Grouping based radio frequency identification anti-collision protocols for dense internet of things application

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ABSTRACT

Radio frequency identification (RFID) is an important internet of things (IoT) enabling technology. In RFIDs collision occur among tags because tags share communication channel. This is called tag collision problem. The problem becomes catastrophic when dense population of tags are deployed like in IoT. Hence, the need to enhance existing dynamic frame slotted ALOHA (DFSA) based electronic product code (EPC) C1G2 media access control (MAC) protocol. Firstly, this paper validates through simulation the DFSA theory that efficiency of the RFID system is maximum when the number tags is approximately equal to the frame size. Furthermore, literature review shows tag grouping is becoming popular to improving the efficiency of the RFID system. This paper analyzes selected grouping-based algorithms. Their underlining principles are discussed including their tag estimation methods. The algorithms were implemented in MATLAB while extensive Monte Carlo simulation was performed to evaluate their strengths and weaknesses. Results show that with higher tag density, fuzzy C-means based algorithm (FCMBG) outperformed traditional DFSA by over 40% in terms of throughput rate. The results also demonstrate FCMBG bettered other grouping-based algorithms (GB-DFSA and GBSA) whose tag estimation method are based on collision slots in terms slot efficiency by over 10% and also in terms of identification time.

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1. INTRODUCTION

Internet of things (IoT) has been defined in different ways by different stakeholders. Obviously, IoT is different things to different people. Whereas some professionals tend to define IoT based on how they will contribute to it, users on the other hand define IoT based on how they may benefit from it. But one consensus definition of IoT is that it is that evolutionary trend of the internet where objects and just anything can exchange data about itself and its surroundings. Evans [1] of Cisco Internet Business Security Group opined that IoT is a state of Internet when objects gets connected and exchange information more that humans. He argued that since the population of things already connected to the internet has surpassed human population in 2008, we are already experiencing IoT. He made a prediction that in 2020 as the population of the world is expected to increase to 7.6 billion, objects connected to the internet are expected to skyrocket to about 50 billion.

Radio frequency identification (RFID) is seen as an inevitable enabling technology for the attainment of IoT's vision of automatic identification and data communication of just everything [2]. RFID is used for diverse applications like in health monitoring [3], shopping mall [4] and in the passports of USA, UK and Malaysia. RFID has numerous advantages over other identification procedures like barcodes, biometrics, and magnetic stripes. in that it can identify things wirelessly, simultaneously and within a long range.

There are three types of RFID based on energy source of their tags namely: active RFID, semi-passive RFID and passive RFID. Whereas both active RFID and semi-passive RFID have batteries installed on each tag, only the active RFID tag can generate its own wave. As shown in Table 1, semi-passive RFID though equipped with batteries, still rely on the backscattering of wave from reader query just like the passive RFIDs. In Table 1, we show the characteristics of these three types of RFID. Passive ultra-high frequency (UHF) RFID is the RFID for IoT as they are cheap and require no batteries [5]. Hence, they can easily be deployed on a very large scale for object identification and sensing. Passive RFIDs are often used interchangeably as RFID itself. Therefore, in this paper we shall be referring passive RFID as RFID.

Table 1. Categorization of RFID based on energy source of their tags

RFID Type	Passive RFID	Semi-passive RFID	Active RFID
Battery presence	NO	YES	YES
Communication principle	Backscattering	Backscattering	Generates own wave
Communication range	10 cm to 7 m	Less than 80 m	Over 100 m
Cost ($) [5]	Less than 0.5	1 to 2	Over 10
Operating frequency	LF (125KHz), HF (13.56 MHz), UHF, Microwave	UHF (860-960 MHz)	UHF, Microwave (2.45 GHz)
Application areas	Access control, security, manufacturing process, animal identification, smart cards, supply chain	Library books tracking, animal monitoring and identification, vehicle immobilizers.	Aerospace, Railroad car tracking, container tracking

RFID suffers three types of collision namely: reader-to-reader collision, reader-to-tag collision, and lastly tag-to-tag type of collision. Tag-to-tag collision is referred to as tag collision problem (TCP) of RFID networks [6]. As depicted in Figure 1, TCP is a situation where tags' signal (T1, T2) collides as they try to respond to reader through backscattering. This is possible because tags use same communication channel to reply to reader queries.
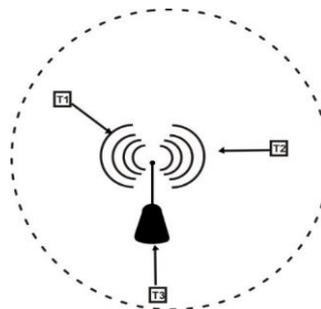

Figure 1. Tag-to-tag collision

In 2005, electronic product code (EPC global) standardized EPC class 1 generation 2 (EPC C1G2) [7], [8] as a DFSA-based media access control (MAC) protocol that addresses TCP for passive ultrahigh frequency (UHF) RFID and for a few tag network. However, as the number of tags increases, the efficiency of EPC C1G2 deteriorates drastically [9]–[11]. Hence, the need to enhance DFSA for high tag density applications like IoT. The focus of paper is on enhancing EPC C1G2 to support IoT application.

