LookUp Algorithm for Adapting Frame Size in DFSA of Passive UHF-GEN2 RFID

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Abstract: - Due to low costs and high applicability in object tracking and building smart environments, passive RFID technologies became very popular in every-day usage. However, there are some MAC level constraints on the efficiency of Reader-Tag communication, because lack of tag computational abilities. In the accordance with standard Framed Slotted ALOHA (FSA) protocols we provide improvement for tag identification which increases throughput of the RFID system and thus minimizes response time from RFID tags. For comparison, simulation results show that our method provide better efficiency then Q-selection algorithm from UHF-Class1-Gen2 standard.

Key-Words: - Framed Slotted ALOHA, transmission control strategy, Q-selection Algorithm, RFID identification, Number of tags estimation

1. Introduction

RFID (Radio Frequency Identification) technologies are used today for building smart environments, different localization and tracking services, or human habits monitoring. Classic RFID system consists of RFID reader connected to computer, RFID antenna and RFID tags. Computer connected to RFID reader is controlling its functions. Reader through its ports sends signal radiated with RFID antenna in order to communicate with tags. According to the type of RFID tags we can divide RFID technologies into three groups [1]:

- Active RFID uses batteries for powering tags and its memory storage. This technology is more expensive but provides more robust, accurate and confident localization technique.

- Passive RFID tags do not have power supply. To power them up, tags use energy of electromagnetic waves radiated by RFID antenna, and thus through backscattering principle sends its memory content back to the reader. Using passive technology we get more cost effective way of localization technique for mass use, because price of UHF passive RFID tag is about 0.10 $ [2]. However, there are disadvantages in reading range or anti-collision control which still need work on its QoS improvements.

- Semi-Active RFID uses batteries for powering tags memory storage but data transmission is similar to passive technologies.

Our work assumes usage of passive UHF-Class1-Gen2, technology, standardized by EPCglobal [3] specifying identification, capturing and exchange of information protocols. Within EPCglobal part [4], specifies communication protocols for tag identification on physical and data link level layers.

In this paper we are addressing problems of limits on efficiency of MAC (Medium Access Control) layer. Standard [4] specifies Framed Slotted ALOHA (FSA) algorithm as a transmission control strategy and proposes Q-Selection Algorithm for adaption of frame length. FSA algorithm is depicted on figure 1. Reader initiates start of frame. Within the frame tags can

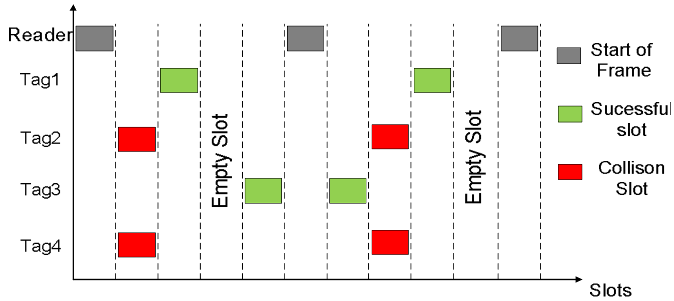

Fig. 1. Framed Slotted ALOHA with length of frame 4, and with 4 tags within of interrogation zone.

transmit their data. To make algorithm efficient it is important to set optimal frame size, which length is equal to the number of tags [5] in order to low number of collisions and empty slots (garbled slots) during a frame. To make it optimal, one needs to know number of tags within interrogation zone and set it as close as possible to that value. Since it is impossible to know dynamics of different environments, we have provided results of monitoring behavior of the number of collisions and successful slots within the fixed frame size, and used those results of simulation for estimation of number of tags, thus deriving optimal frame size.

Rest of the paper is structured as follows: In section 2 we provide detail analysis on FSA algorithm and related works on the trace of several approaches deriving optimal frame size. Section 3 provides analysis and results of our approach on deriving optimal frame size. In section 4 we provide some concluding remarks and future work.

