Tags/s - RFID reader-tag communication throughput using Gen2 Q-algorithm frame adaptation scheme

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Abstract: Radio Frequency Identification (RFID) became the most popular and used technology for items identification and tracking. Typical scenario of its application is a pallet of products bearing RFID tag, which passes by portal equipped with RFID antennas. In such scenario it is important to identify all tags as soon as possible. Access control mechanism widely used in RFID system is Dynamic Framed Slotted ALOHA (DFSA), which throughput can be maximized if one can estimate the correct number of tags and set the size of the next DFSA frame accordingly. Gen2 standard in RFID suggests usage of Q-algorithm for adapting frame size in DFSA. In this paper we provide 3 typical scenarios regarding the physical setup of an Gen2 RFID reader, with all significant details that allows to measure total time to identify all tags. As a result we provide tag identification time in terms of tags/s, by exploiting Q-algorithm frame adaptation scheme.

Key–Words: ALOHA, Dynamic Frame Slotted ALOHA, Gen2 throughput, tags/s.

1 Introduction

RFID technology, based on wireless communication between tags and reader is the most popular technology used for items tracking, identification, business process automation and various industry applications [1]. Typical RFID system is consisted of RFID reader controlled by host computer which communicates through its antennas WITH RFID tags. Regarding frequency bands, RFID technologies can be divided into Low Frequency (LF), and High Frequency (HF) RFID systems used for near-field applications (depending on size of its antennas, up to 30 cm of reading range), and Ultra High Frequency (UHF) and microwave frequencies for far-field applications. More detailed preview of different tags performances are given in [2]. In addition, tags can be with or without battery, which also regulates reading range as well as its price. In terms of best price-performance ratio, and by presenting the enabling technology for Internet of Things (IoT) applications is Gen2 RFID technology [3], where tags could be read up to 10 meters away from the reader, they do not own battery, and their price is about 0.1 USD. Gen2 tags are powered using radio waves transmitted by an reader antenna. Examples of Gen2 tags are shown in Figure 1.

Since Gen2 tags do now own its own battery, and they are powered through received radio-waves they cannot afford themselves energy expensive operations. Therefore, to communicate with the reader, some energy-efficient technique for multiple tag communication in the Medium Access Control (MAC) layer should be employed. In RFID systems widely used protocols for tag access control are random access schemes based on Tree [4, 5], and ALOHA algorithms [6]. The most popular, among suggested algorithms is Dynamic Frame Slotted ALOHA (DFSA) [7], due to its highest efficiency. However, to maximize its throughput is is necessary to set size of DFSA time frame properly.

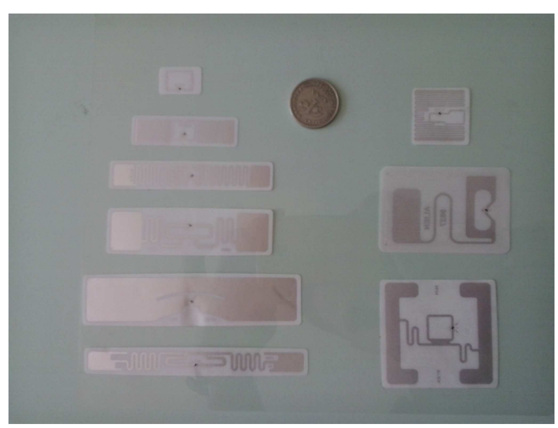

Figure 1: Various Gen2 RFID tags, manufactured by Alien Inc

In this paper we evaluate the performance of Q-algorithm suggested as a frame adaptation scheme in Gen RFID system, with all significant details in order to compute mean time for tags identification.

The paper is structured as follows. In the next section we describe usage of DFSA protocol in RFID systems, along with brief analysis of its throughput. In Section 3 we provide detailed analysis on timing of Gen2 protocol with description of DFSA frame adaptation scheme, called Q-algorithm. In Section 4 we provide simulation results of Gen2 process of tags identification using Q-algorithm for 3 different scenarios. In Section 5 we conclude our paper.

2 DFSA for ALOHA-based RFID systems

In DFSA protocol (reader talks first (RTF) technology), reader-tag communication is divided into the time frames, latter divided into time slots. At the beginning, reader announces the size of the time frame, which tags receive, decode and set themselves into the random position, i.e. time slot, and respond back to the reader once their slot is interrogated. According to the type of the time slot, there are tree possible scenarios:

- none of tags respond within the slot; the slot is assumed to be Empty
- one tag respond within the slot; the slot is assumed to be Successful
- multiple tag respond within the slot; the slot is assumed to be Collision

Example of the interrogation rounds when the size of frame equals 4 is shown in Figure 2. What one actually wants is to reduce the number of Empty and Collision slot in order to increase number of Successfully read slots, and thus make reader-tag communication more efficient.