There have been several efforts to addressing TCP. In literature, approaches by different researchers is categorized into two namely: ALOHA-based approach and tree-based approach [12]–[15]. Tree-based protocols also referred to as deterministic based approach are divided into two, namely: Binary tree protocols (binary splitting) and query tree protocols (QT). Binary tree protocols use random binary number to resolve collision among tags while in QT protocols, the reader uses prefixes in tag IDs to resolve collision. The merit of tree-based protocols is the fact that there is no tag starvation as all tags will eventually be identified albeit, they are computationally complex as they consume more bits and time for tag identification [16]. On the

other hand dynamic frame slotted ALOHA (DFSA-based) (ALOHA-based) protocols are easy to implement [6], ensures fairness in the random access of the shared channel and are promising for high density application of RFID if enhanced and made robust to quickly mitigate collision when they occur.

DFSA is the De Facto algorithm adopted by EPC C1G2 protocol. however, the traditional DFSA still has the challenge of poor tag number estimation and bogus frame size adjustment algorithm which causes either too many idle or collision slots and consequently, affects channel utilization and efficiency of the RFID system. IoT deployment of RFID demands accurate unidentified tag number estimation that would effectively support dense deployment of tags. In the current tag number estimation algorithm, the RFID reader does not have prior knowledge of tag number before the actual process of identification and relies on querying the tags within its read range and estimating tag number using the number of collision slots from the query result. The current estimation algorithm is based on an assumption that a collision means two tags have collided [14]. The equation (1) is the lower bound of collision slot-based tag number estimation which assumes that every collision slot means two tags have collided.

Over the years, researchers have tried to improve on this by proposing probability models that tries to determine the actual value of the collision. However, the works of [17], [18] show that collision slots could occur in an RFID system due to an error prone channel or interference from other signals. Therefore, determining the value of collision slots alone is not enough to guarantee the accuracy of the tag estimation algorithm and protocols developed for IoT with such assumption for collision slots could cause a total system breakdown.

$$\hat{n} = S_s + 2S_c \tag{1}$$

Where $\hat{n}$ is the tag number estimate per query cycle, S_s is the number of tags in the success slot per query cycle and S_c is the number of tags in the collision slot per query cycle.

Furthermore, in DFSA a frame is a collection of time slots, and each RFID tag can only be identified by the reader using a time slot. In frame slotted ALOHA (FSA) and DFSA, the reader queries the tags using frame per cycle unlike in slotted ALOHA (SA). In DFSA each query cycle tries to automatically decrease or increase the number of time slot in a frame (frame size). Hence, the dynamism in DFSA. It follows that efficiency of the RFID systems is a function of how close the frame size is to the estimated number of unidentified tags. Traditionally, slot efficiency SE expressed in (2) is the most popular metric in evaluating the performance of an RFID anti-collision protocol [9]. Hence, a good protocol is one that ensures the efficient utilization of time slots (communication channel).

$$S_E = \frac{S_s + S_c}{S_s + S_i + S_c} \tag{2}$$

Where S_s is number of successful slots, S_i is number of ideal slots, and S_c is number of collision slots.

On the other hand, Tag grouping is becoming a popular technique in RFID anti-collision research [9]. The advantage of grouping can be summarized in that the number of tags is small (per group), and the frame size is equal to the number of tags. This is to say that whereas DFSA gives fair share to all tags in accessing the shared channel while responding to reader queries, grouping based schemes would only present a fewer number of tags (a group or cluster) to the channel at a time even when the RFID tags are so densely populated (IoT scenario).

2. GROUPING METHODS FOR RFID ANTI-COLLISION PROTOCOL

The underlining principle behind grouping is the fact that existing protocol EPC C1G2 can effectively address collision in a few tags' density. Theoretically and in practice, this principle ensures that unlike FSA, DFSA can surpass the optimal throughput of about 36.8% [19]. In this section, we first present an analysis of DFSA for RFID then we discussed each of the selected grouping-based algorithms.

2.1. Analysis of DFSA for RFID

Dynamic frame slotted ALOHA (DFSA) algorithm is a more complex algorithm that equips RFID readers with the ability to dynamically adjust their frame sizes based on the intelligence or knowledge they gather from the RFID system. DFSA addresses the limitation of FSA in terms of readers' fixed (static) frame sizes that either results to high collision rate or wastage of the communication channel depending on the tag density of the RFID environment [20]. Figure 2 describes how DFSA works. From the diagram there are four RFID tags that are to be identified by the reader. During the first read cycle (using frame 1), the reader queries tags and tag 1 and tag 4 randomly chose slot 2 and slot 4 respectively and got successfully read by the

reader while tag 2 and tag 3 randomly chose slot 3 at the same time causing a collision. Apart from the collision, slot 1 and slot 5 were idle causing wastage of bandwidth. However, during read cycle 2 the reader automatically reduced the frame size from 5 to 3 (frame 2) because there are only two remaining tags to be read. However, there were still collision and idle slots. Note that slots 2 and 4 are referred to as success slots S, slot 3 is referred to as collision slot C, while slots 1 and 5 are referred to as idle slots I.

The basic factor in DFSA is the ability of the reader to accurately estimate the number of unidentified tags after each query cycle and have a precise frame size adjustment algorithm [21]. Existing works in literature use collision slots as the basis for tag number estimation. The current RFID MAC protocol: EPC class 1 generation 2 (EPC C1G2) is DFSA based. However, its efficiency is not guaranteed with high tag density application like IoT. This paper evaluates grouping-based RFID algorithms and compares them to traditional DFSA. Therefore, before discussing the selected grouping algorithms, we present an analysis of DFSA algorithm for RFID. As stated earlier the only factor that determines what the frame size should be per query cycle is the estimated number of unidentified tags.