2. FSA Analysis and Related Works

Passive RFID technologies use a few ALOHA based [6] transmission control schemes such as pure ALOHA, where tag reports to reader as soon as get into interrogation range [1] [7], which increases number of collisions. Slotted ALOHA (SA) divides time into slots within tags can reply. This technique reduces number of collisions by a half [1][8], but setting up number of slots will be a problem if there is a number of tags within interrogation area. Problem is solved with Framed Slotted ALOHA (FSA), where time is divided into frames, which are again divided into slots. FSA provides better results in collision ratio than other techniques, but it uses fixed frame size, where SA gives better results. In order to manage frame length Dynamic Framed Slotted ALOHA (DFSA) is used, where reader can adapt frame length when necessary. Another approach in transmission control are Tree-Search Protocols, which [5] have greater complexity since each garbled timeslot generates a distinct sub-tree, whereas with dynamic frame length ALOHA all mobiles corresponding to any garbled timeslot of a frame are combined to one new backlog (the number of tags to retransmit) for the next frame. Framed slotted ALOHA has greater applicability since it takes into account the effects of noise and capturing.

Most commonly used scheme for Medium Access Control in passive UHF RFID technology is Dynamic Framed Slotted ALOHA protocol, where reader informs tags about number of slots (frame length) they can take. Reader broadcasts *Q* using command *Query*, which tags receive and set up their counters as a random value from $0\text{-}2^Q$. When tags receive command *QueryREP*, they decrement their slot value by *1*. First tag reaches the zero value sends its information back to the reader. Figure 1 illustrates Frame Slotted ALOHA where size of frame is 4. During Reader-Tag communication there are three possible scenarios:

1. There is only 1 tag in a current slot reader is inventorying, which occurs with a successful slot.
2. There is more than 1 tag in a current slot, which occurs with collision slot, because reader cannot resolve more than 1 tag signal. However standard [4] proposes resolving 1 signal if possible, but along with tag signal strength it may be not possible to do so.
3. There is no tag in a current slot, which occurs with an empty slot in a frame.

Due to tags low computational abilities, there is nothing much we can do, except varying frame size to avoid number of garbled slots and increase efficiency of a system by increasing number of successful slots in the frame, as it is available in DFSA. To measure quality of different variants of DFSA, standard measures of System Efficiency and Collision ratio are used.

Probability that one tag successfully transmits its ID during a slot is given by [5]:

$$E(p) = Np(1-p) \qquad (1)$$

where *p* is probability of finding each tag within the frame of length *L*, and *N* represents total number of tags. In order to find value *p* which provides maximum of function *E(p)*, we derive (1) which results in:

$$E'(p) = N(1-p)^{N-1} - Np(N-1)(1-p)^{N-2}$$

$$E'(p) = N(1-p)^{N-2}((1-p) - p(N-1))$$

$$E'(p) = 0 \rightarrow p^* = \frac{1}{N}$$

If we take *1/N* as a point of maximum value, i.e. frame length as a number of slots then we get:

$$E(p^*) = \frac{(1-\frac{1}{N})^N}{(1-\frac{1}{N})}$$

$$\lim_{N\to\infty}(1-\frac{1}{N}) = 1$$

$$\lim_{N\to\infty}(1-\frac{1}{N})^N = \frac{1}{e}$$

$$\lim_{N\to\infty}E(p^*) = \frac{1}{e} = 0.368 \qquad (2)$$

Value of *0.368* is maximum efficiency of the FSA if number of tags equals frame length. Now, we can define System Efficiency as a:

$$System\ Efficiency = \frac{number\ of\ successful\ slots}{total\ number\ of\ slots} = \frac{N_S}{N_S + N_C + N_E} \qquad (3)$$

System Efficiency of a FSA system is depicted on figure 2. If we change frame size to be equal to the number of tags we can maximize System Efficiency. Another measure of system quality is:

$$Collision\ Ratio = \frac{number\ of\ collision\ slots}{total\ number\ of\ slots} = \frac{N_C}{N_S + N_C + N_E} \quad (4)$$

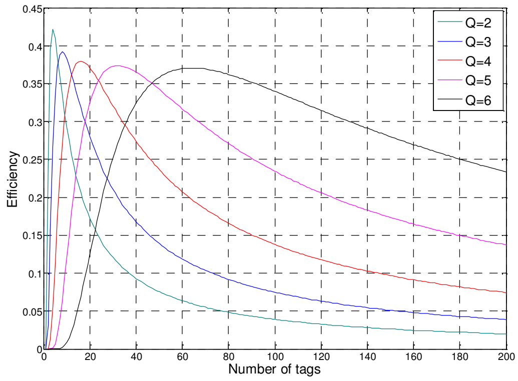

Fig. 2. Efficiency of the FSA for different frame lengths

In DFSA frame length should be adapted in order to increase System Efficiency and to low Collision Ration. Adaption of the frame size in Q-Selection algorithm [4] is depicted on figure 3. Reader is sensing environment by broadcasting *Q=4*. Tags are replying within the frame and the system is counting number of collision and empty slots. If empty slot occurs, *Q* for the next frame will be:

