Early Frame Restart in RFID Systems

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Abstract. Throughput of inventoried tags is one the most important performance parameters for RFID systems. This paper presents an enhancement for the anti collision protocol for frame slotted ALOHA in RFID systems. It is especially designed for application with known size of the tag population such as in assembly lines or conveyer belts. It exploits the fact of low probability regions of the event space and is based on restarting a frame after the observation of a part of the whole frame. The performance of this algorithm is evaluated on different tag populations.

1 Introduction

One of the crucial performance parameters in RFID systems is the throughput of inventoried tags. Framed Slotted ALOHA (FSA) is deployed as anti-collision technique in the currently most popular standard of RF-ID systems in the UHF domain, the ISO/IEC CD 18000-6. In this technique a reader requests tags to answer in a time interval that is divided into F slots. At the beginning of the frame, any tag in the field randomly generates a number between 1 and the frame size F that determines the slot in which it tries to respond. It is intended to obtain as many as possible slots with exactly one response contained, since only then the responding tag is identifiable and can be accessed and controlled furthermore. But whenever more than one tag respond in the same slot, a collision occurs and the data sent by the involved tags are corrupted. The reader estimates the number of tags n in the field and adjusts the frame size accordingly. This update mechanism is usually performed after each frame. A further increase of the throughput is achieved by in-frame adjustment of the frame size (i.e. without quitting the interrogation round).

Special cases of RFID systems are applications where the number of tags in the field is known beforehand. Such as e.g. in an assembly line, or on a conveyer belt where the number of tags that passes the reader system stays constant over time. Other types of application are warehouse systems where pallets that carry the same amount of tags have to be identified. In this paper an algorithm is

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presented that is especially dedicated to RFID applications where the number of tags is known. It exploits the circumstance that if after several slots a status is observed that has a low probability of occurrence, it is beneficial for the throughput to issue a new start of the frame.

This paper is organized as following: In Section 2 a brief overview on related work is given. Furthermore, in Section 3 the concept of the early frame restart algorithm is presented. Results regarding different tag populations scenarios and the optimal number of observed slots for the restart are presented in Section 4. Finally, in Section 5 some conclusions are drawn.

2 Related Work

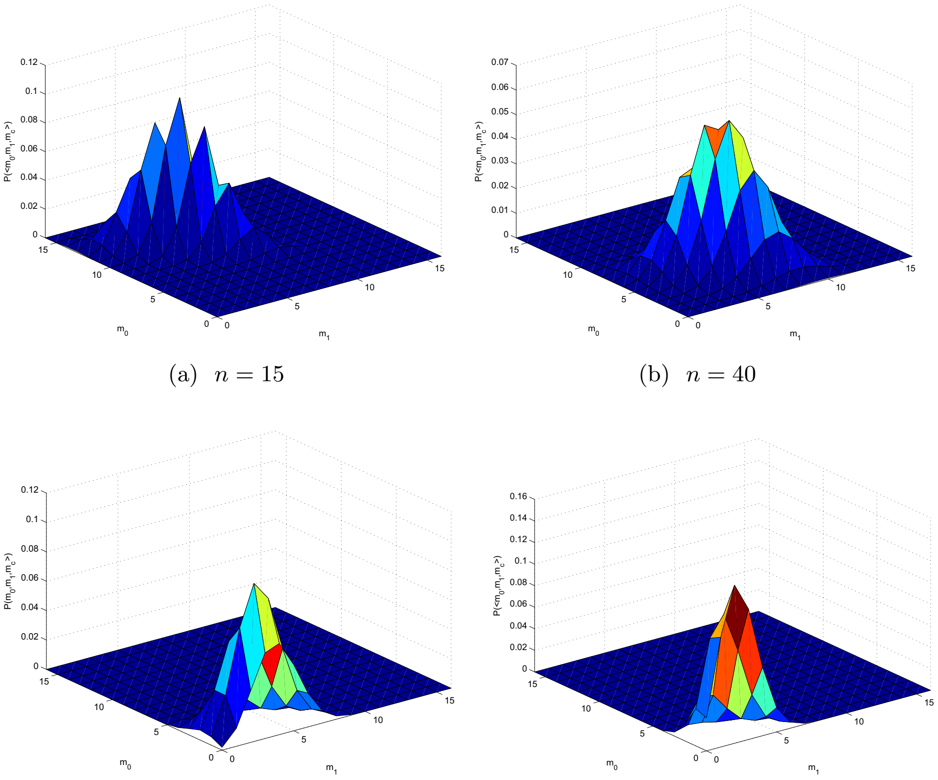
Most work in the area of anti collision algorithms for frame slotted ALOHA protocols in RFID systems sets a focus on optimally choosing the frame size while the size of the tag population is not known.

