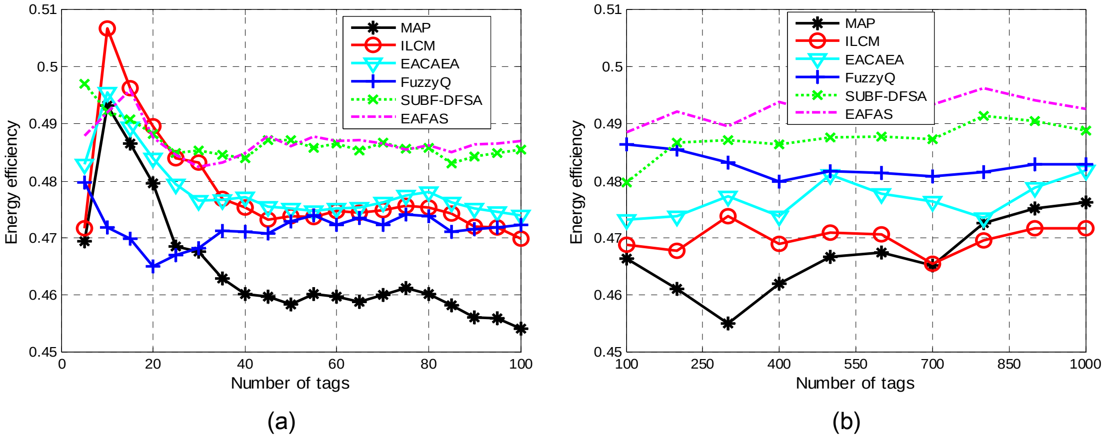


Fig. 1. The flowchart of the proposed algorithm



(a) (b)

Fig. 2. Comparison of system throughput under various algorithms



(a) (b)

Fig. 3. Comparison of energy efficiency under various algorithms

TABLE II
THE PARAMETERS USED IN MATLAB SIMULATION

Parameters	Value	Parameters	Value
R->T modulation	DSB-ASK	T->R modulation	FM0
R->T preamble (μs)	312.5	T->R preamble (μs)	150
R->T frame-syns (μs)	237.5	BLF (kHz)	40
Tari (μs)	25	Data-rate (kbps)	40
DR	8	M	1
Iteration times	1000	T1 (μs)	250
TRcal (μs)	200	T2 (μs)	100
RTcal (μs)	75	T3 (μs)	50
RN16 (μs)	550	EPC (μs)	3350

Figure 2 (a) compares system throughput of various algorithms. The number of tags varies between 5 and 100. The frame size is initialized as 16. As can be observed from Figure 2 (a), the proposed EAFAS achieves more stable performance, especial when the number of tags increases. Such an improvement is due to the reasons that the proposed estimation strategy can obtain the accurate result and the proposed frame setting mechanism can ease estimation error, which in turns reduce the total number of slots. The performance of MAP and ILCM are very closed because their frame size adjustment is based on the same estimation derived from a full frame. As a contrary, the EACAEA, FuzzyQ and SUBF-DFSA adopt PbP strategy to adjust the frame size. Thus, they can provide more stable performance than previous two algorithms. Figure 2 (b) plots the system throughput when the tag number ranges between 100 and 1000. The frame size is also initialized as 16. By comparing both Figure 2 (a) and (b), most of algorithms show discrepant performance. For example, the average system throughput of SUBF-DFSA is lower than MAP, ILCM and EACAEA when the number of tags is between 5 and 100. As the number of tags increases, the impact of the initial frame on system throughput will be weakened. The SUBF-DFSA algorithm is capable of interrupting inappropriate frame through PbP observation for achieving a considerable performance improvement. Since the frame size can be adaptively adjusted to different tag cardinality, the EAFAS can always hold the best system throughput compared to other algorithms.

