Study about the Influence of Tag Collision over the Identified RFID tag signals

Hillner de P. A. Ferreira, Alexandre J. R. Serres, Francisco M. de Assis

***Abstract*—In passive UHF RFID systems, tag collisions occur when multiple tags transmit simultaneously to reader. Due to the mixture of waves, the reader cannot differentiate any information and, consequently, more signals must be retransmitted until all tags are successful identified. The high traffic of RFID signals in real indoor environments can accentuate the multipath effect. In this letter, we conduct measurements in laboratory to study the influence of tag collision over the tag signals identified by the reader. From two scenarios based on high and low probability of tag collision, we evaluate the signal quality of successfully identified tags.**

Keywords — tag collision, RFID, multipath effect, Q algorithm.

I. Introduction

The primary function of Radio Frequency Identification (RFID) technologies is the automated identification and data capture [1]. In recent decades, the global interest on RFID is rapidly growing and becoming one of the most promising solutions for AIDC (Automatic Identification Data Collection). With respect to other AIDC methods, like barcodes, RFID have many advantages, such as non-optical proximity, long transmission range and quick identification [2, 3]. Thus, RFID is currently found in wide range of large-scale applications such as transport systems, electronic ticketing, access control, animal identification, logistics, supply chain management and many more [4, 5].

Typically, passive UHF RFID systems consist of an interrogator (or reader) and a population of transponders (or RFID tags) attached to objects that will be identified. The reader has a dedicated power source and significant computing capability. It power-ups and transmits commands to tags, and the tags transmit back (or backscatter) their information [6]. However, when multiple tags try to transmit simultaneously to reader, the tag signals will collide and no tag is identified. This is called tag collision or tag-to-tag interference [1, 7, 8]. The reader cannot identify the tags because it does not differentiate the mixture of tag signals. The use of Time Division Multiple Access (TDMA) anticollision algorithms allows that the collided tags retransmit to reader until no tag collision occurs.

In real indoor environments, tag collision can establish others limitations on the performance of passive UHF RFID systems. The high traffic of signals between reader and tags contribute to occurrence of multiple reflections, refractions, diffractions and scattering on various obstacles (furniture, floor, walls, metal objects, etc.) causing the phenomenon called multipath effect [2, 9].

Hillner de P. A. Ferreira, hillner.ferreira@dee.ufcg.edu.br; Alexandre J. R. Serres, alexandreserres@dee.ufcg.edu.br; Francisco Marcos de Assis, fmarcos@dee.ufcg.edu.br.

The numerous waves generated by multipath travel in multiple directions and have lower-power and phase-shifted than the original signal. These replicate waves can reach to reader in different times and interfere in both strength and phase of other tag signals captured by the reader.

In this letter, we developed a comparative study about the influence of tag collision over the identified tag signals. From two scenarios based on high and low probability of tag collision, we conduct measurements in an indoor laboratory environment to compare the signal-to-noise ratio (SNR) of successfully identified tags. The initial Q_{fp} parameter of Q algorithm is used to increase and decrease the tag collision conditions and the amount of RFID signals transmitted on the wireless channel.

The rest of this paper is organized as follows. Section 2 discusses about the multipath phenomenon in indoor environments and reviews the identification procedure of Q algorithm. Section 3 describes the proposed scenarios based on high and low probability of tag collision. Simulated results for the traffic of RFID signals on the channel are also illustrated. In Section 4, we show the experimental setup, the measurement procedure and the results SNR obtained for both scenarios. Finally, the conclusions of our analysis are presented in Section 5.

II. Background

A. *Indoor Multipath Phenomenon*

Passive UHF RFID systems have a vast application to identify dense populations of tags (such as asset tracking, automated inventory, supply chain management, etc.) and, therefore, they are almost found exclusively for indoor use [10]. In these places, the multipath effect is even more pronounced due to the passive nature of the tag operation and the inherently low signal to noise ratio (SNR) of the weak backscatter tag signal [11].

In wireless communication systems, the propagation of radio signals is strongly influenced by the indoor environment. In particular, their own dimensions (floor, ceiling, walls, etc.), materials (dielectrics, metals and liquids) and obstacles (chairs, tables, cabinets, etc.) contained therein. The multipath effect occurs due to the multiple divisions of the irradiated signal over the intercepted obstacles. These unpredictable waves propagate through multiple paths, in different directions, and have lower power than the original signal. The interferences of multipath waves can be either constructive or destructive, with a commensurate effect on the measured SNR [1, 2, 9].