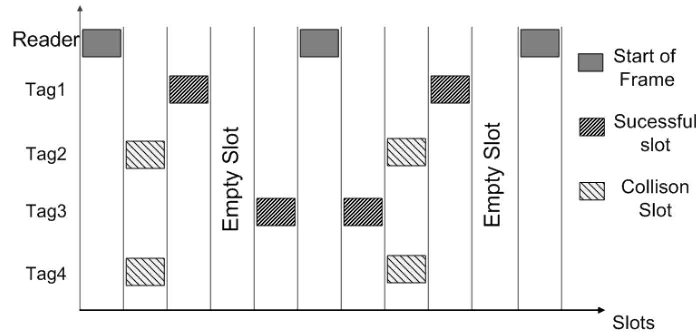

Figure 2: Two reader-tag interrogation rounds, with four tags in the interrogation area.

2.1 Throughput analysis

To increase the throughput of DFSA system, it is necessary to reduce the number of Collision and Empty slots, i.e. to increase the likelihood of detecting Successful slot. Only thing one can adapt is the frame size. For given frame size, providing lesser frame size would increase the probability of detecting collision slot, while providing bigger frame size would increase the number of empty slots. Both cases results in lower throughput. Therefore, the throughput is a function of two variables: the frame size (L), and the number of tags (n), and can be defined as [8]:

$$U(n,p) = np(1-p)^{(n-1)} \tag{1}$$

where $p = 1/L$ stands for the probability of finding tag within a slot of the frame L. To find maximum throughput of (1), first derivative equals to zero, which results in:

$$\frac{dU(n,p)}{dp} = n(1-p)^{(n-2)}((1-p)p(n-1)) = 0 \tag{2}$$

where maximum throughput is obtained when number of tags (n) equals frame size (L), and in such scenario $U(n,p) = 1/e = 0.368$.

As it can be concluded, the throughput of the system can be increased only if the number of tags is estimated correctly, and frame size set accordingly. There has been done a significant amount of work in order to estimate the tag number, such as [9–16], where none of the presented works does not evaluate Gen2 algorithm by means of standard physical setup of an Gen2 RFID reader.

In the following section we provide concrete Gen2 DFSA implementation, including all significant details for its throughput analysis, along with the description and implementation of Q-algorithm given in Gen2.

3 DFSA Gen2 implementation

Gen2 specifies protocol communication between reader and tags. When reader announces size of the frame ($L = 2^Q$) by broadcasting Q through $Query$ command, tags take random spot in the frame using their built-in slot counters. Number initialized in the slot counter is random number in the range 0 - $2^Q - 1$.

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Once counters are initialized, reader begins the interrogation. Tag(s) having their slot counter set to 0, immediately respond back to the reader with their 16-bit random number ($RN16$). If reader successfully decodes tags $RN16$ command, it should be acknowledged using (ACK) command, which tag follow with their Electronic Product Code (EPC). EPC actually stands for the tag Identifier which is used as a user-level code for item identification. Once EPC is successfully read, the slot is considered to be successful. If $RN16$ or EPC is for some reason unsuccessfully decoded, reader transmits not acknowledged (NAK) command, and those tags are to be identified in future frames. If the slot is successful, reader issues $QRep$ command. When tags decode it, they decrement their slot number by 1. Again, tags having slot set to 0 respond back to the reader. These steps are repeating until all slots get interrogated, i.e. there will be $2^Q - 1$ $QRep$ commands. In the case of the Empty slot, reader shall not wait the total time of $RN16$, due to request that tags should respond to the reader $QRep$ in given time.

Interrogation in Gen2 is organized in rounds, which does not end until all tags get identified. When the first frame of the first round finishes, only collision tags are moving to the next frame of the same round. Given round does not complete until there are collision slots. Once the round is complete, reader begins another interrogation round and identifies all tags again.

However, all Gen2 commands are of different durations, where we in the next subsection provide analysis on the duration for commands in Gen2 protocol, that will allow us to compute total time for tags identification.

