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New Tag Estimator for the Dynamic Framed Slotted Aloha Anti-Collision Algorithm in RFID Systems

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Abstract— **Radio frequency identification (RFID) technology is a wireless identification technique that has been used in many fields. This paper investigates the use of this technology for traffic monitoring which is the backbone of any intelligent transportation system. One of the main issues that face this technology is tag collisions. This study examines the performance of two known anti-collisions protocols: the Basic Framed Slotted Aloha (BFSA) and the Dynamic Framed Slotted Aloha (DFSA). For such application, it was found that the DFSA method outperforms the BFSA method. However, the DFSA method requires the use of tag estimator. For this reason, the study compares also the performance of three tag estimators associated with the DFSA: Vogt, Zhen and Schoute. It is observed that the Vogt method is the best if the number of tags is low, while the Schoute approach is superior for higher value. The study proposes a new hybrid tag estimator that combines the strength of the Vogt and Schoute approaches.**

Keywords— **RFID; Basic Framed Slotted Aloha; Dynamic Framed Slotted Aloha; Tag estimator function; Vogt estimator; Zhen estimator; Schout estimator.**

I. Introduction

Radio Frequency Identification (RFID) technology is growing and spreading rapidly in the last decades. One of the key factors that drive its growth is its ability to identify or track objects wirelessly without line-of-sight but within certain proximity [1]. In addition, it emerges as one of the key technologies that the Internet of Things depends on. It has been successfully used in many areas such as industrial production, logistics, agriculture, highway toll collection, healthcare management and many other fields [2-5]. The RFID system consists of a reader and one or more tags embedded in objects that need to be identified or tracked [6]. The reader sends out radio waves which are detected by tags located within the range of the reader. These tags will respond by sending out their unique identifier IDs stored in their local memory. The range of the reader depends on the type of the tag which can be passive, semi-active or active. The range varies from few meters to hundreds of meters.

In this study, we are interested in the application of the RFID technology in traffic monitoring which is an important task in any intelligent transportation system. Tags will be placed on vehicles while readers are installed above a roadway. Tags carry the important information about the vehicles. However, in the process of RFID identification of multiple tags, the collision due to simultaneous tag responses is a key issue affecting the efficiency of RFID identification [2, 7]. This type of problem is called tag collisions. Another type of collision is called reader collision. It occurs when multiple readers attempt to access the same tags simultaneously [2, 8]. In order to minimize collisions, each RFID reader must use an anti-collision protocol. In this paper, an anti-collision algorithm is developed taking into account road traffic volume.

The paper is structured as follows. An overview of anti-collision algorithms is summarized in Section II. The paper methodology is described in Section III while the results and discussion are presented in Section IV. Finally, Section V concludes the paper.

II. Overview of Anti-Collision Algorithms

The use of anti-collision protocols is essential for any RFID system. In fact, collisions during the RFID identification process can result in unread tags, increased delay and waste of energy [8]. Several anti-collision algorithms have been proposed to resolve tag collisions issues. These algorithms can be classified as probabilistic methods based on Aloha protocols and deterministic methods based on tree structure. Another class of algorithms called hybrid protocols which combine the two approaches [2, 4].

First, for the Aloha algorithms, tags are allowed to transmit without considering whether the channel is busy or free. These algorithms are designed to minimize the probability of occurrence of tag collisions and are divided into three main categories: pure Aloha, slotted Aloha and frame-slotted Aloha [4]. Second, the tree algorithms are characterized by the construction of an identification tree where leaves represent tags. It includes tree splitting, query tree, binary search and bitwise arbitration. The main weakness of these methods is the need to rebuild the tree for any new incoming tag which leads to higher delays and significant memory overhead [6]. Finally, the hybrid methods have many categories such as tree-slotted aloha, hash tree, hybrid query tree and its variants [8].

This paper studies the performance of two methods that fall under the category of frame slotted Aloha which are the Basic

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Framed Slotted Aloha (BFSA) and the Dynamic Framed Slotted Aloha (DFSA). Both approaches are discussed in the following subsections.