	Reset	Request	Slot 1	Slot 2	Slot 3	Slot 4	Slot 5	Request	Slot 1	Slot 2	Slot 3
Reader off											
Reader On			I	S	C	S	I		I	C	I
Tag 1 UID: 1001				1001							
Tag 2 UID: 1100					1100					1100	
Tag 3 UID: 1010					1010					1010	
Tag 4 UID: 1011						1011					

Frame 1   **Frame 2**

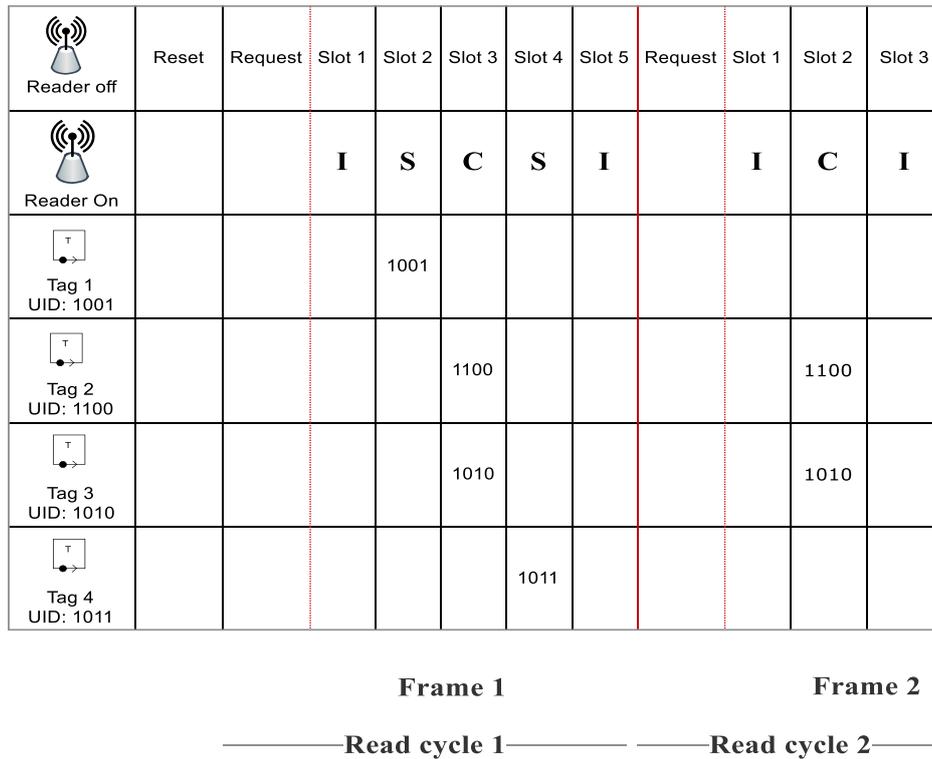————————Read cycle 1———————— ————Read cycle 2————

Figure 2. DFSA anti-collision algorithm for RFID

In analyzing what the estimated tag number should be in relation to the frame size we assume that the probabilities that tags choose slots are equal (fair access to the shared channel). Therefore, where n is the estimated number of tags and L is the frame size and using the binomial distribution, the probability that there are r tags in a slot is given by:

$$a_r = \binom{n}{r}\left(\frac{1}{L}\right)^r \left(1 - \frac{1}{L}\right)^{n-r} \tag{3}$$

Hence, the probability that there is only one tag in a slot is given by:

$$a_1 = n\left(\frac{1}{L}\right)^r \left(1 - \frac{1}{L}\right)^{n-1} \tag{4}$$

While the probability that there is no tag in a slot is given by:

$$a_0 = \left(1 - \frac{1}{L}\right)^n \tag{5}$$

Consequently, given the frame size L, in a query cycle the number of success slot are:

$$S_s = L * a_1 = n\left(1-\frac{1}{L}\right)^{n-1} \tag{6}$$

While the number of idle slots is:

$$S_i = L * a_0 = L\left(1-\frac{1}{L}\right)^{n} \tag{7}$$

Therefore, the number of collision slots is:

$$S_c = L - S_s - S_i = L - n\left(1-\frac{1}{L}\right)^{n-1} - L\left(1-\frac{1}{L}\right)^{n} \tag{8}$$

Efficiency of the RFID system can be calculated as (9):

$$\eta = \frac{S_s}{L} \tag{9}$$

To maximize efficiency, we calculate:

$$\frac{dS_s}{dL} = \left(1-\frac{1}{L}\right)^{n-1} + n\left(1-\frac{1}{L}\right)^{n-1}\ln\left(1-\frac{1}{L}\right) = \left(1-\frac{1}{L}\right)^{n-1}\left[1 + n\ln\left(1-\frac{1}{L}\right)\right] = 0 \tag{10}$$