Figure 1 illustrates an example of path diagram for passive UHF RFID system. The reader sends a request signal and then listens the response signals from the tags. With obstacles present, the incident waves that arrive at the reader antenna consist of the desired signal and multipath waves. The desired component is the Line-Of-Sight, LOS, backscattered signal from the tag. The multipath waves include direct reflections from nearby obstacles, uplink multipaths (reader-obstacle-tag) and downlink multipaths (tag-obstacle-reader). Only the backscattered tag signal in LOS is useful for tag identification. The other two components are interferences that can result in error [12].

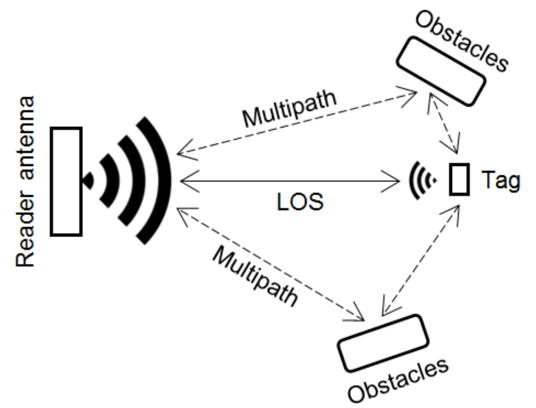

Fig. 1. An example of multipath in passive UHF RFID systems.

Due to the multiple paths have different lengths; there are different versions of multipath waves traveling to reader in different times. This problem becomes critical because passive UHF RFID systems use time-based anticollision algorithms to identify the tags. Thus, the delay spread of multipath waves can significantly distort the amplitude and/or phase of tag signals subsequently backscattered, causing destructive interferences on the waveform used to represent the transmitted bits [2, 13].

B. *EPCglobal Class 1 Generation 2 Protocol*

EPCglobal, an international RFID standardization organization, provides in EPC Class 1 Generation 2 (Gen2) a TDMA mechanism called Q algorithm [14, 15]. This anticollision algorithm describes the rules for identification of passive UHF RFID tags.

Q algorithm is slotted ALOHA-based scheme. In essence, the reader divides the time in tag transmission intervals called slots. The set of slots available to tags is called frame. Functionally, the reader transmits a continuous waveform (CW) to power-up the tags and then sends the *Query* signal to initialize a new inventory. Then, the tags enter in reply mode to send the 16-bit random number (RN16) data. Each tag randomly picks a slot in the frame and waits to transmit your data. Tags that pick zero-slot transmit RN16 immediately. Tags that pick nonzero-slot must wait the following commands to be sent by reader: *QueryAdjust* (to update the frame and pick another slot) or *QueryRepeat* (to decrement the slot by one) [14].

If a unique tag transmits RN16 into the slot, the reader acknowledges the tag message and transmits back a valid ACK attaching the same RN16. After received the ACK message, the communication link is established and the acknowledged tag transmits its ID or 96-bit EPC (electronic product code) to reader.

However, if multiple tags transmit RN16 into the same slot, the tag collision will occur potentially prohibiting the RN16 demodulation at the reader. Consequently, the reader transmits a NACK response and the collided tags must pick other slots to retransmit their RN16 signals again.

The algorithm Q is used to mitigate the tag collision. The reader transmits the initial $Q = Q_{fp}$ to adjust the number of slots in frame as 2^Q. Thus, each tag picks a random slot from 0 to 2^Q - 1 and waits to transmit. The reader monitors each slot and promotes Q_{fp} updates. The floating-point Q_{fp} increases by c value when tag collision occurs and decreases by the same constant ever idle slot (no tag transmit) is detected. For successful slot response (i.e., a unique tag transmits), Q_{fp} remains unchanged. At the end of each frame read or if $Q \neq round(Q_{fp})$, a new frame is immediately initialized with 2^Q slots, where $Q = round(Q_{fp})$ and *round*() is the nearest value in $\mathbb{Z}$. The flowchart of Q and Q_{fp} update is showed in Figure 2.