$$Q_{fp} = \max(0, Q_{fp} - C)$$

Or if collision slot occurs, *Q* for the next frame will be:

$$Q_{fp} = \min(15, Q_{fp} + C)$$

At the end of frame, reader broadcasts a new *Q*. Algorithm is repeating, where *Q* can be in range of *0-15*, and the constant value *C* is chosen in the way to be small for high number of tags and large for low number of tags.

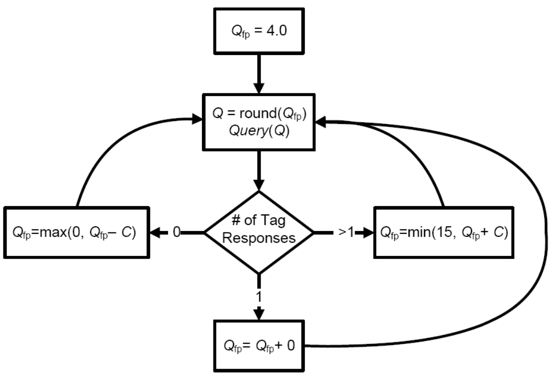

Fig. 3. Q-selection Algorithm sequence diagram from GEN2 [4] standard

Implementation and use of Q-selection is efficient and simple. Frame size should be adopted in order to minimize the number of garbled slots but to increase number of successful slots in the frame. However, several authors proposed their solutions [9-14] for adopting frame size in order to minimize number of garbled slots. Authors in [10] use chebyshev's inequality as a minimal distance between expected value of distribution and random measuring result. Another approach [9] gives Bayesian estimation of number of tags from last Z number of frames. [11] assumes that there are only garbled slots and empty slots in the frame. [12] presents transmission control strategy by approximation of number of tags as a Poisson distribution. Authors in [13] estimate number of tags as a collision rate for maximal throughput times number of collided slots a frame. Work [14] proposes setting of frame length as a

$$Q = ld\,\frac{N_s}{0.368}$$

which in high rate of tags provides better results than Q-Selection. DFSA frame size adaption in [15] uses expected value of *2.39* for backlog estimation. Frame adaption is done only when the estimated tags number is *1.15* times greater than tags number in previous cycle.

In this paper we provide another approach which includes measuring number of collision and successful slots within fixed frame length. Obtained results shows linear behavior of changes, which extrapolation to each frame size shows better results than Q-Selection Algorithm and other approaches. In the next section we provide algorithm of our approach as well as it results.

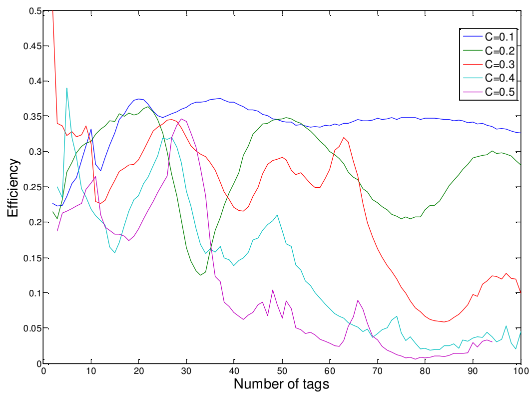

Fig. 4. Efficiency of Q-Selection Algorithm as Number of tags changes for different C value

3. Lookup Matrix and Search Algorithm

For definition of measuring scenario several assumptions must be considered:

1. We use passive RFID technology, UHF-class1-gen2 tags
2. Reader talks first technology
3. Space of testing must be ideal, without interfering of other devices and reflection interference.

4. There is no early cancelation of the transmission during the frame, as it is done within work of several authors [9-10].

5. There were no errors in wireless channel during identification procedure. That means that error due to propagation delay, path loss, and noise is ignored.

