Hindawi
Wireless Communications and Mobile Computing
Volume 2019, Article ID 6218671, 11 pages
https://doi.org/10.1155/2019/6218671

Research Article

Efficient Missing-Tag Event Detection Protocols to Cope with Unexpected Tags and Detection Error in RFID Systems

Chuyen T. Nguyen, Tuyen T. Hoang, Linh T. Hoang, and Vu X. Phan

School of Electronics and Telecommunications, Hanoi University of Science and Technology, Vietnam

Correspondence should be addressed to Chuyen T. Nguyen; chuyen.nguyenthanh@hust.edu.vn

Received 17 May 2018; Revised 9 October 2018; Accepted 11 November 2018; Published 28 February 2019

Academic Editor: Jun Cai

Copyright © 2019 Chuyen T. Nguyen et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

This paper investigates the issue of missing-tag event detection in practical radio frequency identification (RFID) systems with the presence of not only unexpected tags but also the detection error. Among all the previous works, the recently proposed protocol "RFID monitoring with UNexpected tags (RUN)" is one of the first studies taking the unexpected tags into account. The protocol is proven to outperform conventional ones in terms of achieving a required reliability. Nevertheless, it completely ignores the effect of the so-called detection error, which is a common phenomenon in the literature of RFID, on tag reading. The phenomenon might result in the false-alarm detection of the event and it is believed that RUN is no longer efficient and reliable. We therefore propose two modified versions of the RUN protocol, namely, mRUN1 and mRUN2, as solutions for the issue. Similarly to RUN, the protocols execute multiple Aloha reading rounds to cope with the unexpected tags. On the other hand, they utilize tracking counters supposedly available at the reader to mitigate the effect of the detection error. While mRUN1 requires many counters to monitor the existence of each expected tag (the tag's identity is already known), mRUN2 uses only one counter to deal with the event caused by either real missing tags or the detection error. Performance analysis will be investigated to find optimal parameter settings for the protocols. Computer simulation results are also provided to validate our analysis as well as to show the merit of the proposed protocols in comparison with the conventional protocols.

1. Introduction

Radio Frequency IDentification (RFID) has been considered as one of the key technologies in future networks [1–3] owing to many great benefits, such as low cost (5 cents per tag [4]) and non-line-of-sight wireless transmission. The technology has also been ubiquitously employed in many different applications such as warehouse management, object tracking, authentication, and inventory control [5]. In those applications, each object is attached with a tag, which can be passive, semipassive, or active, represented by a unique Identity (ID). While semipassive and active tags have their own internal power sources, passive ones are powered up by harvesting the RF energy from RFID readers. The passive tags are therefore limited in communication range, much cheaper than the others, and are our target in this study. The readers try to collect and monitor the ID information of all tags as quickly as possible thanks to different standard Medium Access Control (MAC) protocols such as tree-based and Aloha-based ones [6].

Although RFID technology has created a multibillion dollar market [7], there are still numerous major troubles in the RFID-based industry as shoplifting, employee theft, and vendor fraud [8, 9]. The troubles become more serious in large-scale systems where thousands (Australian farms with tens of thousands of goats) or even millions (Amazon warehouses) of objects need to be monitored [10, 11]. According to [12], retailers lost an estimation of 34.5 billion dollars due to these causes in 2011. In order to cope with this situation, research in RFID has been investigated so intensively in recent years. Most of them focus on the tag-collection problem where all the IDs need to be identified in a short period of time. The main challenge in those works is to resolve the radio collision when tags respond to the reader in the same time slot. Although significant contribution has been gained in the literature so far [13, 14], proposed algorithms/protocols probably take much time for the ID collection due to a huge number of tags with corresponding 96-bit (or 128-bit) IDs. Another approach is to monitor the existence of expected tags (i.e., the tags whose IDs are already known to the reader) and give a necessary warning/alarm to system managers. This is referred to as the missing-tag event detection problem, which attracts much attention from researchers thanks to its practically important role [15].

