Cubic spline-based tag estimation method in RFID multi-tags identification process

Méthode d'estimation d'étiquettes par interpolation spline cubique dans les processus RFID d'identification muti-étiquettes

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Radio Frequency Identification (RFID) system is a communication technology used to identify objects using electromagnetic waves. The key advantage of RFID systems stems from their ability to simultaneously identify multiple tagged objects. However, communication of multiple tags with a reader may result in a collision problem, which is both time and energy inefficient, hindering the effectiveness of tag identification process. Presently, several anti-collision algorithms can be applied in order to reduce the collision probability. The reader's *a priori* knowledge of tag quantity significantly affects the overall performance of the system. Since the exact number of tags is not available for the reader, it is essential to develop an accurate tag estimation method to increase the efficiency of tag identification process. This paper presents a novel tag quantity estimation method, whereby, after simulating the tag distribution process, cubic spline interpolation method is employed to approximate the number of tags. According to the simulation results and the evaluation of the previous estimation methods, the new proposed method estimates the number of tags with a higher accuracy yielding an error rate of less than 1%, on average. Moreover, this low error rate is preserved even when the number of tags increases considerably.

Un système Radio Fréquence d'identification est une système qui utilise les ondes électromagnétiques pour identifier des objets. Le principal avantage des systèmes RFID réside dans leur capacité à identifier simultanément des objets multi- étiquetés. Cependant, la communication d'étiquettes multiples avec un lecteur peut aboutir à un problème de collision, d'où résulte une augmentation de la durée du processus et de l'énergie nécessaire, entravant ainsi l'effectivité du processus d'identification. De nos jours, plusieurs algorithmes anticollision existent et peuvent être appliqués dans le but de réduire la probabilité de collision. La performance globale du système d'identification est affectée de façon significative lorsque le lecteur a des informations *a priori* sur le nombre d'étiquettes. Puisque le nombre exact d'étiquettes n'est pas accessible au lecteur, il est essentiel de développer une méthode précise d'estimation d'étiquette dans le souci d'améliorer l'efficacité du processus d'identification. Cet article présente une nouvelle méthode d'estimation du nombre d'étiquettes, par lequel l'interpolation par spline cubique est employée pour estimer le nombre d'étiquette après simulation du processus de distribution des étiquettes. Se référant aux résultats des simulations et à ceux des méthodes d'estimation présentes dans la littérature, la méthode que nous proposons estime le nombre d'étiquettes avec une meilleure précision qui correspond à un taux d'erreur moyen inférieur à 1%. Plus encore, ce faible taux d'erreur est maintenu même lorsque le nombre d'étiquettes augmente.

Keywords: Anti-collision algorithm; cubic spline method; radio frequency identification; tag estimation method.

I Introduction

Radio Frequency Identification (RFID) system is a communication technology based on electromagnetic waves, used for identifying tagged objects uniquely. At present, RFID systems are widely used in almost all scientific fields. Owing to the suitability of RFID technology for applications that require controlling and managing objects, the usage of this technology has significantly increased. In most such applications, RFID systems are included of two vital components—readers and tags. However, despite their widespread usage and evident advantages over extant alternatives such as barcode, RFID systems still suffer from some technical problems. For example, the reader's *a priori* knowledge of tag quantity may significantly affect the overall performance of the system. Therefore, estimating the number of tags in a more accurate manner is an essential issue in RFID systems.

Tags include a unique ID number that identifies an object uniquely. Thus, tag identification process is used in applications where objects have to be individually recognized. As the first step of tag identification process, a radio frequency signal is sent by the reader, as a query to all the tags in the interrogation zone of the reader. In response, tags transmit their data back to the reader, which requires energy. Thus, based on their source of energy, RFID tags are categorized into active and passive tags. A passive tag does not have an independent source of energy and transmitter, thus the energy it requires for communication with the reader is sourced directly from the readers' waves. On the other hand, an active tag has an independent source of energy and transmitter required for sending its data back to the reader. As passive RFID tags are small in size, simple in implementation, and thus cheap to produce, most RFID systems use passive tags [1].

However, despite the numerous and significant advantages of passive tags, there are also some drawbacks, one of which is the collision

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problem that occurs when multiple tags send their IDs to a reader concurrently. As pointed out before, passive tags do not have power source and transmitter. Therefore, the tags cannot communicate with other existing tags in the vicinity, which hinders the detection of potential collisions. Thus, in an event of a collision, tag identification fails, and the process must be repeated, which significantly reduces its time and energy efficiency. Since concurrency is a part of RFID identification system, this problem must be resolved. Thus, in an attempt to address this issue, we aimed to minimize the probability of collision occurrence through the development and implementation of the anti-collision algorithm presented here.