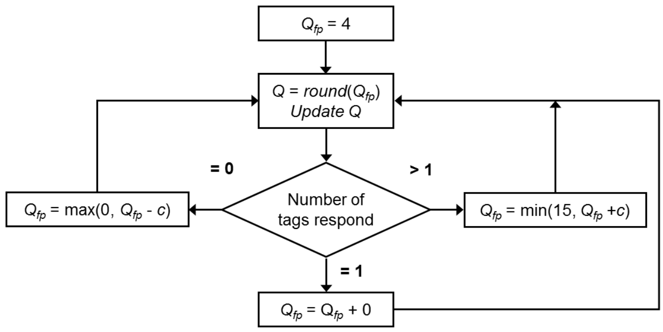

Fig. 2. Updates of Q and Q_{fp} parameters [14].

As the value of c is not specified in EPC Class 1 Gen. 2, we assume the values suggested in [16] for our simulation. Thus, If $0 \leq Q \leq 2$, $c = 0.5$; if $Q \geq 10$, $c = 0.1$; else, $c = 1/Q$.

III. Tag Collision Scenarios

In ALOHA-based algorithms, when the number of tags in the interrogation zone is larger than the initial number of slots, multiple tags pick the same slots and, consequently, the reader captures a large number of simultaneous tag signals. As a result, we have a high probability of tag collision until the anticollision algorithm adjusts the number of slots in frame to closer to number of tags will transmit. On the other hand, when the number of tags is close to the initial number of slots, we have a small number of simultaneous tag signals and, consequently, a low probability of tag collision.

Let n, Q_H and Q_L, respectively, the number of tags, the initial Q_{fp} parameter for high and low tag collision probably, Table 1 describe the parameters used for each scenario.

TABLE I. Initial Q_{fp} parameter for tag collision scenarios.

n	4	8	12	16	20	24	28	32	36	40
Q_H	1	1	1	1	1	1	1	1	1	1
Q_L	2	3	4	4	4	5	5	5	6	6

Figure 3 shows the average and standard-deviation for the simulated RFID signals traveling in the channel, T_{rt}, based on Q_H and Q_L scenarios. We repeat 1,000 simulations and calculate the average for the sum of *Query*, *QueryAdjust* and *QueryRepeat* commands, ACK and NACK messages and RN16 and ID tag responses.

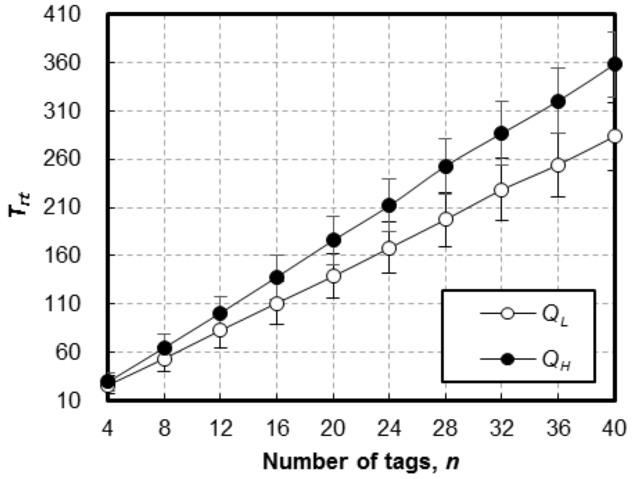

Fig. 3. Comparison of T_{rt} signals for Q_H and Q_L scenarios.

We observe a larger T_{rt} in Q_H than Q_L. This shows that, to identify the same number of tags, more RFID signals are transmitted between reader and tags in high tag collision scenario than low tag collision. Consequently, the signals captured by the reader tend to suffer more interference of multipath waves in Q_H than Q_L. Figure 4 shows the average T_{rt} normalized by n.