A. Basic frame slotted ALOHA

The BFSA consists of fixed number of frames and the user is constrained to transmit in a synchronous fashion [4,6, 9]. The time is divided into slots of one packet duration of equal length and these slots are grouped into frames. All tags keep track of transmission slots and are allowed to initiate transmission only at the beginning of a time slot. In addition, each tag transmits its data at most once in a frame.

When tags enter the reader's range, they will be asked to send their IDs during a randomly selected time slot. If two tags or more select the same slot during the same frame, then collision will happen. These tags may retransmit their IDs during the next frame for correct identification. This process continues until all the tags transmit their ID successfully provided that they are within the reader's range. However, when collisions occur during the last frame of the identification process, the tags are lost and couldn't be identified [6, 9]. Once tags are properly identified, they may be muted by the reader to avoid unnecessary transmission during the remaining frames [6]. The BFSA can achieve a maximum throughput of 36.8% if the number of tags that fall under the reader's range is not large.

There are two main drawbacks for fixing the frame size in the BFSA. First, if there are too many tags, then most of the time slots will experience collisions. This cause longer delay for the identification of tags and in some cases many tags will not be identified. So the speed of the identification process will be affected [10, 11]. Second, if the number of tags is low, most of the time slots will be idle and thus wasted [10]. To solve this issue, the DFSA was introduced.

B. Dynamic frame slotted ALOHA

The DFSA scheme is similar to the BFSA except that the number of slots per frame is dynamic and it can be modified after every read cycle. This property improves the speed of the identification process in comparison with the BFSA. Theoretically, the optimal frame size is equal to the number of tags [10]. However, in many applications such as traffic monitoring the number of tags is varying, so to it is important to find an estimation algorithm of high accuracy. In this regard, many tag estimation techniques were proposed in the literature such as the work by Vogt [12], Zhen et al. [13], Schoute [14], Cha et al. [15], Khandelwal et al. [16], Floerkemeier [17-18], Kodialam et al. [19], Chen et al. [20], etc. This study investigates the application of DFSA for traffic monitoring in two lanes highway and using tag estimator function proposed by Vogt, Zhen et al., and Schoute. All these methods are based on the results of the previous frames.

Vogt [12] proposed a simple method for the estimation of the number of tags around the reader. It is based on the fact that a collision involves at least two tags. Therefore the estimated number of tags is given by

$$N_{est} = c_1 + 2\, c_k \tag{1}$$

where c_1 and c_k are the number of slots with only one tag and the number of slots in collisions respectively. They are determined from the results of the previous frame.

Another estimation approach has been proposed by Zhen [13]

$$N_{est} = c_1 + M\, c_k \tag{2}$$

This estimation is based on the computation of the expected number of collisions in each slot using the following posterior probability of *k* tags choosing the slot

$$P_k^0(i) = \begin{cases} 0 & if\ k = 0,1 \\ \frac{P_k(i)}{1 - P_0(i) - P_1(i)} & if\ k \geq 2 \end{cases} \tag{3}$$

This means that the *a posteriori* expected value of the number of tags is respectively, 0 for an empty slot, 1 for a success slot, and $\sum_{k=2}^{N} kp_k^0(i)$ tags for slots in collisions. Zhen has shown that the estimate of the number of tags in the frame *i+1* is given by

$$M = \lim_{N\to\infty} \sum_{k=2}^{N} kp_k^0(i) = 2.39 \tag{4}$$

Finally, Schoute assumed that the tag number obeys the Poisson distribution with the average value of one and proposed the following estimation [14]:

$$N_{est} = c_1 + 2.3922\, c_k \tag{5}$$

III. Methodology

For this study, it is assumed that every vehicle is equipped with a passive tag and the RFID reader is mounted over the middle of the two lane road of a typical highway as shown in Fig. 1. It is also considered that the reading range is up to 30 m which can be easily achieved with the existing RFID system available in the market [6]. In the first stage of this project, a comparison will be made between the BFSA and the DFSA protocols when implemented in the RFID system for traffic monitoring application. In the second stage, a new algorithm is proposed and tested.