Several conventional anti-collision algorithms have been proposed, which can be classified into ALOHA-based [2-9] and tree-based [10-12] anti-collision algorithms. Despite their variety, in almost all anti-collision algorithms, the knowledge of tag quantity plays an important role in the overall algorithm performance [13]. In Slotted ALOHA algorithms, for instance, the maximum performance is obtained when the total number of allotted reading slots (frame size) is identical to the number of tags. The tree-based algorithm also employs the knowledge of tag quantity to attain the optimal branch number [14]. Since, in practice, the exact number of tags is not known, different methods can be applied to provide an estimate. Thus, higher level of accuracy is the main objective of the tag number estimation methods.

As we already mentioned, as the first step in the tag identification process, the reader sends a query along with the frame size (N) to all tags in its interrogation zone. Thereafter, at ALOHA-based anti-collision algorithms, all the tags that have received the query choose a slot randomly, and send back their IDs using that slot. Since, this study analytically investigates the tags; the actual data transmitted by the tags are not interested. We therefore capture the read cycle's outputs, in which all of the slots were scanned. After any read cycle we obtain parameters C_0, C_1 and C_K, which representing the number of empty slots (idle slots), number of slots including one tag (successful slots), and the number of slots including more than one tag (collision slots), respectively [15-19]. At this point, based on the current frame size and the values of C_0, C_1 and C_K, the number of tags can be estimated.

Similar to other estimation methods, we consider the results of the read cycle (C_0, C_1, C_K) and the current frame size (N) to estimate the number of tags. In this case, other factors are not taken into account, such as the difficulty to distinguish a collision from a transmission error, capture effect and loss of the tags' data.

The rest of this paper is organized as follows. Section II investigates the related work on tag estimation and briefly discusses about the previous methods. Section III introduces our proposed tag estimation method. Our estimation scheme is analyzed in Section IV, where the estimation error of the proposed method is also evaluated. Finally, Section V concludes this paper.

II Related works

In RFID systems, the initial estimation method is obtained from collision definition that describes the lower bound. Based on the simple assumption that at least two different tags were involved at the same collision slot; the lower bound estimates by means of the (1).

$$\varepsilon_{LB} = C_1 + 2 \times C_K \tag{1}$$

Among conventional tag estimation approaches, lower bound estimate [15], Schoute estimate [6,16], and idle slot estimate [17], are considered as the simplest ones. To date, these approaches have not been utilized in ALOHA-based systems, due to the fact that their estimation results are inaccurate [13]. Other, more complex, methods are less error-prone, including Vogt estimation [15], Maximum A Posteriori (MAP) estimation [18] and Bayesian tag estimation methods [13]. In Vogt approach, the number of tags is obtained by computing the minimum difference among the existing and expected values for the number of idle, successful, and collision slots, after any read cycle [15]. In contrast, MAP method attempts to estimate the total number of tags through acquiring maximum a posteriori probability [18]. Finally, Haifeng Wu and Yu Zeng also employed the Bayes' rule in another tag estimation approach [13].

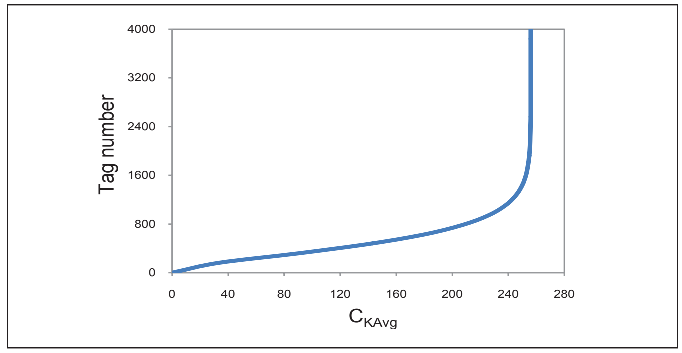

Figure 1: *Tag number as a function of average number of CK (CKAvg) for frame size of 256.*

Yinghua Cui and Yuping Zhao [14] presented a new estimation approach, known as Fast Zero Estimation (FZE), based on Zero estimation method. This method estimates the number of tags according to the number of idle slots and the given values of error bound (ε), confidential probability (p), and the satisfaction level (T).