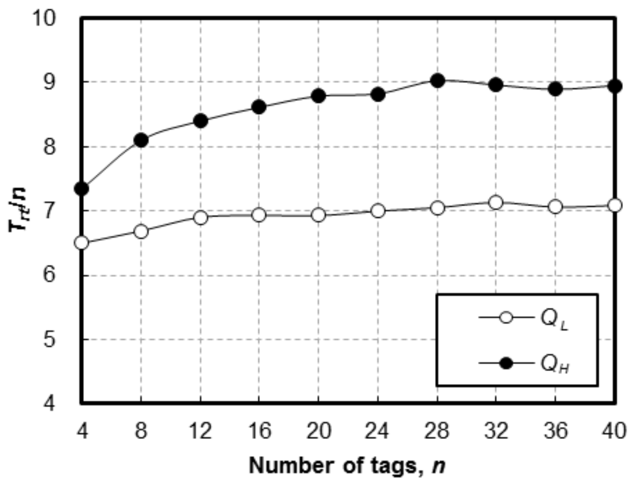

Fig. 4. Comparison of Trt per tag for high and low tag collision scenarios.

Since Q_L scenario the initial Q_{fp} = 1 is fixed and the number of tags is changed, we can conclude that the RFID systems demands more signals to identify each tag as the difference between n and $f(0) = 2^{Qfp}$ increases. In our interval, we observe that Q_H has an average T_{rt}/n increased by 24.15% compared to Q_L.

IV. EXPERIMENTAL RESULTS

To analyze the quality of tag signals captured from the reader, we perform measurements in real indoor environment. Figure 5 shows the layout of the radiometry laboratory of Federal University of Campina Grande. Figure 6 shows the photo of experimental setup. Here, we use UHF RFID reader model IF2 Network Intermec connected to one Intermec RX/TX circular polarized antenna with 9dBi gain (positioned at 90 degrees and 0.6m above the ground) and mounted on portal structure [17, 18].

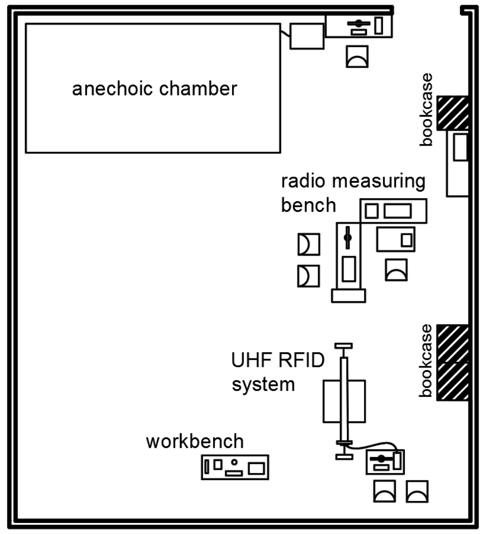

Fig. 5. Layout of radiometry laboratory at Federal University of Campina Grande. The lab room dimensions have length 11m, width 12.2m and height 4m.

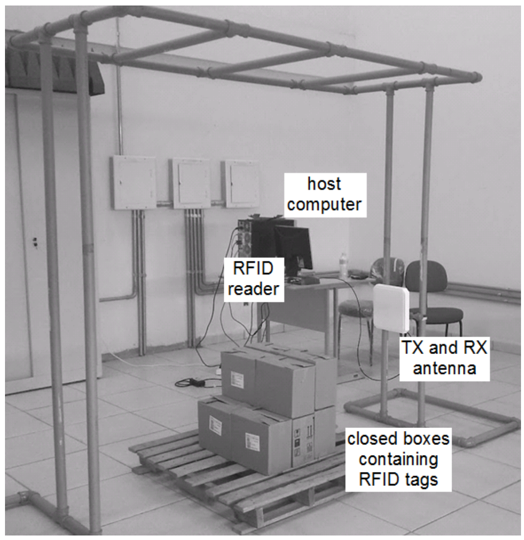

Fig. 6. Experimental setup used for measuring RFID tags.

Figure 7 shows the top view of passive RFID tag. The tag is designed to operate in UHF RFID band that spans 860–960 MHz. A double-sided copper clad FR-4 board material with substrate thickness of 1.52mm and dielectric permittivity $\varepsilon_r = 4.4$ is used to design the tag antenna inspired in rectangular patch antenna. An EPCC1G1 RFID chip model UCODE I²C SL3S4011_4021 from NXP Inc. is pasted on tag antenna terminals. The tag design is not part of the scope of this work.