6. Due to tag random generators we consider that generation of random numbers have the uniform distribution.

Our improvement include estimation of total tag numbers within the interrogation zone and thus deriving Q as a $log_2(N)$. Estimated total tag number is obtained experimentally. If we take fixed frame length ($L=2^Q=16$) and $n=100000$ experiments of throwing $N=64$ "balls" (tags) into random frame spot we obtain Lookup matrix considering two variables, the number of collision slots and the number of successful slots. Lookup matrix provides estimated number of tags for all combinations of successful and collision slots in the frame. Value in the Lookup matrix is a mean value of realizations for each collision and successful slot pair. As a mean value we took position mean value of mode, as a more accurate representative. Maximum value Lookup Search Algorithm can provide is estimated N for $Q=7$, for all collision slots scenario, when frame size is *16*, while Q-Selection can provide maximum $Q=6$ for all collision slots scenario if we choose $C=0.1$ for a large number of tags. Value C can be higher, then we can estimate higher tag number, but also gain lower efficiency of the system, because of high number of empty slots, as it is depicted on figure 4.

For the Algorithm implementation we use first frame with $Q=4$ for sensing the environment (finding pair of collision-successful slot number), and the size of the next frame is obtained from lookup matrix for resulting scenario of collision and successful slots. For the pair, number of tags is obtained from Lookup matrix and thus using $Q=round(log2(N))$ optimal frame size is derived. Figure 4 represents linear behavior of collision-successful slots changes results in the Lookup matrix (*Q=4, n=100000 experiment, N=64 tags*) when number of tags is increasing.

Results provided on figure 5 can be displayed in 2-dimensional space as a combination of collision slots and estimated tags number, where parameter is a number of successful slots. Other way to display it is using number of successful slots and estimated number of tags, where parameter is a number of collision slots. Both variants are depicted on figures 5 and 6. If we consider figure 6 we can model the lines as depicted on figure 7 and extrapolate them to be usable in any frame length, as a lines which are equidistant within frame length of any size. We use minimum and maximum points and derive line through predefined points. Minimums and maximums are constrained with the frame size. Constraints meaning are that total number of tags cannot be larger than number of collisions and number of successful slots. Last line for $N_C=16$ actually represents a single point, but experiments showed that full collision scenario actually represents frame length of $2^7=128$, so we modeled it accordingly, as it is depicted on figure 7. With results obtained from Lookup matrix we generalize behavior for every frame length *1-32768*. Pair of minimum and maximum is derived for each collision slot scenario within the frame, and proper value of number of tags is calculated. Next frame length is adopted according to estimated N as a $round(log_2(N))$. Lines modeling in this paper are obtained experimentally, but future work will include combinatorial model of theoretical thresholds.

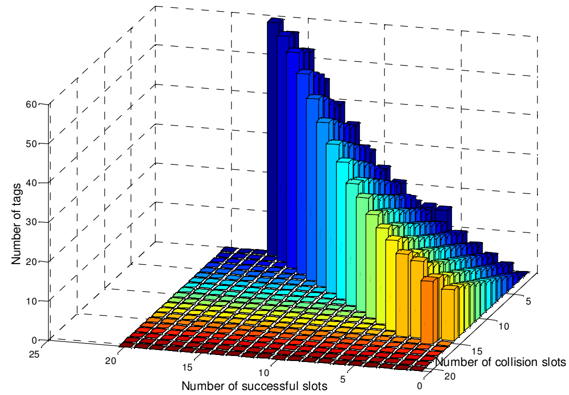

Fig. 5. Lookup matrix graph, with constraints on frame size, Q=4

To make comparison standard measure of efficiency (3) is used, together with collision ratio (4) as another result dimension, describing model parameters as number of successful, collision or empty slots in a frame.

Using extrapolated data from the developed model implemented algorithm estimates frame length for every frame size. Efficiency of described model is depicted on figure 8.

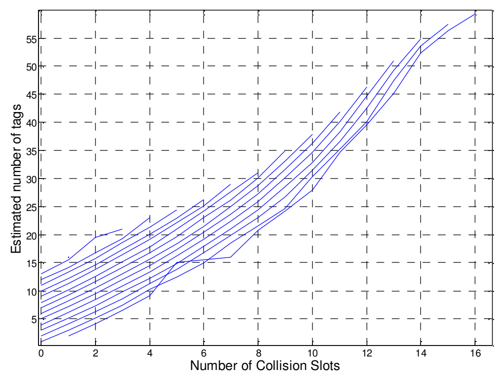

Fig. 5. Behavior of estimated number of tags if number of collision changes during a frame (Q=4). Parameter is number of successful slots (down-up 1-16)