Vogt [5] introduced the minimum squared error estimator and analyzed its behavior for completely observed frames. The ISO/IEC 18000-6 D utilizes the so-called Q-algorithm to adjust the frame size based on the evidence of partly observed frames. This approach does not estimate the size of the tag population and thus allows for a quick and easy implementation [1, 4]. A further in-frame adjustment algorithm is presented by Knerr et al. [2]. Here, a minimum squared error estimator for the tag population in FSA anti-collision schemes for partly observed frames is formulated. Its general near-optimal performance has been demonstrated in comparison with the maximum likelihood estimator.

3 Early Frame Restart

In the work of Knerr et al. [3] the maximum likelihood (ML) estimator for the number of tags for completely and partly observed frames has been presented. This closed formula allows for computing the probability P of the event $\langle m_0, m_1, m_c \rangle$, where m_0 denotes the number of empty slots, m_1 the number of slots with only one tag answer (socalled singletons), and m_c the number of slots with collisions, under the frame size F, the observed slots N, and the amount of tags n. With this formula the socalled event space for all possible constellations of m_0, m_1, and m_c for constant parameters n, F, and N can be derived.

For example the Figures 1a, 1b, 1c, and 1d depict the event space for different scenarios of tag populations n. It becomes obvious that certain regions of this event space exhibit a low probability of occurrence compared to the high peak in this event space. In order to determine the regions of the event space with low probability of occurrence for different tag populations n the indicator $P_s = \sum_{n=n_{min}}^{n_{max}} P(\langle m_0, m_1, m_c \rangle)$ is computed. For example in Figure 2 an event space with this indicator P_s is depicted. Thus, two regions with a low indicator can be identified. The first one R_1 is denoted by a low number of singletons m_1 and an equal number of m_0 and m_c. The second region R_2 is specified by the number of singletons m_1 near to N.



(a) $n = 15$ (b) $n = 40$

(c) $n = 80$ (d) $n = 100$

Fig. 1: Probabilities of the event space for $N = 16$ and $F = 32$ for different tag populations n.

An observation of an event that is located in region R_1 indicates that it it will be beneficial to wait the whole frame because it is expected to have more than average number of frames detected in the second half of the frame.

The exploitation of region R_2 can be formulated as that if after N slots the number of observed tags m_1 is greater than its expectation the frame is immediately restarted. In order to compute the expected number of singletons we start with a binomial distribution which describes the fill level of r tags in a given slot.

$$B_{n,\frac{1}{F}}(r) = \binom{n}{r} \left(\frac{1}{F}\right)^{r} \left(1 - \frac{1}{F}\right)^{n-r}. \tag{1}$$

Here, F denotes the available slots and n the number of tags in the field. The expected number of slots $E_r = E\left(\mathcal{X}_r = \mathcal{X}_1\right)$ with just a single tag response, i.e.

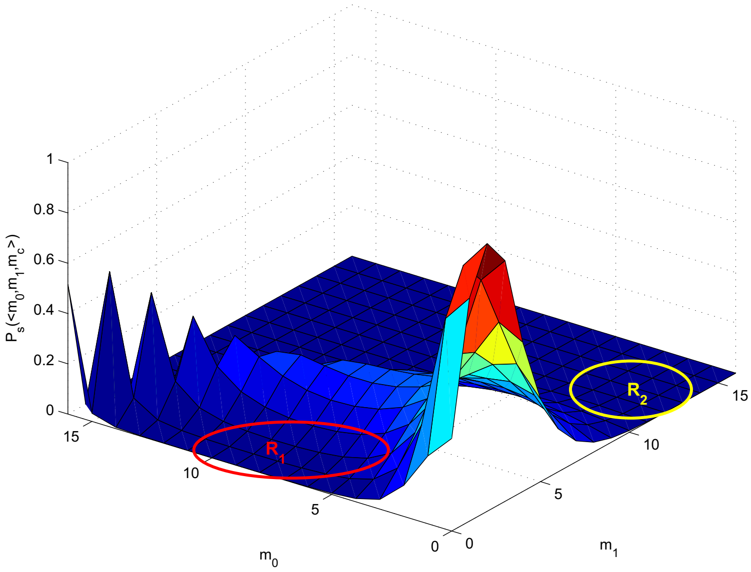


Fig. 2: Accumulated event plane for $F = 32$, $N = 16$ and tag population $n = 10, \ldots, 120$.

fill level $r = 1$, is of major interest to measure the throughput $T = \frac{E(\mathcal{X}_1)}{F}$ of the system. The number r of tags in a particular slot is called its *occupancy number*. Since the distribution (1) applies for all slots of a frame, the expected number of slots $\mathcal{X}_r$ with *occupancy number* r is given by:

$$E_r = E(\mathcal{X}_r^{F,n}) = F B_{n,\frac{1}{F}}(r). \tag{2}$$

Thus, for $r = 1$ the expectation is given

$$E_1 = Nn\left(1 - \frac{1}{F}\right)^{n-1}. \tag{3}$$

In Listing 1.1 a pseudocode example of the restart algorithm is presented. At first the parameter n is set according to the a priori known size of the tag population (Line 1). Afterwards in a loop new frames are initiated until the number of tags in the field is 0. Further the frame size is adapted in dependence on the new size of the tag population n according to the scheme of Knerr et al. [2] (Line 3). In Line 4 the parameter `FRAME_RATIO` determines the fraction of the frame that is used for the early frame restart. Next N slots are observed and the number of observed singletons is stored in $m1$. After computing the expectation of singletons (Line 10) according to (3) this is compared with the observation

$m1$. In case of $m1 > E1$ immediately a new frame is started. Additionally, a parameter `MIN_F` is utilized to tune the early restart only in case of a minimum frame size.