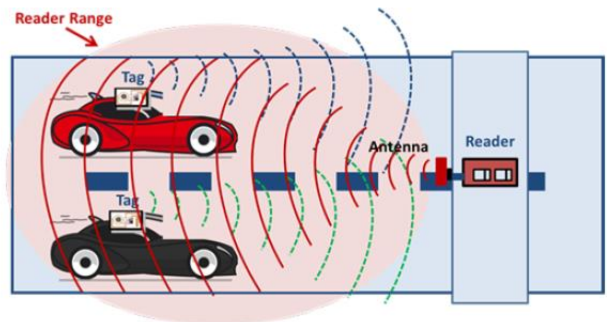

Fig. 1 Typical setup of an RFID system in a two lane road [6].

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A. Investigation of the BFSA protocols

The number of frame size in the BFSA protocol is set equal to the maximum number of vehicles within the reader's range since the traffic volume in any road can vary from low to high or vice-versa. The number of slots per frame, N, can be estimated by the following expression [6]

$$N=(n_L\ R)/L_v \qquad (6)$$

where n_L is the number of road lanes covered by the reader, L_v is the average vehicle length and R is the reader's range. In our case, we consider $R=30\ m$, $n_L=2$ and $L_v= 5\ m$. Therefore for the BFSA, the number of slots per frame is expected to be 12. Since the number of slots per frame is normally a power of 2, then $N=8$ or $N=16$. To evaluate the performance of the BFSA for a number of tags (n) varying from 1 to 12, we use the system efficiency (SE) which is a common evaluation metrics and is expressed as [21]

$$SE= c_1/N \qquad (7)$$

where c_1 is the number of slots that contains only one tag.

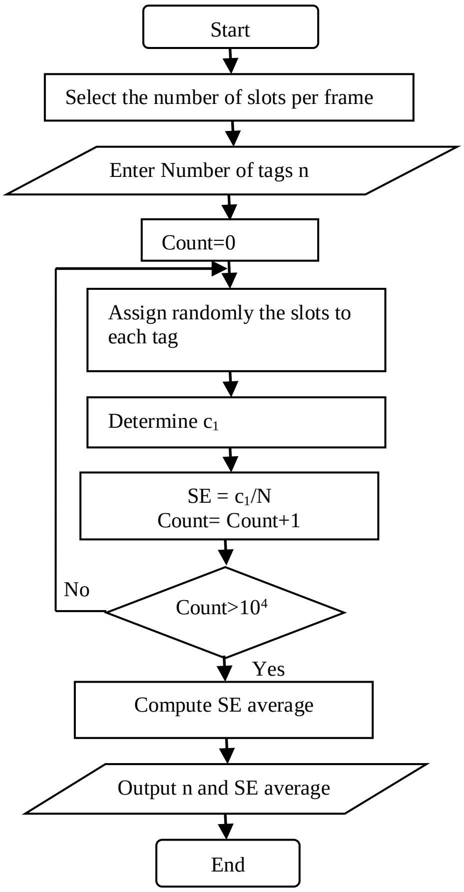

Fig. 2 Flow chart for the BFSA algorithm.