Empirical evidence, however, suggests that most tag number estimation approaches generally suffer from either inaccuracy or high computation costs. In this paper, we simulate the tag distribution process and propose a novel tag number estimation method, which is not only more accurate compared to the previous methods, but also avoids complex processing, thus reducing the overhead computation costs.

III Cubic spline-based tag estimation method

As the first step in the tag identification process, the reader sends a query along with the frame size (N) to all tags in its interrogation zone. Thereafter, all the tags that have received the query choose a slot randomly, and send their IDs using that slot. After one read cycle, in which all of the slots were scanned, the proposed method just counts the number of collision slots. At this point, based on the current frame size and the value of C_K, the number of tags will be estimated.

In this study, we demonstrate that fixed frame size leads to an increase in C_K corresponding to the greater number of tags; in other words, there is a direct relation between tag quantity and the magnitude of C_K in a fixed frame size. In this work, we are thus seeking a tag number estimation method applicable to cases with unknown frame size and C_K. As in our method, there is no need to obtain C_0 and C_1, the computation cost is reduced and estimation speed increased.

Given fixed frame size N, and the number of tags n, it is assumed that all the tags are distributed into slots independently and based on a uniform function [20]. After distributing the tags, we record the value of C_K; i.e., after each of the n tags chooses a slot randomly, the collision slots are counted to produce C_K. It should be noted that C_K is obtainable after any read cycle, whereby collisions are not distinguished from a transmission error [15, 19]. Given that the tags are distributed using a stochastic function, there is a potential for recording different values for C_K in different experiments. Therefore, in order to obtain an optimal value for C_K, we simulate the distribution of n tags in N given slots using Visual C# programming language as simulator. After this operation is repeated 10 000 times, the average of C_K is calculated and denoted as C_{KAvg}. This parameter represents the average number of collision slots when n tags are distributed in N slots. For example, for a frame size of 256, C_{KAvg} is calculated for a variable number of tags. Fig. 1 demonstrates the behavior of C_{KAvg} when the number of tags is