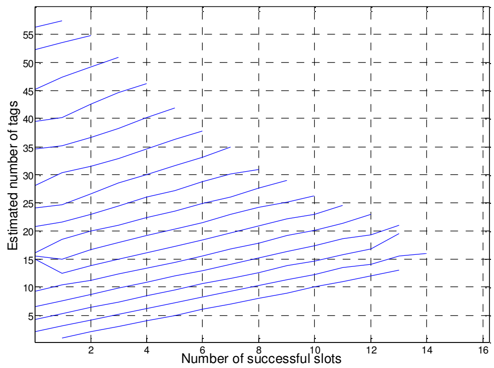

Fig. 6. Behavior of estimated number of tags if number of successful slots changes during a frame (Q=4). Parameter is number of collision slots (down-up 1-16)

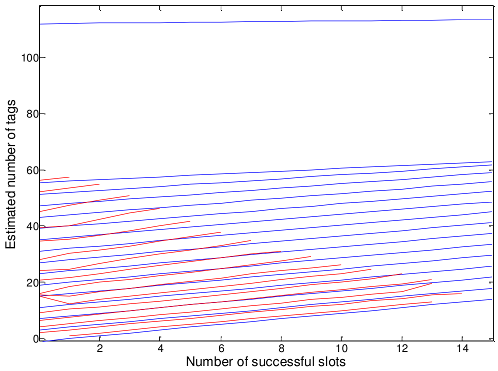

Fig. 7. Modeling of the lines from fig 4, as a linear model

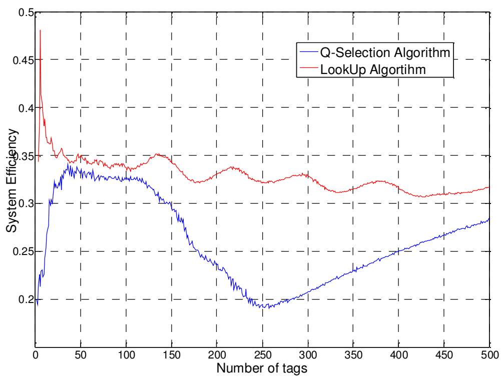

Fig. 8. Efficiency of Q-Selection and LookUp Algorithm

On Figure 9, collision ratio is depicted both for Q-Selection and Lookup Algorithm. Results for Q-Selection is for C=0.1, as best chosen C for high tag rate, as it is depicted on figure 4. With low collision ratio of Q-Selection algorithm, results of empty slots ratio is higher, because of lower efficiency than LookUp algorithm. It means that Q-Selection algorithm for higher tag ratio estimates larger frame size, and thus increases the number of empty slots. Authors in [10] provide mean collision ratio value of 0.25 for their algorithm approach; however our work lowers it on several segments as it is depicted on figure 9.

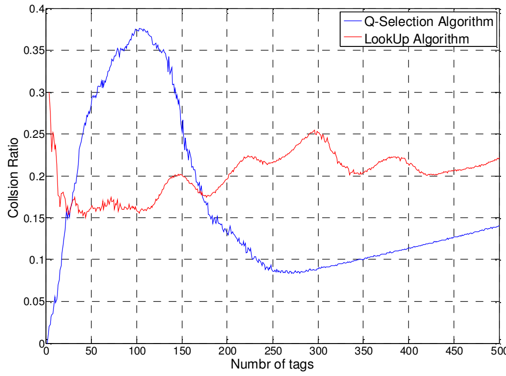

Fig. 9. Collision Ratio of Q-Selection and Lookup Algorithm

4. Conclusion

In this work we presented the improvement for tag estimation number in the manner of more precise frame length definition and thus reducing tag identification time. Algorithm includes finding pair of collision and successful slots number in the LookUp matrix, which is the mean value of experiments realized for collision-successful pair and represents estimated tag number within interrogation zone. Using estimated number of tags we derive optimal frame size as a Q=log2(N). Results obtained in LookUp matrix, can be extrapolated as a equidistant lines within the frame of any size, thus deriving optimal Q. Provided results show that our algorithm gives better System Efficiency results than standard Q-Selection Algorithm.

Future work will include combinatorial model of number of number of tags estimation and theoretical thresholds for collision-successful slot pair, since they are provided experimentally in this paper. To verify LookUp Algorithm approach authors will use A Flexible Software Radio RFID Reader, built using USRP Software Radio Platform in conjunction with GNU radio framework, developed by [16].

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