When n is known:

$$L = \frac{1}{1-e^{\frac{1}{n}}} = \frac{e^{\frac{1}{n}}}{e^{\frac{1}{n}}-1}$$

When the value of n is very large:

$$L = \frac{1+\frac{1}{n}}{1+\frac{1}{n}-1} = n + 1 \tag{11}$$

Therefore, it is proven in DFSA that the closer the frame size L is to number of unidentified tags n, the higher the efficiency of the RFID system. Moreover, in Figure 3, we use simulation to validate this theoretical model in (11) with a tag density of 300. From Figure 3, it can be seen that for different frame sizes L (16, 32, 64, 128, 256), efficiency is maximum when tag density n is almost equal to L.
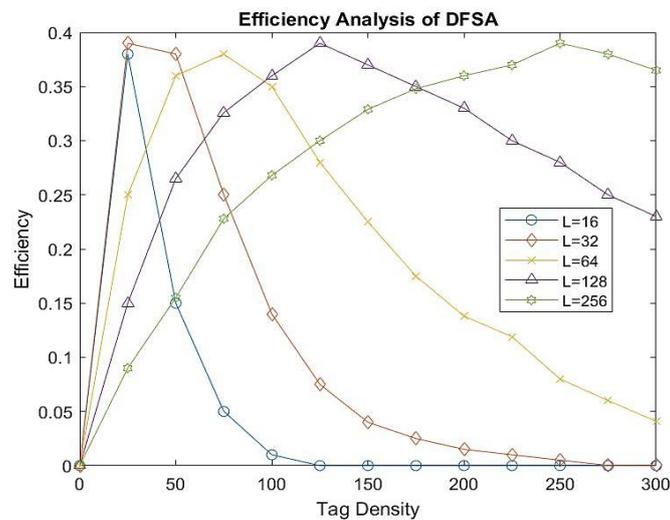

Figure 3. System Efficiency as a function of tag number in DFSA

2.2. Fuzzy C-means grouping algorithm

Fuzzy C-means grouping algorithm (FCMBG) is a DFSA based anti-collision scheme that uses fuzzy C-means machine learning technique together with Mahalanobis distance measure to group RFID tags using their EPC codes. The algorithm is set up in such a way that the reader uses the grouping condition of tags to predict frame size that would cause minimal collision. In the fuzzy C-means algorithm [19], RFID tags are assumed to be n vectors that are firstly grouped ($X = \{x_1 x_2 \dots x_n\}$) into c fuzzy sets ($S_1 S_2 \dots S_n$) with c clustering centers as set $v = \{v_1 v_2 \dots v_n\}$. Then the cluster center of each group is computed so that the value of the objective function is minimized. The fuzzy membership degree u_{ik} can be computed for each tag using (12) while the centroid is computed using (13). The objective function is stated in (14):

$$u_{ik} = \frac{1}{\sum_{j=1}^{c} \left(\frac{d_{ik}}{d_{jk}}\right)^{\frac{2}{m-1}}} \tag{12}$$

$$v_i = \frac{\sum_{k=1}^{n} (u_{ik})^m x_k}{\sum_{k=1}^{n} (u_{ik})^m} \tag{13}$$

$$L \approx \frac{1+\frac{1}{n}}{1+\frac{1}{n-1}} = n + 1, \ n \gg 1 \tag{14}$$

Here is the procedure for grouping in FCMB grouping algorithm:
- Step 1: initialize the cluster center (centroid) v, number of groups c, fuzzy weighted index m and range of frame size $[L_{min} L_{max}]$;
- Step 2: compute the fuzzy membership degree matrix u using (12)

$$u_{ij} = \begin{cases} [\sum_{k=1}^{c} \frac{\|x_i - v_j\|^{\frac{2}{m-1}}}{\|x_i - v_k\|^{\frac{2}{m-1}}}]^{-1} & \|x_i - v_k\| \neq 0 \\ 1 & \|x_i - v_k\| = 0 = j \\ 0 & \|x_i - v_k\| = 0 \neq j \end{cases} \tag{15}$$

where u_{ij} is the fuzzy membership degree given that x_i belong to group j, and v_j is the centroid of group j.
- Step 3: update each centroid v according to (16)

$$v_j = \frac{\sum_{i=1}^{n} u_{ij}^m x_i}{\sum_{i=1}^{n} u_{ij}^m} \tag{16}$$

where n is the number of primary data vector (tags).
- Step 4: using (17) the target number of groups is computed and if the minimum condition of the objective function is not met go to step 2 else continue.

$$c = \begin{cases} c - 1 & l_i < L_{min} \\ c + 1 & l_i > L_{max} \\ c & L_{min} \leq l_i \leq L_{max} \end{cases} \tag{17}$$

- Step 5: compute the number of tags for each group. If it falls within the range $l_i \notin [L_{min} \ L_{max}]$, update the centroid and go to step 1, else STOP.