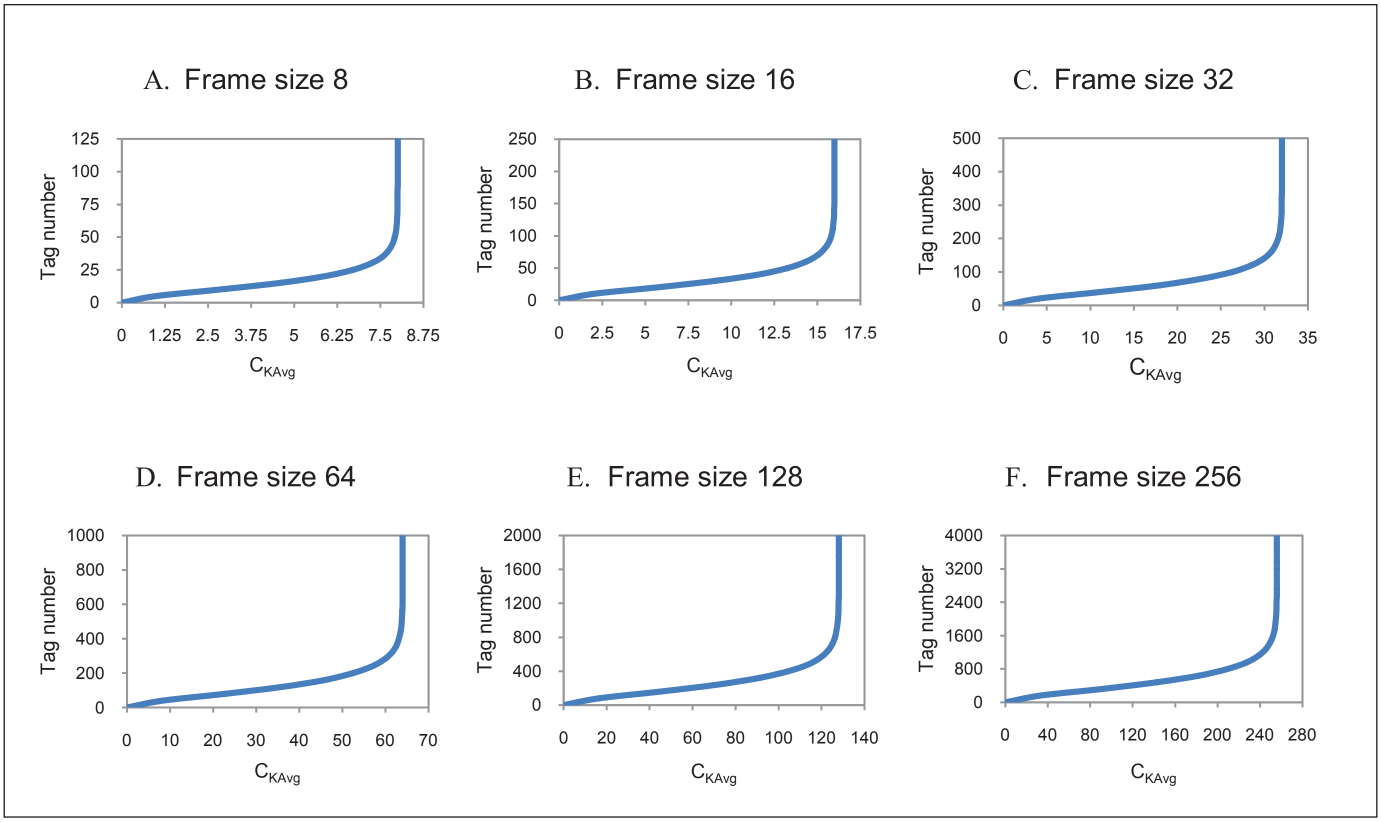

Figure 2: *Tag number as a function of average number of CK (CKAvg) for different frame sizes.*

increased from zero to 4000. As is depicted in Fig. 1, by increasing the number of tags, number of collision slots also increases. This is a bidirectional relation, implying that an increase in the number of observed collisions indicates an increase in the number of tags.

According to the Vogt articles [15, 19], in order to reduce the tag complexity, the available frame sizes are limited to powers of two, implying that a frame size equal to 8, 16, 32, 64, 128 or 256 is optimal. According to the author, frame size greater than 256 cannot be selected, due to the limited tag memory capacity. In the next step, we repeat the above described simulation process using different frame sizes (as recommended by Vogt). The results of these experiments are presented in Fig. 2. It is evident that, even though all the curves have the same shape, the values on the horizontal and vertical axes are different.

It is clear from the graphs depicted in Fig. 2, that by doubling a frame size, the values on the horizontal and vertical axes are also doubled, indicating their dependency on the frame size. Thus, in order to eliminate the dependence on frame size, we divide the values of the horizontal and vertical axes by the frame size (N) to normalize the curves. Fig. 3 shows the charts for different frame sizes where the horizontal axes represent the ratio of average number of collisions and the frame size (C_{KAvg}/N) and the vertical axes represents the number of tags over frame size (n/N). Clearly, all the normalized curves are identical.

Thus, to further illustrate the similarity of curves depicted in Fig. 3, they are plotted on the same chart. As shown at Fig. 4 all curves overlap each other. It is evident that the curves are fully independent of the frame size, i.e. values remain constant irrespective of the chosen frame size.

As can be seen in Fig. 4, a single curve is produced for all frame sizes. Hence, based on the proposed curve, regardless of the frame size, for a given value on the horizontal axis, we can obtain the corresponding value on the vertical axis.

Thus, the key value of this method is that, once the curve is calculated, it remains valid for all subsequent cases. Since we already know the frame size (N), and average number of collision (C_{KAvg}) is obtainable, calculating the corresponding value on the horizontal axis is straightforward. Therefore, using the curve, and by means of cubic spline method [21], we can obtain n/N for any value of C_K/N. Consequently, multiplying n/N by the frame size (N) leads to the number of tags (n). The pseudo code shows the process of proposed tag number estimation method.

IV Performance comparison and discussion

The performance of our estimation method in comparison with previous works is presented in Fig. 5. Frame size is set to 128 in all methods and the number of tags increased from 50 to 350. The average results are presented for 500 repetitions of the experimental procedure. As can be seen, the Vogt, Bayesian and MAP methods estimate tags quantity with almost identical error rate, which is much better than that associated with the Idle slot method. When the number of tags increases, the accuracy of these methods decreases, insofar as, Schoute and lower bound methods estimate the number of tags as 255 and 217, respectively, when the actual number of tags are 350 [13]. In contrast, our proposed method estimates the number of tags accurately.