3.1 Timing in Gen2

Figure 3 gives all collision, empty and successful slots time details. $Query$ command is consisted of reader-tag preamble (PRT) and 22 bits, where duration of each reader bit is denoted with Reader bith length (Rbl). Rbl is based on Tari value, (2Tari+0.5Tari)/2 $\leq$ Rbl $\leq$ 3Tari/2, while 6.25μs$\leq$ Tari $\leq$ 25μs. PRT can be set to $12.5 \cdot 10^{-6}$+ Tari + 2.5Tari+ 1.1TRCal, where TRcal is tag-reader calibration symbol and equals DR $\cdot$ Tpri, where DR stands for Division Ratio which can be set to 64/3 or 8. DR is used for defining tag-reader symbol rate, along with Tpri=1/BLF, and BLF stands for Backscatter Link Frequency (tag-reader response frequency), 40kHz $\leq$ BLF $\leq$ 640kHz. Lower limit for PRT is $12.5 \cdot 10^{-6}$+ Tari + 2.75Tari+ 3RTCal, where RTcal is tag-reader calibration symbol (1.5Tari $\leq$RTcal $\leq$ 2Tari). Duration of $Query$ command is then:

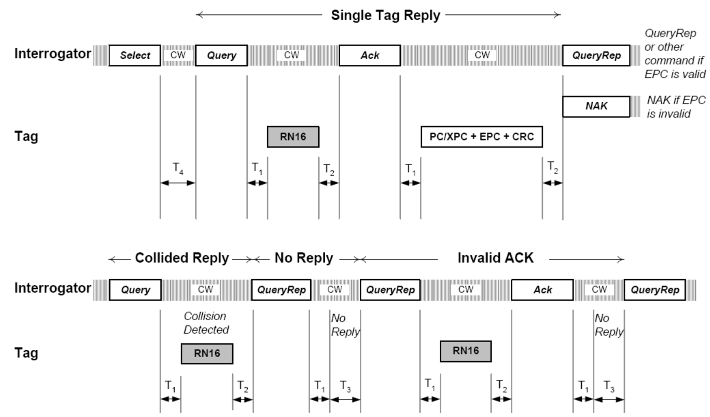

Figure 3: Timing details for each slot type in Gen2 RFID

$$T_{Query} = \text{PRT} + 22\text{Rbl} \quad (3)$$

ACK command is consisted of Time Frame Sync ($12.5 \cdot 10^{-6}$+ Tari + 2.5Tari $\leq$ TFS $\leq$ $12.5 \cdot 10^{-6}$+ Tari + 3Tari) and 18 Rbl bits. Duration of ACK command is then:

$$T_{ACK} = \text{TFS} + 18\text{Rbl} \quad (4)$$

$QRep$ command is contained of TFS and 4 Rbl bits, i.e. its duration is:

$$T_{Qrep} = \text{TFS} + 4\text{Rbl} \quad (5)$$

Time T1 is in between max(RTcal,10Tpri)$\cdot$(1-0.1)-(2$\cdot$($10^{-}6$), and max(RTcal,10Tpri)$\cdot$(1+0.1)+(2$\cdot$($10^{-}6$), while time T2 is in between 3Tpri and 20Tpri. Time T3 is given by minimum of 0.1Tpri, however this cannot be easily implemented in practice, due to tag response offset, and more sophisticated readers. Further, M denotes the number of Miller subcarrier cycles in tag response, which could be set to 1 (FM0-code), 2, 4 and 8. TRext value 0 (TRext_0=4) or 1 (TRext_1=16) denotes the presence or absence of pilot tone. Using given values, duration of $RN16$ command is:

$$T_{RN16} = ((\text{TRext}_i \cdot \text{M})/\text{BLF}) \quad (6)$$
$$+((6\text{M})/\text{BLF}) + ((17\text{M})/\text{BLF}) \quad (7)$$

where last bit, i.e. 17th bit is dummy. Further, duration of EPC command is:

$$T_{EPC} = ((\text{TRext}_i \cdot \text{M})/\text{BLF}) + ((6\text{M})/\text{BLF}) \quad (8)$$
$$+((\text{M} \cdot (16 + 96 + 17))/\text{BLF}) \quad (9)$$