2.3. Group-based binary splitting algorithm

To ensure good coverage of the different approaches to RFID anti-collision in our evaluation of grouping-based algorithms, this paper also selected a binary splitting based algorithm which is tree-based grouping algorithm by [9] called group-based binary splitting algorithm (GBSA). In GBSA, tags are divided into multiple subsets using a tag number estimation n and an optimal grouping factor f_{opt} then identified using a modified binary splitting (MBS) approach. The algorithm which is described in the block diagram in Figure 4 starts with the reader performing the first query cycle by showing the initial frame size. After the tags responds to the first query, the reader computes the n and f_{opt} using the statistics of the success, collision, and idle slots. Consequently, the tags within the read range of the reader are grouped into $N = n. f_{opt}$ groups. Afterwards, the modified binary splitting is used for tag identification in each group. In

their modified binary splitting strategy, GBSA deployed a 1-bit random binary generator R to pre-split contending tags. Since the time used for collision arbitration is eliminated, hence, efficiency and throughput are enhanced. For their tag number estimation function, GBSA adopted [22] and it is based on the result of the first sub-frame. They considered n tags are assigned L slots, after each query cycle, the probabilities that a slot is success slot S_s, or collision slot S_c or idle slot S_i is given by:

$$P(L_{sub},\ S_sS_cS_i) = (\frac{L_{sub}!}{S_s!S_c!S_i!}) \times P_0(S_i) \times P_1(S_s|S_i) \times P_2(S_c|S_i,S_s) \tag{18}$$

where P_1, P_2 and P_0 are probabilities of success slot, collision slot and idle slot. The estimated number of tags in a given sub-frame is gotten when the probability of (18) is maximum. This means that $\hat{n}_{sub} = n$ when $P(L_{sub},\ S_sS_cS_i)$ is maximum. Therefore, for the full frame L, the estimated tag number is computed:

$$\hat{n}_{est} = \hat{n}_{sub} \times \frac{L}{L_{sub}} \tag{19}$$
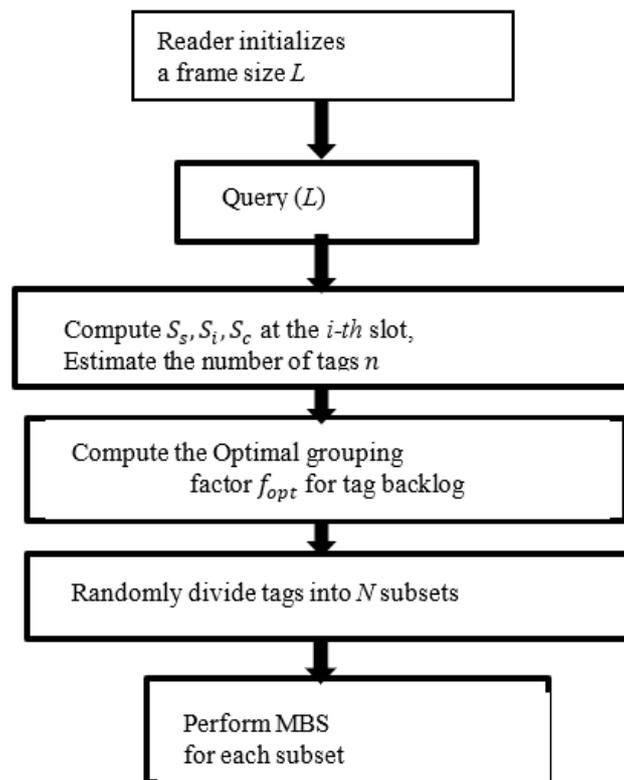

Figure 4. Function block diagram for GBSA

2.4. Grouping-based DFSA with fine groups (GB-DFSA)

One of the first works on grouping based of RFID anti-collision algorithms was proposed by [23]. Their algorithm has two stages. Firstly, the grouping phase and then the identification phase. Grouping is achieved in the first phase using the fact that RFID systems attain maximum throughput when the number of unidentified tags equals the frame size. Evenly, maximum throughput is attained when the tags are small, and the frame size is equally small. However, as the number of tags decreases, throughput increases hence, they performed the partitioning of tags into smaller groups and then identify with DFSA using Schoute's tag number estimation method [24]. In GB-DFSA shown in Table 2, the RFID reader first estimates number of groups s, by performing few queries then it enters into the identification phase where the reader arranges the tags into s groups then use DFSA to read the tags. The algorithm has six variables: f represents the frame size, s represents number of groups, p_{th} is for threshold, i is number of queries in the grouping phase, m is fraction factor. $tags_g$ represents tags within a group.

Table 2. GB-DFSA grouping algorithm

GB-DFSA Grouping Algorithm
GB-DFSA(tags) {
f=4; //Frame size
s=1; //the number of groups
p_{th}=8; //Threshold
i=1; //the number of iterations
m=4;
$tags_g$=$tags$;
//grouping phase
do{
n_c=FSA($tags_g, f$);
If (2.39*n_c>p_{th});
i=i+1;
s=m^{i-1};
[$group_1, ..., group_s$]=grouping ($tags, s$);
//randomly choose one of the groups}
$tags_g$=random ([$group_1, ..., group_m{}^{i-1}$]);
end if
}**until** (2.39*$n_c <= p_{th}$)
//identification phase
$f = p_{th}$;
$group = group_1$;
$identified\ tags$ =DFSA($group, f$);
for i=2 to s **do**{
$f = number(identified\ tags)/(i-1)$;
$group = group_1$;
$identified\ tags$
$= identified\ tags \cup$ DFSA($group, f$);
}
return $identified\ tags$
}

3. PERFORMANCE EVALUATION/RESULT AND DISCUSSION

In this section, we present an evaluation of the performance of the three selected grouping-based algorithms for RFID anti-collision together with the traditional DFSA. For fairness and better coverage, the selection considered DFSA based RFID anti-collision algorithms in conformity with EPC C1G2 and one tree-based grouping algorithm. All simulations were performed in MATLAB software (8.5.0, MathWorks, Natick Massachusetts, USA). Different scenarios of tag density and frame sizes were used to generate results in an extensive Monte Carlo simulation. We assume the communication channel is devoid of any capture effect and noise. In RFID anti-collision research, there are two main metrics that can be used to derive the appropriate frame size of the RFID system namely throughput rate and channel utilization factor (slot efficiency) [25]. We also compared the algorithms performances in terms of time consumption which [26] defined as total number of slots used by an algorithm to read all tags successfully.