To evaluate the accuracy and performance of tag number estimation methods, tag estimation error (ε) is defined using the (2), where $\hat{n}$ is the estimated number of tags and n is the actual number of tags [13, 14].

$$\varepsilon = \frac{|\hat{n} - n|}{n} \times 100\% \tag{2}$$

Fig. 6 illustrates the tag estimation error versus the number of tags, when the numbers of tags are increased from 50 to 350. Lower bound and Schoute methods show the poor error rate, as for 350 tags they show the 38% and 27.2% estimation error respectively. The error rate

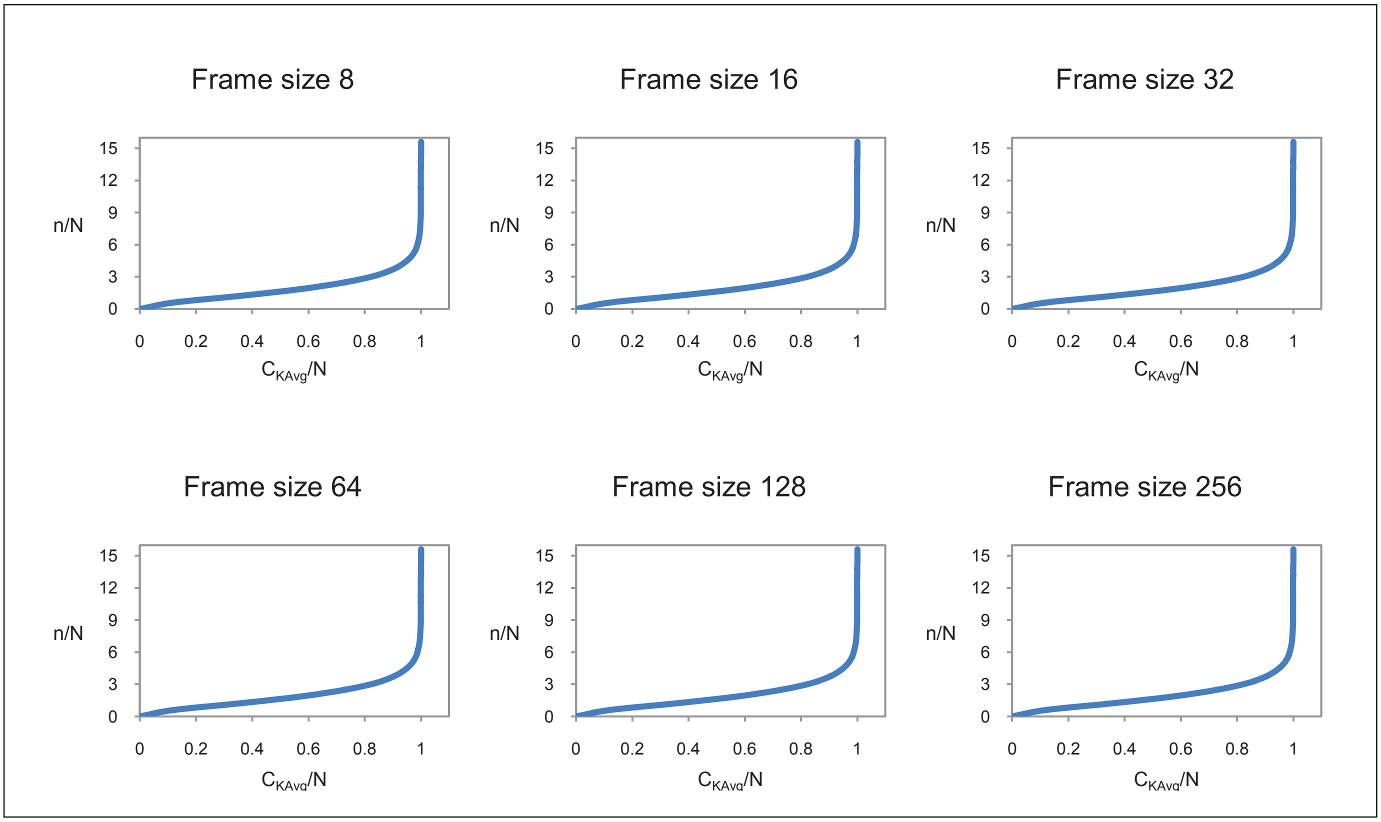

Figure 3: *n/N per CKAvg /N for different frame size.*

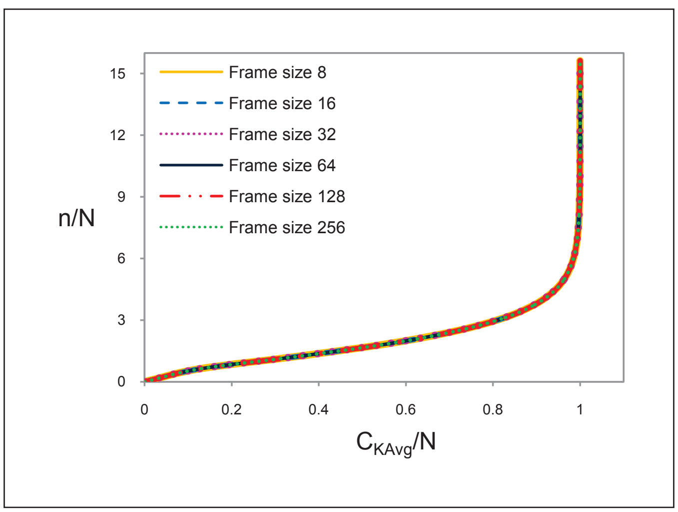

Figure 4: *n/N per CKAvg /N for different frame sizes are plotted together.*

of the Idle slot method is greater than 5%, increasing to 9% when the actual number of tags is 350. However, Vogt, Bayesian, and MAP method exhibit higher accuracy, with error below 5%. Nonetheless, our proposed methods, with approximately 1% error rate, is superior to all extant approaches.

Fig. 7 depicts the error rate from 0% to 5%. It provides a clear visual representation of the errors associated with different methods. Since Idle slot's error rate exceeds 5%, it is not observable in Fig. 7.

In all previous graphs, the frame size is assumed to be fixed and is set based on the Vogt's recommendations (frame size in power of two). In this part, we test our method by increasing the number of tags from 100 to 2000, whereby the frame size is selected based on the number