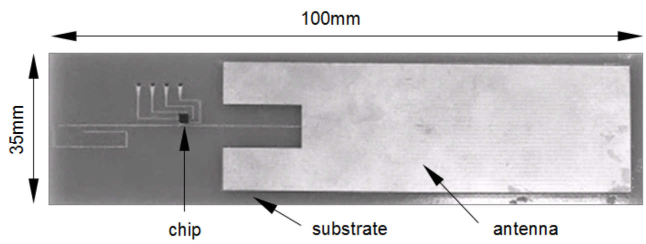

Fig. 7. RFID tag used in measurements.

The measurement procedure can be explained as follows. On a pallet located below the RFID portal reader, we placed closed cardboard boxes containing four tags. The tags are separated by 3cm from each other and fixed to the inner side; orthogonally and favorably oriented in relation to the incident waves and in LOS with the reader. Each box has dimension of 22.5x27.5x14.0cm and there are no objects inside. New closed boxes are added at the distance between 0.70 and 1.15m away from the reader antenna. After the limit of 6 boxes (3 consecutive rows of 2 boxes), the others are placed following the same layout and above the first ones. We made 1,000 measurements with 500ms interval for each one of n tags. The boxes position is fixed for both measurements. A host computer connected to RFID reader and telnet-based software are used to register the tag data.

To analyze the performance of RFID system in both scenarios, we measure the signal-to-noise ratio (SNR) from the tag signals successfully identified. The SNR compares the level of desired signal to the level of background noise. A ratio higher than 1:1 indicates more signal than noise.

Figure 8 shows the average of measured SNR in dBm for high and low tag collision scenarios. We obtain SNR_{dBm} by converting the measured values to SNR, averaging and returning the value to dBm scale. The fluctuation of SNR_{dBm} curve is explained by the different geometric positions of RFID tags in relation to the reader antenna.

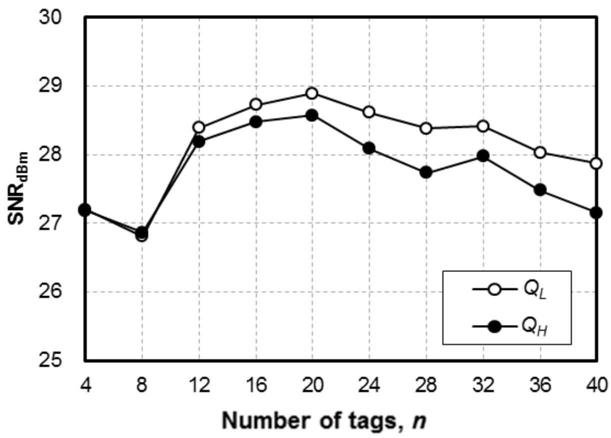

Fig. 8. Comparison of average SNR_{dBm} for high and low tag collision scenarios.

We observe Q_L scenario has higher SNR_{dBm} than Q_H. These results suggest that the high tag collision probability in real indoor environment intensifies the occurrence of multipath waves and, consequently, interfere on the signals of identified tags. Between 28 and 40 tags, the average SNR is reduced by 14.50% in Q_H compared to Q_L. A low SNR increases the bit error rate (BER) making impossible the tag reading [13].

It is noteworthy that other tag-to-tag interferences, such as the electromagnetic coupling between neighboring tags, can also influence the SNR in Q_H and Q_L scenarios. The presence of tag antennas very close to each other alters the current distribution, the radiation pattern and introduces mutual impedance [1, 11].

V. CONCLUSION

In this letter, we presented a comparative study about the influence of tag collision over the identified tag signals. Using the initial Q_{fp} parameter of Q algorithm we created two tag collision scenarios. Simulated results show that Q_H scenario has an average of transmitted RFID signals 24.15% greater than Q_L. In real laboratory environment, we measured the SNR_{dBm} from the successful identified tags for both scenarios.

The measured results suggest that the high tag collision condition increases the number of RFID signals traveling in the laboratory and, consequently, intensifies the multipath effect that interfere on the signals of identified tags. According to our observation, the average SNR_{dBm} tends to degrade as the number of tags increases. The difference between the number of tags (a priori unknown) and slots in the initial frame (Q_{fp} is predefined) can negatively influence the tag identification process.

As future work, we intend to install the experimental setup inside the anechoic chamber and use the same measurement procedure for comparison purposes.

VI. REFERENCES

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