3.1. Simulation parameters and data

Electronic product code (EPC) is a unique identifier of all RFID tags. Just like barcodes, they are used to identify any physical object in the world uniquely. This attribute is one of the reasons RFID is imperative to attaining IoT, which is to enable just anything have connectivity. Tag EPC is 96-bits and is accessible in the cloud via EPC information service (EPCIS). As shown in Table 3, EPC is long and in conformity with EPC C1G2, this paper uses only 16-bits out of the 96-bits for our evaluation. As shown in Table 3, the EPC code has four parts. The first 8 bits specifies the version of RFID tag while in the domain management, the manufacturer identifies the tag uniquely from the organizational side. The object class of 24-bit is used by the EPC management to identify the type of item while the 36-bit serial number is unique within each object class. This unique serial number forms the basis for our grouping in this paper as 16-bit binary data are generated randomly in MATLAB to simulate the tags' RN16. In our study, the 16-bit data ID is used in the clustering (grouping) of tags for each algorithm-traditional DFSA, GBSA, GB-DFSA and FCMBG.

Table 3. RFID tag coding

EPC 96-bit ID	Version no.	Domain Management	Object Class	Serial no.
No. of bits	8	28	24	36

The simulation was under a single reader and multiple tags scenario with assumed error-free channel. Also, part of the assumption was that no tags leave or enter the RFID read range. We set up a high tag density RFID scenario with one reader. The tags ranges from 100 to 1,000 same as in [9]. The parameters used in the simulation are in conformity with EPC C1G2 and are listed in Table 4. So, at the time of simulation, 1,000 groups of 16-bit binary data were generated at random with the MATLAB software to simulate the EPC code of RFID tags. Noteworthy is the fact that like in EPC C1G2 specifications, in our evaluation, the different grouping algorithms were implemented using the different correct time slots value for the success slot, collision slot and idle slots T1, T2 and T3, respectively.

Table 4. Simulation parameters

Parameters	Value	Parameters	Value
Reader-to-tag data-0	1 Tari	RTcal	37.5 µs
Reader-to-tag data-1	2 Tari	TRcal	50 µs
Reader-to-tag rate	80 Kbps	T1	62.5 µs
Tag-to-reader rate	160 Kbps	T2	62.5 µs
Tpri	6.25 µs	T3	100 µs
Tari	12.5 µs	Probe	4 bits
feedback	3 bits	RN16	16 bits
Query	22 bits	ID	96 bits
Query Adj	9 bits	Ack	18 bits
R-T Preamble	112.5 µs	QueryRep	4 bits
T-R Preamble	37.5 µs	Framesync	62.5 µs

3.2. Results and discussion

In the experiment we performed the effect of tag density on throughput rate of the RFID system using the throughput rate formula in (20):

$$Thr = \frac{S_s.T_s}{S_i.T_i + S_s.T_s + S_c.T_c} \qquad (20)$$

where S_s and T_s represent the value and time of success slots per query cycle, S_i and T_i represent the value and time of idle slots per query cycle and lastly S_c and T_c represent the value and time of collisions slots per query cycle.

As can be seen in Figure 5, different frame sizes L, were used to evaluate the throughput rate result of the four algorithms. In Figure 5(a), given a frame size of 64, FCMBG shows edge over the other three algorithms recording a throughput rate of over 55% which is far better than traditional DFSA which gives a result of about 35% throughput while GBSA followed FCMBG with about 50% throughput rate. It can also be seen in Figure 5(b) that GBSA shows more stability in throughput rate with very high tag density of 800 and above than FCMBG that shows decline in throughput rate. This can be attributed to tag starvation problem of DFSA based protocols. A situation where some tags might never be read by the reader due to very high population of tags unlike tree based protocols [27]. Consequently, this study discovers that the sharp decline occurred only when frame size was minimal L=64. This means that whereas FCMBG gives an improved throughput than traditional DFSA with increasing tag density, FCMBG works best when the tag density is high and when the frame size is as large as the number of tags as seen in Figures 5(c) and 5(d). This finding is in agreement with the theoretically analysis in (11).

Furthermore, in Figures 5(b), 5(c) and 5(d), given frame sizes L=128, L=256 and L=512 respectively, FCMBG shows highest throughput rate among the four algorithms while the other two grouping-based algorithms; GB-DFSA and GBSA closely followed. DFSA throughput rate crashed with increasing tag density. This huge difference in throughput rate between DFSA and the other three algorithms is because unlike DFSA, tag grouping in the other algorithms is a proactive means of minimizing collision even before the tags randomly respond to reader queries. Hence, from our study we deduce that using fuzzy C-means algorithm to group or cluster RFID tags before running traditional DFSA yields a better throughput rate when the number of RFID tags to be identified by the RFID reader are of high density.