Current missing-tag detection algorithms/protocols can be classified into two types: *probabilistic* [16–18] and *deterministic* [19–21]. In particular, the former only reports the detection of the missing-tag event and thus has a fast execution time. On the other hand, the latter certainly requires more time since it feedbacks the ID of each missing tag to the reader. Both the two types have their own merits and can be used together. Nevertheless, those above works assume a perfect system implementation that includes only expected tags. The assumption is, clearly, not practical since there also exists unexpected tags (the ones whose IDs are not known a priori to the reader) in real RFID systems. This fact can be seen in monitoring baggage of passengers of different airline companies where each company uses its own readers. Another example is at retail stores where readers are used to monitor only expensive merchandise such as jewelry but still receive responses from inexpensive ones [22]. Many similar examples could be also observed in hospitals, prisons, and shopping malls [23, 24]. In such scenarios, the unexpected tags might result in more severe radio collision and wrong observations of the status of each time slot, and thus, the previous protocols may report false alarms on the event detection.

To cope with the unexpected tags, a new method, namely, "RFID monitoring protocol with UNexpected tags (RUN)" has been proposed in [25, 26] using the standard Aloha-based protocol. This method is one of the first missing-tag detection works considering the existence of unexpected tags. RUN executes multiple Aloha reading rounds with different frame size and different random seeds, denoted by f and R, respectively. Each tag within the reader's transmission range uses f, R, and its ID to select a slot to respond to the reader in the frame by evaluating a hash function $h(f, R, \text{ID})$. The value of the function is uniformly distributed in $[1, f]$. Here, the reader knows exactly which slots are nonempty if all expected tags are present in the considered system. Therefore, by using different frame sizes and random seeds in different reading rounds, the effect of unexpected tags on the monitoring protocol is mitigated thanks to the mechanism of random responses. At the same time, RUN minimizes the protocol execution time by choosing an optimal frame size in each reading.

Not similar to previous studies, RUN has been proven to be able to achieve a required reliability in the presence of unexpected tags. Nevertheless, RUN completely ignores the so-called detection error [27–29]. In the literature of RFID, this phenomenon is common and might result in wrong observations of tag responses in time slots. In particular, due to multipath fading and noise, the received signal strength at the reader during a time slot might be lower than a required sensitivity threshold. As a result, the slot might be observed as empty even when several tags respond to the reader in that slot. Therefore, conventional missing-tag event detection protocols such as RUN might very frequently give false-alarm/warning on the event to the system administrator. It, then, takes much more time and energy to check and confirm which one is missing and also the reason, which makes the protocols no longer efficient and reliable.

In this paper, we study the missing-tag event detection issue in a practical model with the presence of not only unexpected tags but also the detection error. To the best of our knowledge, this is also one of the first works dealing with both the factors in the literature. Two modified versions of RUN, namely, mRUN1 and mRUN2, are then proposed. As with RUN, mRUN1, and mRUN2 protocols execute multiple Aloha reading rounds to cope with the unexpected tags. In addition, they utilize tracking counters supposedly available at the reader to mitigate the effect of the detection error. The event is announced to happen only if the counters reach a predefined threshold. While mRUN1 requires many counters to monitor the existence of each expected tag, mRUN2 uses only one counter to deal with the event. Performance analysis will be given to find optimal parameter settings of the proposed protocols. Computer simulation results are also provided to validate our analysis as well as to show the merit of the proposed protocols in comparison with the conventional protocols.

The remaining of this paper is organised as follows. In Section 2, the considered RFID system with Aloha-based protocols, the detection error, and the conventional RUN is described. Proposed protocols are developed in Section 3, and numerical results and discussions are presented in Section 4. Finally, conclusions are drawn in Section 5.