Algorithm: tag estimation method by using cubic spline

Input: N (frame size)
Output: $\hat{n}$ (tag estimation number)

1. FOR I = 0 TO iteration
   //All the tags choose a random slot to transmit their IDs to the reader
   1.1 FOR Tag = 0 TO number of tags
       all tags choose a random number (0 < RN < N)
       increase slots [RN]
   1.2 NEXT Tag
       // Count the collision slots
   1.3 FOR Slot = 0 TO N
       IF slots[Slot] > 1 THEN
           increase C_K// C_K= collision slots
       END IF
   1.4 NEXT Slot
2. NEXT I
3. $C_{KAvg} = C_K$/ iteration //Average number of C_K
4. cN = C_{KAvg}/ N
   // estimate the number of tags
5. use the cubic spline method
   5.1 Define some points of the curve as default points (Fig. 4)
       X = some given points for horizontal axis of curve
       Y = some given points for vertical axis of curve
   5.2 nN = Estimated the number of tags based on X, Y and cN using cubic spline interpolation.
   5.3 $\hat{n}$ = nN * N // Tag estimation number
6. PRINT $\hat{n}$

of tags with 200 iterations [14]. In the remaining figures, we compare our results to those produced by four different methods, namely lower bound [15], Schoute's method [6, 16], Zero estimation method [14],

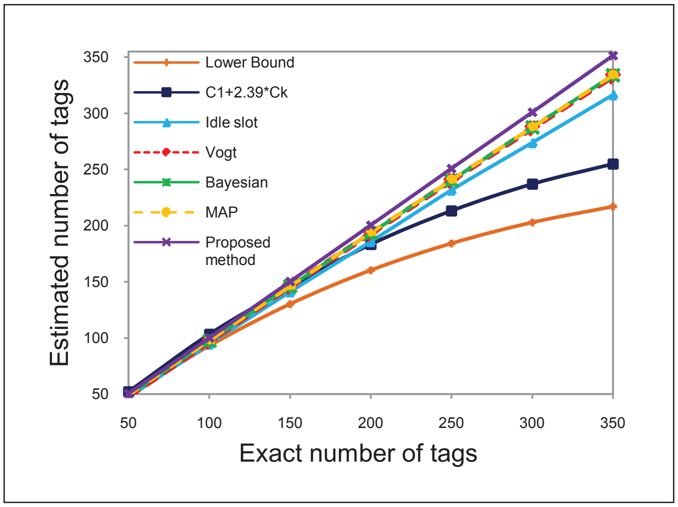

Figure 5: *Estimated number of tags using different methods for frame size of 128.*