Slot efficiency also referred to as channel utilization factor is the ratio of not empty slots and total timeslot (frame). Slot efficiency expressed in (2) is a measure of whether a given protocol wastes communication channel or not in the identification process. In DFSA based RFID anti-collision, the shared channel is divided into time slots and a tag can only reply to reader queries using a slot. The more slots a particular protocol uses to identify all of a given set of tags the lesser its channel efficiency [9], [12]. Therefore, slot efficiency is a very important metric in evaluating the performance of any RFID anti-collision protocol. In our simulation result shown in Figures 6(a) to 6(d) unsurprisingly, GBSA has perfect slot

efficiency. This is because tree-based protocols have the advantage of utilizing the channel well albeit, with a consequential trade off which is too much time delay as seen in Figure 7. This delay is due to fact that tree-based protocols are deterministic and cause too much computational space to implement. Hence, the choice of DFSA in EPC C1G2 protocol due to limited computational space of passive tags. However, FCMBG performed better than the other two DFSA based algorithms in terms of channel utilization.
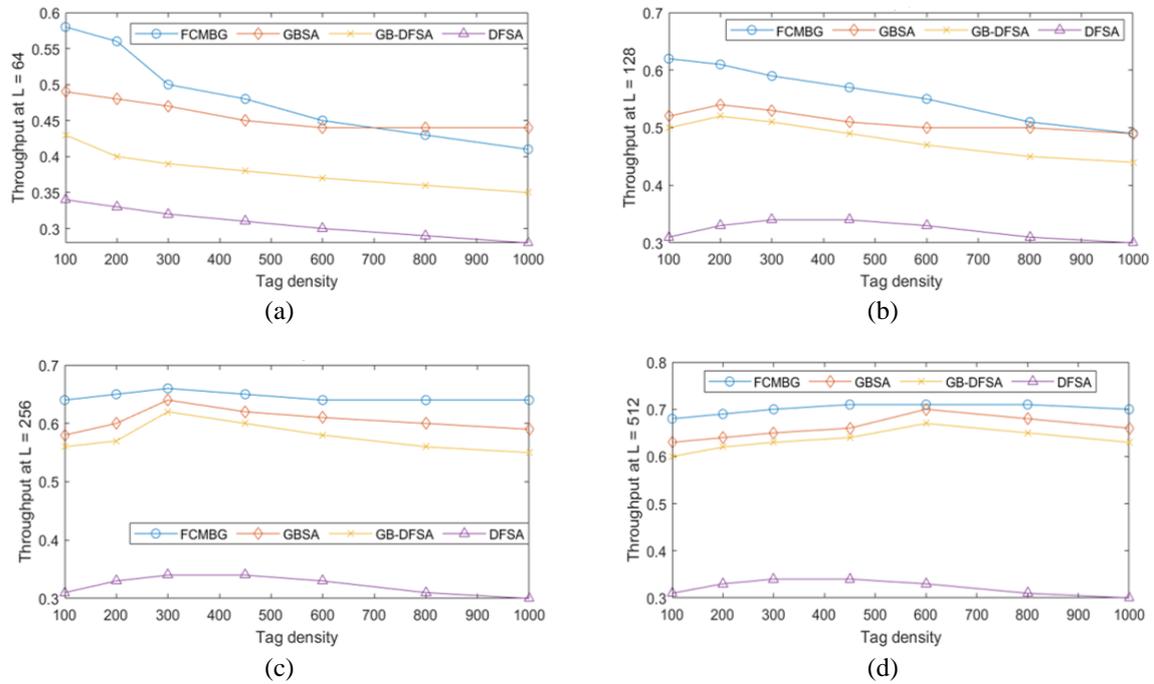

Figure 5. System throughput rate comparison for the different algorithm using (a) frame size of 64, (b) frame size of 128, (c) frame size of 256, and (d) frame size of 512
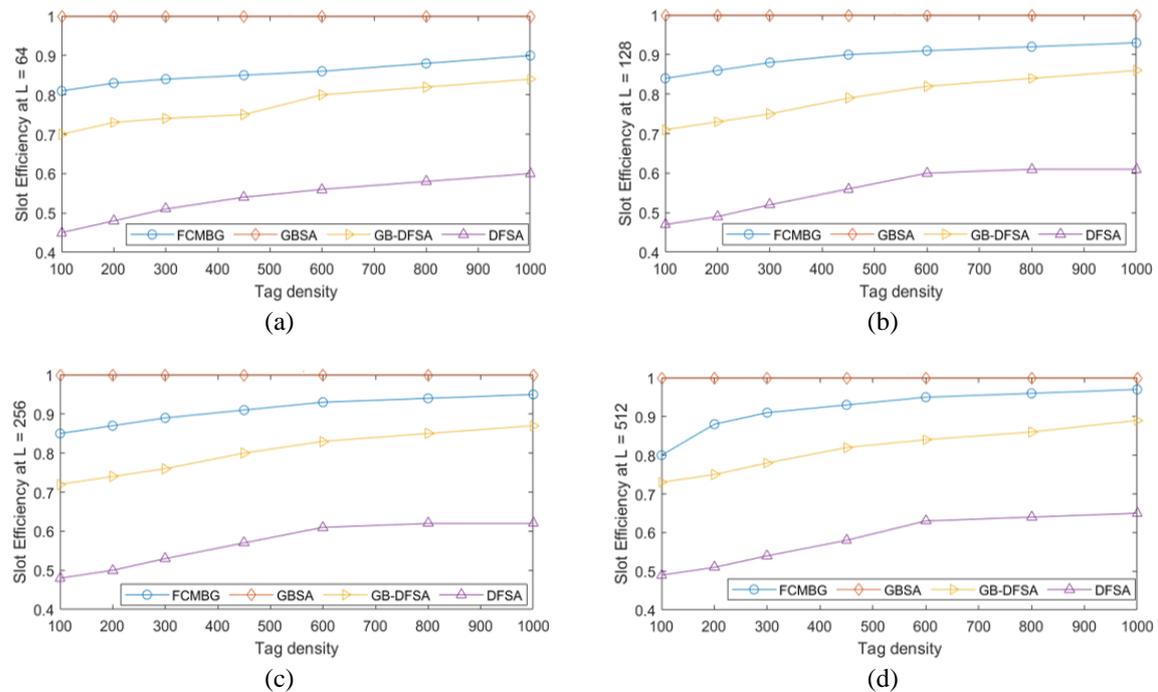