Listing 1.1: Pseudocode for early restart algorithm.

```
EarlyRestart() {
  n = SIZE_OF_TAG_POPULATION;
  while (n > 0) {
    F = getThroughputTable(n);
    N = ceil(F*FRAME_RATIO);
    for(i = 1; i <= N; i++)
    {
       Event<m0,m1,mc> = processCurrentSlot();
       update<m0,m1,mc>;
    }
    E1 = getExpectation(m1);
    if(m1 < E1 || F < MIN_F)
    {
      for(i = 1; i <= N; i++)
      {
        Event<m0,m1,mc> = processCurrentSlot();
        update<m0,m1,mc>;
      }
    }
    n = n - m1;
  }
}
```

4 Results

The restart algorithm includes the parameter `FRAME_RATIO` which determines the restart behavior of the algorithm. It has been tested for different parameters of `FRAME_RATIO` thus looking for the highest average throughput that can be achieved. In Figure 3 it is shown that the highest throughput is achieved if frame restarts occur after $F/2$. Furthermore, the restart algorithm has been tested on several tag population sizes. Thus, for each tag population n the number slots S that are needed to detect all tags in the field is measured. Hence, a throughput of $T = n/S$ can be deduced. The results are averaged for 10000 runs ($T_{\text{avg}} = \frac{1}{1000} \sum_{i=1}^{10000} T_i$). The result of this experiment is depicted in Figure 4. It is compared to the performance of this algorithm without early frame restart feature. A performance gain can be achieved for tag population which are in the size of a frame size jump ($n = 23, 24, 46, 47, 93, 94, 187, 188, 374, 375, 749, 740$) according to the scheme of Knerr et al. [2]. Whereas in the regions where the frame size matches the tag populations ($n = 70, 150, 200, 250, 500, 650$) no performance gain is obtained. The upper dashed curve shows the theocratically possible throughput performance if the outcome of the tag response of the frame

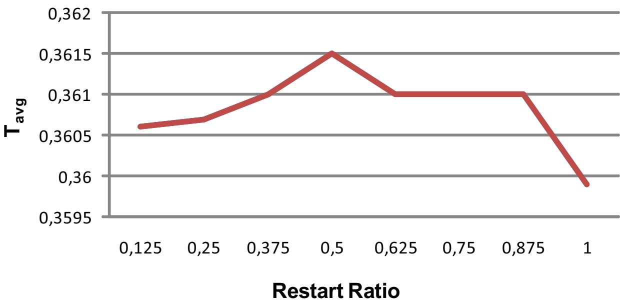


Fig. 3: Throughput in dependence on the parameter FRAME_RATIO.

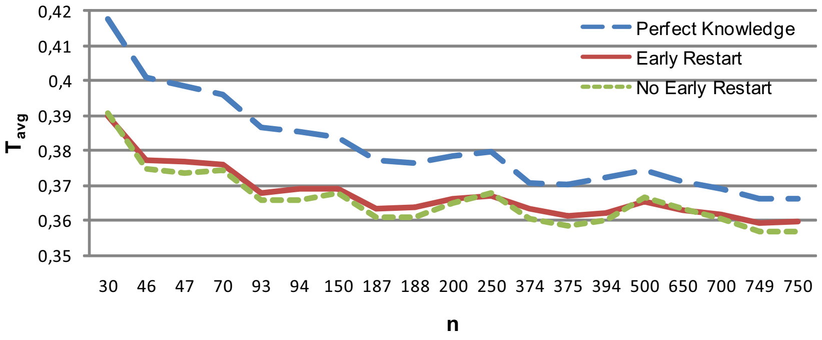


Fig. 4: Average throughput for different tag population sizes.

would be known beforehand. I.e. at the half of the frame the decision is made if the number of remaining singletons in the frame is lower than the already detected number of tags based on perfect knowledge of the furture.

5 Conclusions

This paper presents an enhancement to the anti collision protocol for frame slotted ALOHA in RFID systems. This algorithm is especially designed for application with known size of the tag population. It exploits the fact of low probability regions of the event space and waits until half of the frame length is executed and performs a frame restart in the case of an observed event with low probability of occurrence. It achieves a performance gain of the average throughput if the initial frame size is not well suited to the tag population size. Further work will try to combine this technique with other slot-by-slot updating algorithms for applications with unknown tag population size.

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