To further compare the performance of the EAFAS to other methods, a 95% confidence interval of system throughput for various algorithms is summarized in the Table III. As can be observed, the lower bound of the EAFAS is even higher than the upper bound of MAP, ILCM, EACAEA, and FuzzyQ at any number of simulation runs. Therefore, we believe our proposed method shows robust performance under different simulation runs.

For the purpose of evaluating the energy consumption of anti-collision algorithms, Figure 3 shows the energy efficiency of various algorithms. We can observe from Figure 3 (a), the curves of all algorithms fluctuate when the number of tags is small. As the number of tags is above 50, their performance become more stable, this is especially true when the number is above 100 in Figure 3(b). When the number of tags is closed to the initial frame size, all algorithms can achieve the highest performance. However, with a continue increase of tag numbers, all algorithms show deteriorate performance because of the extra slots used to estimate the unread tags. It is also noted that the energy efficiency depends on both identification time and estimation complexity, the proposed EAFAS is the only algorithm can maintain good performance in both throughput and energy efficiency. Moreover, since our presented solution is based on the EPCglobal C1 Gen2 standard, it is compatible with most of hardware platforms thus saving cost.

VI. CONCLUSION

This tutorial has discussed energy efficient RFID anti-collision algorithms regarding design concept and analysis, especially on the performance of MAC layer. We have mainly analyzed and compared the performance of system throughput and energy consumption of various anti-collision algorithms. In our view, our proposed EAFAS solution makes RFID capable of adapting to energy-aware scenarios and meeting future green IoT application requirements of energy efficiency and high system throughput. The acquired new insights on the MAC performance could also provide a precise guideline for the efficient designs of practical and reliable RFID communications systems. Hence these results will potentially have a broad impact across a range of areas, including supply chain management, inventory control, and asset tracking.

TABLE III
THE 95% CONFIDENCE INTERVAL OF SYSTEM THROUGHPUT FOR VARIOUS ALGORITHMS

Algorithms ST	MAP	ILCM	EACAEA	FuzzyQ	SUBF-DFSA	EAFAS
100	0.336 ∼ 0.345	0.314 ∼ 0.330	0.335 ∼ 0.339	0.309 ∼ 0.315	0.344 ∼ 0.352	0.350 ∼ 0.356
200	0.335 ∼ 0.342	0.319 ∼ 0.333	0.334 ∼ 0.339	0.309 ∼ 0.317	0.345 ∼ 0.352	0.349 ∼ 0.355
300	0.336 ∼ 0.344	0.319 ∼ 0.332	0.334 ∼ 0.339	0.309 ∼ 0.317	0.344 ∼ 0.351	0.349 ∼ 0.355
400	0.336 ∼ 0.344	0.319 ∼ 0.332	0.334 ∼ 0.339	0.309 ∼ 0.315	0.344 ∼ 0.351	0.350 ∼ 0.356
500	0.336 ∼ 0.344	0.319 ∼ 0.332	0.334 ∼ 0.338	0.309 ∼ 0.315	0.345 ∼ 0.351	0.349 ∼ 0.355
600	0.336 ∼ 0.344	0.319 ∼ 0.331	0.335 ∼ 0.339	0.308 ∼ 0.317	0.345 ∼ 0.351	0.350 ∼ 0.355
700	0.336 ∼ 0.343	0.319 ∼ 0.331	0.335 ∼ 0.339	0.310 ∼ 0.317	0.345 ∼ 0.351	0.350 ∼ 0.355
800	0.336 ∼ 0.344	0.319 ∼ 0.332	0.334 ∼ 0.338	0.310 ∼ 0.317	0.345 ∼ 0.351	0.349 ∼ 0.355
900	0.336 ∼ 0.344	0.319 ∼ 0.332	0.335 ∼ 0.338	0.309 ∼ 0.316	0.344 ∼ 0.351	0.349 ∼ 0.355
1000	0.336 ∼ 0.344	0.319 ∼ 0.332	0.335 ∼ 0.339	0.308 ∼ 0.316	0.345 ∼ 0.351	0.349 ∼ 0.355

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