2. System Description

2.1. System Model. Our considered RFID system described in Figure 1 includes a reader, sets of expected tags, and unexpected tags denoted by $\mathbb{E}$ and $\mathbb{U}$, respectively. While expected tags' identities (IDs) have been recorded at the reader, those of unexpected tags are still not identified. The unexpected tags also need not to be monitored, and the reader neither knows their IDs nor the cardinality of $\mathbb{U}$. An unknown number of tags out of $|\mathbb{E}|$ tags denoted by m is supposed to be missing, where $|\cdot|$ stands for the cardinality of a set and $0 \leqslant m \leqslant |\mathbb{E}|$. The main task of this work is to design an efficient protocol/algorithm that can quickly detect a *missing-tag event* with a required probability $\geq \alpha, (0 \leq \alpha < 1)$ whenever the number of missing tags m exceeds a predefined threshold denoted by T.

2.2. Communication Protocol: Aloha, Wireless Channel Model, and Detection Error. The communication between the reader and tags is based on the so-called frame slotted Aloha (FSA) specified in the EPCGlobal Class 1 Generation 2 (C1G2)

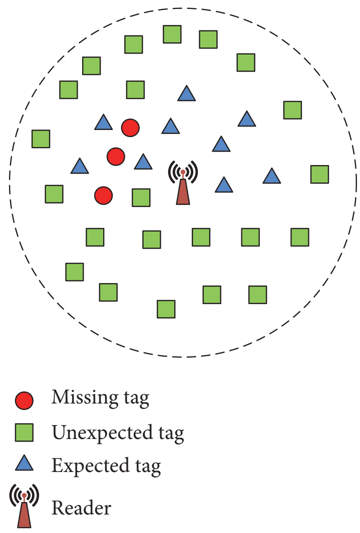

Figure 1: RFID system model.

RFID standard as its Media Access Control (MAC) layer communication protocol [30]. The reader first broadcasts a message consisting of a frame size f and a random seed R. Then, each tag randomly responds to the reader in one of the f slots where the slot selection is calculated via a hash function $h(f, R, \mathrm{ID}) \in [1, f]$. The responding message, due to privacy and security concerns, is one bit or a few bits instead of the ID. It is also noted that only one bit is needed to distinguish an empty slot from a nonempty one, which might be based on the received signal strength at the reader. Since all expected tag's IDs are available, the reader knows exactly the slot that an expected tag is mapped to. Nevertheless, a particular slot that contains only missing tags might be identified as nonempty due to the presence of unexpected tags.

On the other hand, the communication channel in this work is assumed to be flat Rayleigh fading with an Additive White Gaussian Noise (AWGN). The model is supposed to ignore effects of path-loss phenomenon, which might be still valid in indoor environments [31]. In particular, the received signal model from the i-th tag at the reader is described as

$$y_i = \sqrt{P} h_i s_i + v_i, \quad (1)$$

where s_i, y_i, and P are the transmitted Binary Phase Shift Keying (BPSK) signal, received signal, and transmit power, respectively. v_i is an AWGN with $v_i \sim \mathscr{CN}(0, \sigma^2)$. h_i is the channel coefficient whose probability density function (pdf) denoted by $f(h_i)$ is Rayleigh distributed, i.e.,

$$f(h_i) = \frac{|h_i|}{\sigma^2} \exp\left(-\frac{h_i}{2\sigma^2}\right). \quad (2)$$

It is also noted in (1) that we only consider the uplink channels from tags to reader, for simplicity, in which the transmit power from each tag is assumed to be the same. The reason is that this work focuses on designing missing-tag detection algorithms. The more sophisticated and practical channel models in terms of physical-layer perspectives will be reported in the future works. Due to the fading and noise, a slot, which is expected to be nonempty, might be detected as empty with an average probability of P_{de}. This is when the received signal power at the reader during that time slot is lower than the reader's sensitivity threshold denoted by γ_{R}. This phenomenon is widely known in the literature of RFID as detection error. Moreover, since tags respond in slots randomly, we assume in this paper that the average probability P_{de} at each nonempty slot is the same regardless of the number of responding tags in the slot.