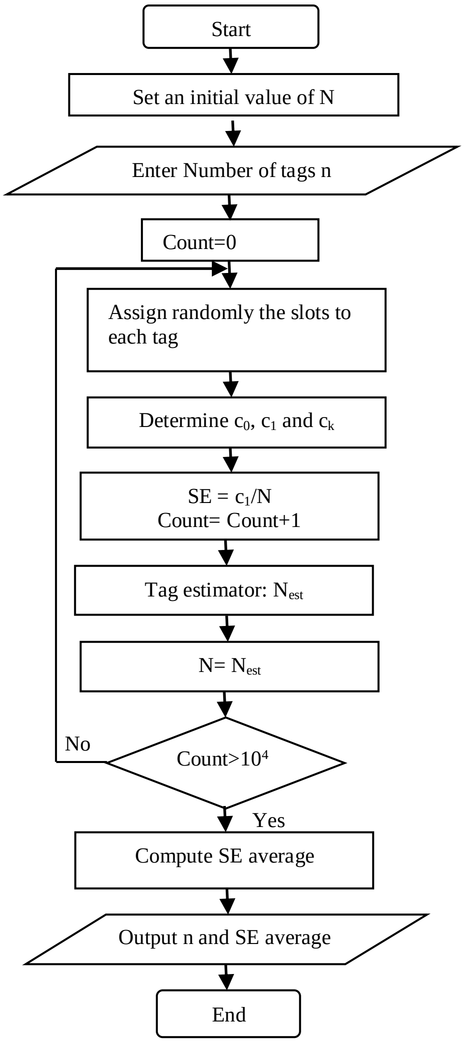

Fig. 3 Flow chart for the DFSA algorithm.

The BFSA algorithm used in this study follows the flow chart shown in Fig. 2 which can be described by the subsequent procedure:

1) It allows the user to select the number of slots per frame N which is in this case either 8 or 16.
2) For each value of N, the number of tags n can be selected from 1 to 12 since the number of tags should not exceed 12 as explained earlier.
3) The selected tags are allocated into the N slots randomly, if two or more tags are placed in the same slot, then collision occurs.
4) The number of slots with only one tag (c_1) is determined and the system efficiency SE is computed from (5).
5) Step 3 and 4 are repeated 10,000 for each value of n in order to obtain an average SE which is normally close to the real value [22].
6) Compute the average SE.

B. Investigation of the DFSA protocols

The algorithm used for the DFSA is illustrated by the flow chart in Fig. 3. It is similar to the BFSA algorithm except that

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the number of slots per frame is dynamic and can be modified after every read cycle. For this reason, after setting the initial value of N in Step1, a tag estimator is inserted. In addition, the number of empty slots (c_0) and the number of slots in collision (c_k) are determined along c_1. The rest of the algorithm is the same as the BFSA.

The first aim of this study is to compare between the performance of the DFSA and the BFSA methods when considering the RFID system. The second aim is to evaluate the performance of the DFSA associated with three types of tag estimation techniques: Vogt [12], Zhen *et al.* [13] and Schoute [14]. The three tag estimators are described by (1), (2) and (5) respectively. Finally, a new method will be proposed for the tag estimator.

IV. RESULTS AND DISCUSSIONS

A MATLAB code was developed for the BFSA algorithm and the results of the average SE are shown in Fig. 4 for a fixed number of slots $N=8$ and $N=16$. It is observed that in general a better performance is obtained when $N=8$ and $n \leq 11$. However, when considering $n=12$, SE will be better if $N=16$. Therefore for most cases, a frame size $N=8$ for the BFSA is more efficient for the application under study.

In the second stage, the system efficiencies of the BFSA with $N=8$ and the DFSA using Vogt estimator were compared and the results are shown in Fig. 5. It is clear that the DFSA method is superior to the BFSA especially when the number of tags is much lower than the frame size *N*. In such case many time slots are idle and wasted. For this reason, the DFSA protocol is recommended for the RFID system in traffic monitoring application. However, there are many proposed tag estimator for the DFSA protocol that should be investigated. In the next step, a comparison is made between the performance of three estimators which are proposed by Vogt, Zhen and Schoute.

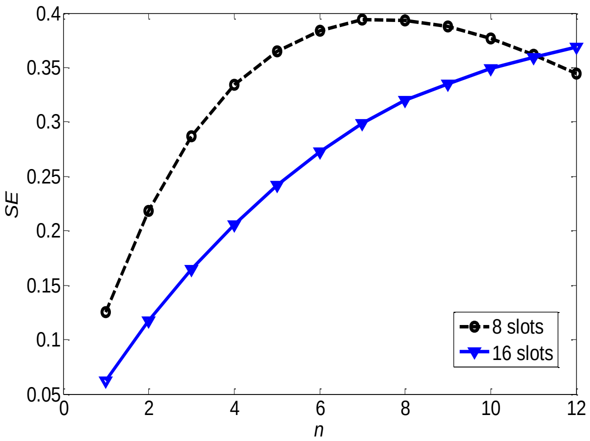

Fig. 4 System efficiencies of the BFSA with $N=8$ and $N=16$.