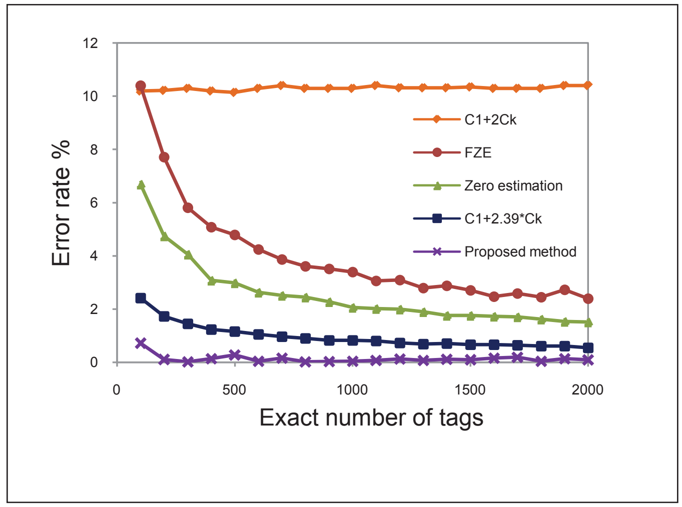

Figure 8: *Error rate of different estimation methods when frame size is equal to the number of tags.*

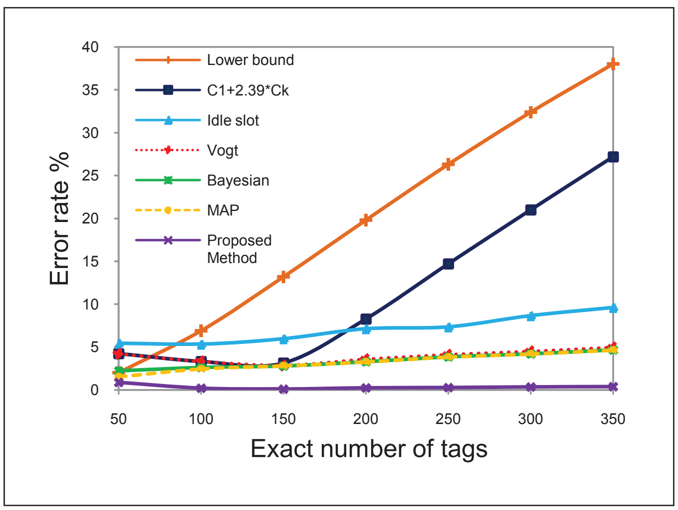

Figure 6: *Simulation results for tag estimation error of different methods.*

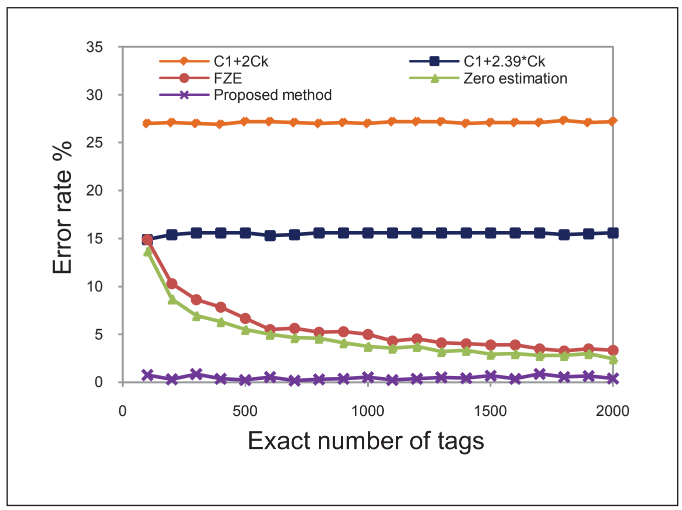

Figure 9: *Error rate of different estimation methods when frame size is equal to half of the number of tags.*

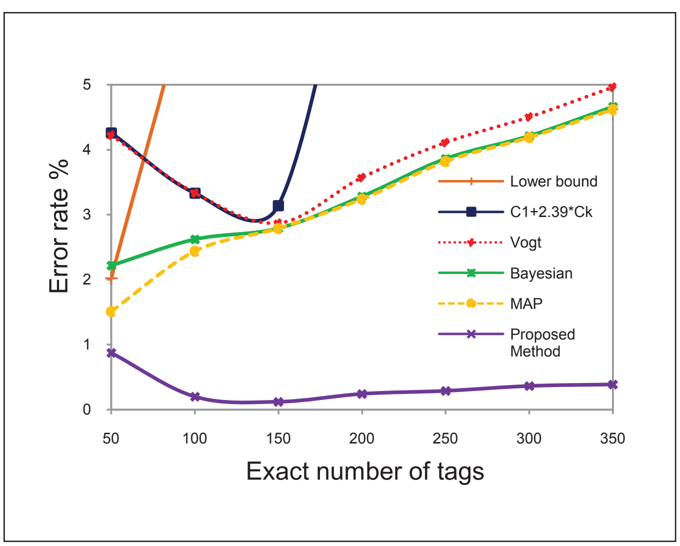

Figure 7: *Simulation results for tag estimation error in different method (0% <error rate <5%).*