The performance of the Aloha protocol in our model is summarized via a simple example in Figure 2 considering the effects of unexpected tags and the detection error. A message that includes frame size of 5 is sent to the tags. After receiving the tags' response, the reader observes that slots 1, 4, and 5 are empty while slots 2 and 3 are nonempty. This is because slot 3 includes an unexpected tag, while the detection error happens in slot 4. Furthermore, the missing-tag event is detected successfully in this example since slots 4 and 5, which are expectedly nonempty, are observed as empty. Nevertheless, while slot 5 accurately reflects the event, observation in slot 4 results in a false detection due to the detection error, which reduces the performance efficiency of the protocol.

2.3. Conventional Approach-RUN Method. RUN (RFID monitoring protocol with unexpected tags) has been proposed in [25] as one of the first missing-tag detection methods to cope with the presence of unexpected tags. To detect if any tags in $\mathbb{E}$ is missing, RUN executes n Aloha frames with different random seeds. When the reader executes a frame, RUN finds if the observed status of each slot is similar to expected one. Here, it is noted that the reader knows which slots in the frames should be nonempty if all the tags in $\mathbb{E}$ are present. Therefore, if an expectedly nonempty slot is observed as empty at the i-th ($1 \leq i \leq n$) frame, the reader stops and declares that some tags are missing without transmitting the remaining $(n - i)$ frames.

To improve the efficiency of the method, RUN estimates the optimal frame size denoted by f_i before the i-th execution. To do so, the reader first estimates the value of $|\mathbb{U}|$ at the start of the i-th frame denoted by $|\mathbb{U}_i|$ by averaging over the previous $(i - 1)$ frames as follows:

$$|\mathbb{U}_i| = -\frac{1}{i-1}\sum_{l=1}^{i-1} f_l \ln\left\{1 - \frac{X_{01}^l}{f_l - k_l}\right\}, \quad (3)$$

where k_l is the expected number of nonempty slots out of the f_l slots precomputed by the reader using the hash function. X_{01}^l is the observed number of slots that is expectedly empty in the l-th frame but observed as nonempty. Here, it is worthy mentioning that (3) can be easily obtained thanks to the random responses from tags over slots of a frame. Then, the optimal frame f_i is proven to be

$$f_i = \frac{T - |\mathbb{U}_i| - |\mathbb{E}|}{\ln\left(1 - (1 - \alpha)^{1/nT}\right)}. \quad (4)$$

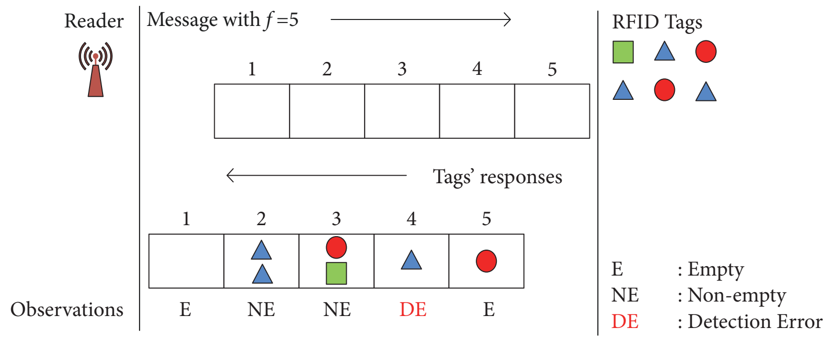

Figure 2: Aloha communication protocol with unexpected tags and detection error.

We can see in RUN that effects of the detection error on the tag reading (and thus, the false-alarm detection) are completely ignored. Therefore, we believe that it would be useful if RUN is reconsidered in a more practical model where both the unexpected tags and the detection error are taken into account.