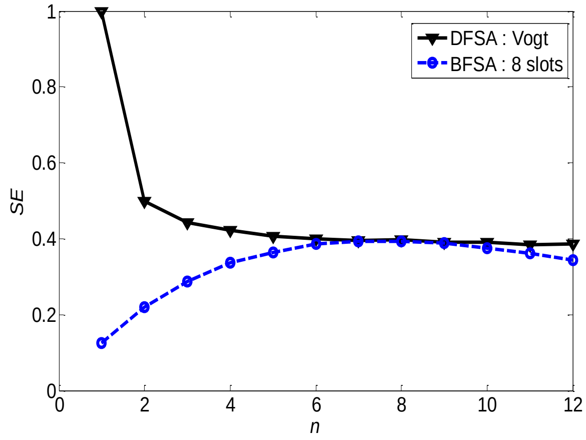

Fig. 5 System efficiencies of the BFSA and DFSA with Vogt estimator.

The simulation of the DFSA protocol using the three tag estimators: Vogt, Zhen and Schoute were performed and the results of the system efficiencies were obtained and displayed in Fig. 6. It is noted that the Vogt method is the best if the number of tags is low, in our case $n \leq 2$. However as *n* increases, the Schoute approach becomes superior. The performance of the Zhen method is comparatively lower than the other two methods. Based on these observations, it is suggested to propose a new hybrid approach that combines the strength of the Vogt and Schoute methods. This can be done by choosing Vogt estimator for a number of tags $n \leq 2$, and for higher values of *n* the Schoute estimator is selected. Fig. 7 shows that the proposed estimator produces the desired results.

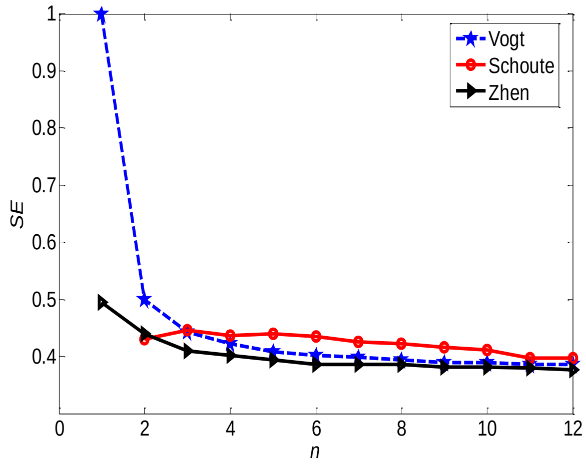

Fig. 6 Comparison of the system efficiency for the DFSA protocol with Vogt, Schoute and Zhen estimation methods.

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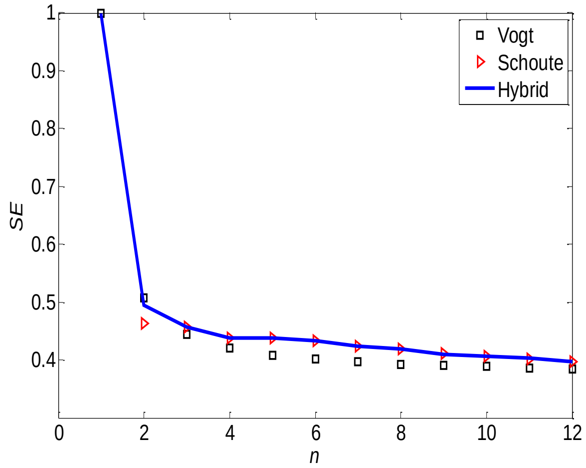

Fig. 7 Comparison between the new hybrid approach, Vogt and Schoute methods.

V. CONCLUSIONS

This paper investigates the use of an RFID system for traffic monitoring applications and focuses on the main issue which is tag collisions. Overview over anti-collisions protocols is presented with detailed discussion of the BFSA and DFSA. The paper uses the system efficiency to study the performance of two protocols when applied to the traffic monitoring applications. Based on the results, it is recommended to use the DFSA protocols with a hybrid tag estimator that combines the strength of the Vogt and Schoute approaches.

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