Figure 6. Slot efficiency (channel utilization factor) for the different algorithms using (a) frame size of 64, (b) frame size of 128, (c) frame size of 256, and (d) frame size of 512

In comparing identification time used by each algorithm to identify all the tags, there is inconsistencies among different authors in literature. For instance [19], [20] in presenting their results define identification time as the total time slot number used in identifying all the tags while [28] considered both total time slot number and total query rounds. However, for the purpose of this evaluation we define Identification time as total number of timeslots utilized by each algorithm to identify all the tags. This is in accordance with [19] because the work is part of our performance comparison. Going by the result presented in Figure 7 and as expected GBSA which uses modified binary splitting consumes the highest time to identify all tags.
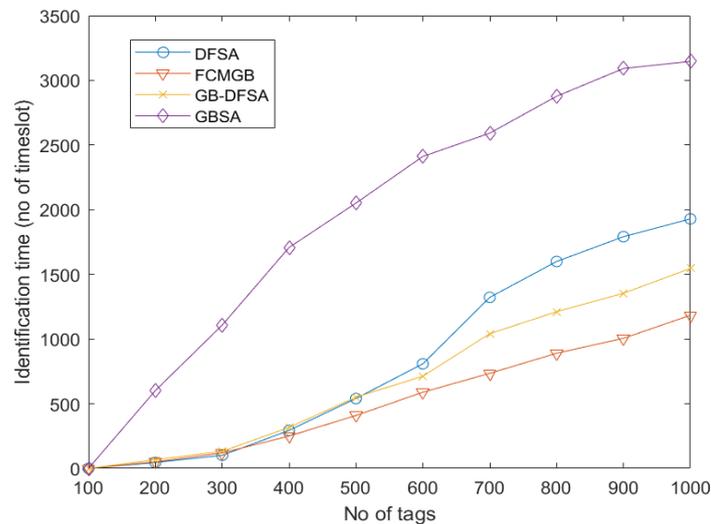

Figure 7. Identification time for the different algorithms

However, it was surprising to observe that even when the tag density was as low as 100, GBSA shows a result of over 200% more time to identify all 100 tags. This is associated with the recursive nature of breaking collision slots into ones and zeros continuously to form a tree-like structure of tree-based algorithms and binary splitting in particular. Based on this observation, we infer that for IoT application of RFID where time and computational space is a challenge, binary splitting algorithms might not be suited.

On the other hand, FCMBG which uses fuzzy C-means machine learning to group tags performed best in terms of identification time when the tag number is very dense (over 500). Initially when the tag density was less than 300, the traditional DFSA, GB-DFSA and FCMBG all show low identification time. But as the tag density increases to 500 and to 1,000, FCMBG shows much lower time than all the other three algorithms. This could be attributed to the fact that unlike the traditional DFSA, FCMBG uses the uniqueness of tags EPC (RN16 code) to group tags effectively, making it less probable for tags to randomly select same time slot (collision). Consequently, minimal collision means minimal retransmission by the reader and lesser time used in identifying all the tags within the read range of the reader.

4. CONCLUSION

Firstly, this paper validates through simulation the assertion that the efficiency of the RFID system is maximum when the number of tags is almost equal to the frame size the reader uses to query the tags. The paper also demonstrates the edge grouping-based RFID anti-collision algorithms have over traditional RFID anti-collision algorithm when the number of tags to be identified are large like in IoT. The paper shows that when the unique serial number of RFID tags are used to classify or group tags like in FCMBG protocol, collision is further mitigated while system throughput and time delay are enhanced. Because RFID tags have unique EPC codes, binary 16-bit codes were generated in MATLAB to model the tags, while different grouping algorithms (FCMBG, GB-DFSA, GBSA) were implemented in MATLAB including traditional DFSA algorithm. Results show that all the three selected grouping-based RFID anti-collision algorithms gave better performances than traditional DFSA when tag density is high in terms of throughput rate, channel utilization while FCMBG and GB-DFSA performed better in terms of identification time. The study also demonstrates that machine learning could be the most efficient technique in performing RFID tag grouping

since FCMBG gave the best result among the selected algorithms. Therefore, grouping based RFID anti-collision algorithms are promising and could be the sine qua non for RFID MAC protocol development for IoT application.

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