and Fast Zero Estimation method [14]. Again, simulation results illustrate that our proposed method not only yields an accurate number of tags for frame sizes 8, 16, 32, 64, 128 and 256, but also offers a high level of accuracy in estimating the number of tags for any frame size. The results presented in Figs. 8, 9 and 10 demonstrate that our proposed method is valid for any frame size and it preserves its accuracy for large numbers of tags.

In Fig. 8, every frame size is equal to the number of tags (frame size is increased from 100 to 2000). In this scenario, lower bound shows a higher error rate, which is almost fixed at around 10%. Zero estimation has lower error rate compared to FZE method. However, when the number of tags increases, both FZE and Zero estimation methods yield results that are more accurate. Although Schoute's method is not more accurate than our method, it offers a better result in comparison to the other three methods. Schoute's error rate is less than 1% when the number of tags exceeds 600. However, our proposed method, with error rate less than 0.2%, is clearly superior to all current approaches.

In Fig. 9, every frame size equals to half of the number of tags (frame size is increased from 50 to 1000). In this scenario, although lower bound method still has almost a fixed error rate, decreasing the

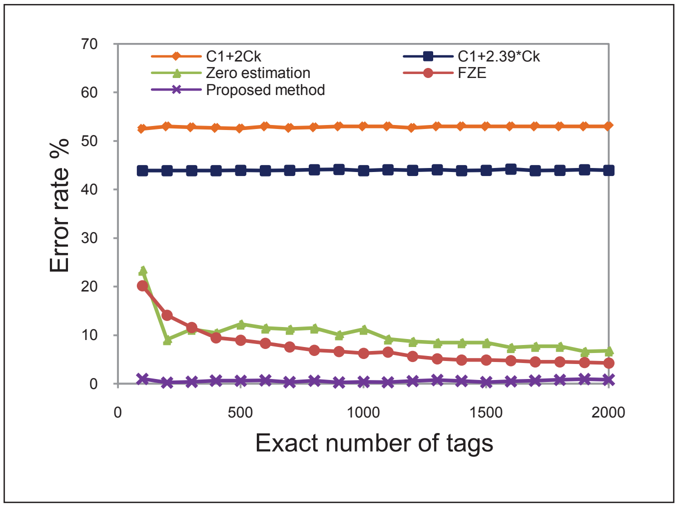

Figure 10: *Error rate of different estimation methods when frame size is equal to a quarter of the number of tags.*

frame size in relation to the number of tags causes the error rate to increase considerably (up to 27%). The accuracy of Schoute's estimation method also decreases to almost a constant error rate of around 15%. Zero estimation has lower error rate compared to FZE. Thus, with error rate less than 1%, unaffected by the reduction in frame size, the accuracy of our method is superior to all the other methods.

In Fig. 10, every frame size is set to a quarter of the total number of tags. In this experiment, the number of tags is increased from 100 to 2000, with the corresponding increase in frame sizes from 25 to 500. Again, in this scenario, smaller frame size leads to reduction in accuracy, with the corresponding increase in error rate for all extant methods. More specifically, lower bound's estimation error reaches 53% and Schoute's estimation method shows the error rate of around 44%. It is also worth pointing out that, although the error rate of both Zero estimation and FZE methods increase, the Zero estimation error increases at a higher rate. In contrast, our proposed method still has an error rate of less than 1%.

V Conclusion

In this paper, we present a novel and accurate estimation scheme for RFID systems with a high-speed estimation process. The method employs cubic spline technique to estimate the number of tags. We also define the estimation error rate, compare our method to previous estimation methods and illustrate that the proposed method has much higher accuracy. We show that our method is not only valid and accurate for recommended Vogt's frame sizes (based on power of two), but is also accurate for other frame sizes. It also shows a high accuracy when the number of tags increases considerably.

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