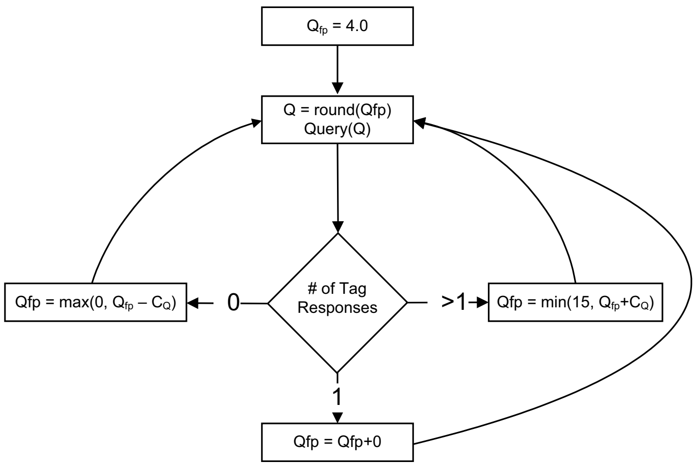

Figure 4: Q-Selection algorithm suggested in [3], where $0.1 \leq C_Q \leq 0.5$

Therefore, duration of Empty slot is given by:

$$T_E = T_{Qrep} + T1 + T3 \tag{10}$$

the duration of collision slot is:

$$T_C = T_{Qrep} + T1 + T_{RN16} + T2 \tag{11}$$

and the successful slot:

$$T_S = T_{Qrep}+T1+T_{RN16}+T2+T_{ACK}+T1+T_{EPC}+T2 \tag{12}$$

Using equations (10, 11, 12), throughput in terms of tags/s is then given with ratio of successfully read tags divided with the duration of the frame:

$$U_t = \frac{N_S}{T_E \cdot N_E + T_C \cdot N_C + T_S \cdot N_S + T_{Query}} \tag{13}$$

3.2 Q-algorithm

Q-Algorithm suggested for usage to identify tags uses simple mechanism that is based on Q-learning algorithm [17]. It works in the way that system is learning from the previous evidence of number of Empty, Successful and Collision slots. Interrogation starts with some initial Q_{fp}, i.e. $Q_{fp} = 4.0$, and while interrogating slots, it learns in the following way: in the case of empty slot, Q_{fp} should be decreased for some C_Q, while collision slot would increment Q_{fp} for value C_Q. However, proposed system is faulty since it does not specify the way how to choose constant C_Q. Once reader finishes interrogation of current time frame, it updates and broadcast new Q, as $Q = round(Q_{fp})$. The state diagram of Q-algorithm is given in Figure 4.

	Scenario1	Scenario2	Scenario3
Tari	25μs	16μs	6.25μs
RTCal	2Tari=50μs	Tari+0.75Tari =28μs	Tari+0.5Tari =9.375μs
BLF	40kHz	340kHz	640kHz
T1	27.7ms	29.412μs	12.063μs
T2	50ms	29.412μs	4.6875μs
TRext	0	0	0
M	8	4	1
T_{RN16}	5.4ms	458.82μs	60.937μs
T_{EPC}	27.8ms	1.8ms	235.94μs
T3	12.4ms	152.94μs	0.15625μs
PRT	0.2625ms	128.5μs	48.125μs
TFS	0.1125ms	72.5μs	34.375μs
Rbl	37.5μs	22μs	7.8125μs
T_{Query}	1.1ms	612.5μs	220μs
T_{ACK}	787.5μs	468.5μs	175μs
T_{QRep}	262.5μs	160.5μs	65.625μs
T_S	35.8ms	3ms	571μs
T_C	6.4ms	678.15μs	143.31μs
T_E	5.9ms	342.85μs	77.844μs

Table 1: Gen2 reader-tag interrogation parameters

4 Simulation Results

In order to provide results of identification time for different C_Q values, we have conducted exhaustive Monte-Carlo simulations of Gen2 process of identification, with 10000 experiments by changing number of tags from 1 to 250. All simulations are conducted in the for the channel that is error free. Experiments were conducted for 3 Scenarios, given in Table 4. Scenario 1 is the lowest throughput scenario, which maximizes probability that tags responses will be successfully detected. Scenario 2 describes interrogation parameters with mean interval parameters of interrogation, while scenario 3 gives the highest Gen2 tag reading throughput. Throughput example, and impact on Q-usage of Gen2 protocol for the Scenario2 is shown in Figure 5.

Tag identification times for all tree scenarios is provided in Figures 6, 7, and 8. As it can be concluded from simulation results, $C_Q = 0.3$ provides the best option, which provides the most stable results.

5 Conclusion

In this paper we have analysed throughput of Gen2 protocol when number of tags and tag interrogation parameter changes. From presented results it can be

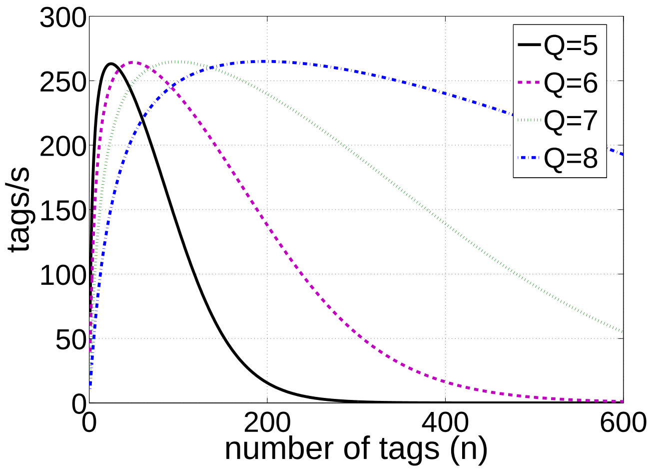

Figure 5: Influence of choosing Q for tag reading in the interrogation Scenario2.

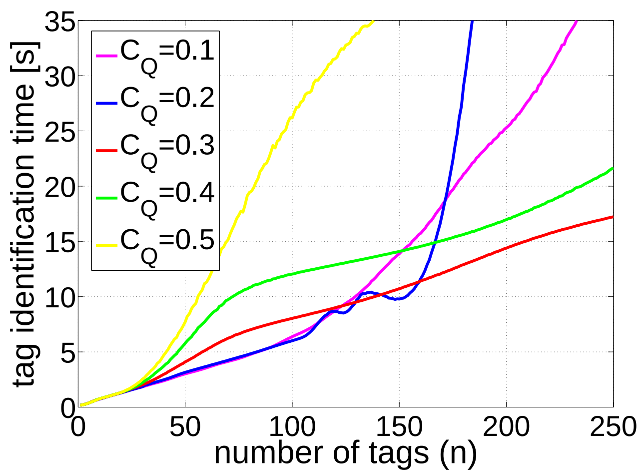

Figure 6: Scenario1 throughput when one varies C_Q

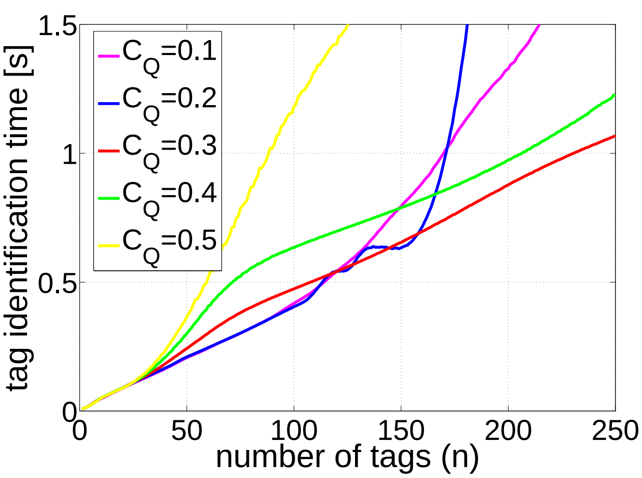

Figure 7: Scenario2 throughput when one varies C_Q

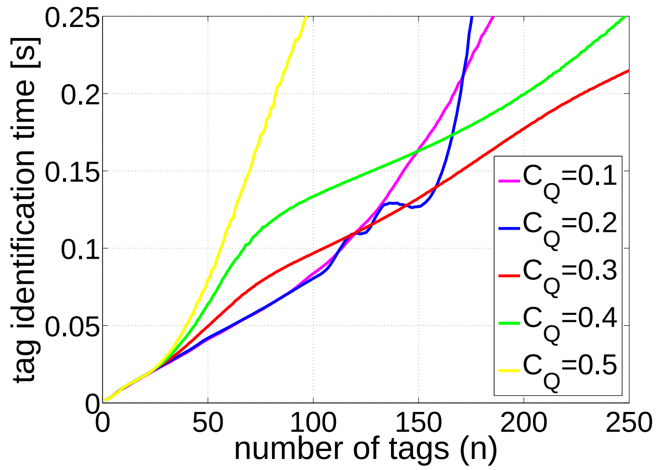

Figure 8: Scenario3 throughput when one varies C_Q

seen that usage of $C_Q = 0.3$ from Gen2 standard provides the lowest tag identification time. Future work will include implementation of other algorithms for frame size adaptation, and its comparison with Q-algorithm, as well as the implementation and evaluation on Software Defined Radio (SDR) application [18], as done in [12].

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