3. Proposed Missing-Tag Event Detection Protocols

In this section, we propose two modified versions of RUN protocols, namely, mRUN1 and mRUN2, for missing-tag event detection considering not only unexpected tags but also the detection error. Both the Aloha frames and assumed tracking counters supposedly available at the reader are utilized to mitigate the effects of the phenomena.

3.1. Protocol Description. The proposed protocols plan to use n detection rounds, which might be initially set as $+\infty$, for a detection of the missing-tag event. In the i-th ($i \leq 1 \leq n$) round, the reader broadcasts a message consisting of a frame size f_i and a random seed R_i. Tags upon receiving the message randomly respond to the reader in one of the f_i time slots where the random slot selection is based on the hash function described in Section 2. Here, owing to the hash function, the reader knows exactly which slots are nonempty if no tags in $\mathbb{E}$ are missing.

The reader is assumed to have tracking counters that are initially set to zero. The purpose of the counters is to mitigate the effects of the detection error on the protocols' performance. In particular, if a slot, which is expected to be nonempty, is observed as empty, the proposed protocols increase counters involved in the slot by one. If any counter reaches a predefined threshold denoted by C_{th}, mRUN1 and mRUN2 stop executing and declare that the missing-tag event happens. Otherwise, the reader estimates the number of unexpected tags $|\mathbb{U}|$ by which the optimal frame size used for the next round and the remaining number of detection rounds denoted by f_{i+1} and n_{i+1}, respectively, can be reestimated. These assumptions are valid in RFID domains thanks to the power of the reader, and were used in several works [31, 32]. If the reader does not detect the missing-tag event after the total number of detection rounds, it declares that the number of missing tags m is less than T.

More specifically, mRUN1 requires $|\mathbb{E}|$ counters denoted by $\mathrm{C}_1^1, \cdots, \mathrm{C}_{|\mathbb{E}|}^1$ to monitor the existence of the corresponding $|\mathbb{E}|$ expected tags. During the i-th frame, if the missing-tag event is detected in several slots, the counters of all expected tags involved in the slots are increased by one. The reader then keeps transmitting the same frame size and the random seed in next reading rounds. In the other cases where no missing event is detected, the counters are kept unchanged and the detection process continues with different frame size and random seed. The transmission is repeated until a counter reaches C_{th}. Thanks to this mechanism, the missing event caused by real missing tags happens again at the same slots. Moreover, the probability that the existing tags are notified as the missing tags due to the detection error is significantly reduced. Nevertheless, mRUN1 although can find exactly which tag is missing, it costs more hardware implementation at the reader (for $|\mathbb{E}|$ counters) and the time (number of time slots) to monitor each tag.

On the other hand, the reader uses only one counter denoted by C^2 for mRUN2 to monitor the missing-tag event. If the event is found in a detection round, the reader increases C^2 by one and stops executing the remaining slots of the current frame (this mechanism is different from that of mRUN1 where all the slots of each frame are utilized). Then, the reader retransmits the same frame size and the random seed. In this case, if the event is still detected at the same slot, C^2 is increased by one again, and this retransmission process is repeated until C^2 reaches C_{th}. During the process, if the event is not detected, C^2 is set to zero and a new message with different frame size and random seed is created and broadcasted to the tags. mRUN2, different from mRUN1, only deals with the missing-tag event without showing the specific missing tags. Also, since only one counter is employed, mRUN2 reduces the hardware complexity and, the total protocol execution time in comparison with mRUN1. The proposed protocols are summarized in Figures 3 and 4.

3.2. Parameter Optimization under Impacts of Unexpected Tags and Detection Error. The proposed protocols try to quickly detect a *missing-tag event* with at least to a required probability α, $(0 \leq \alpha < 1)$ whenever the number of missing tags m exceeds the threshold T. Therefore, protocols' parameters such as f_i and n_i before the i-th round should be optimally selected to not only satisfy those predefined

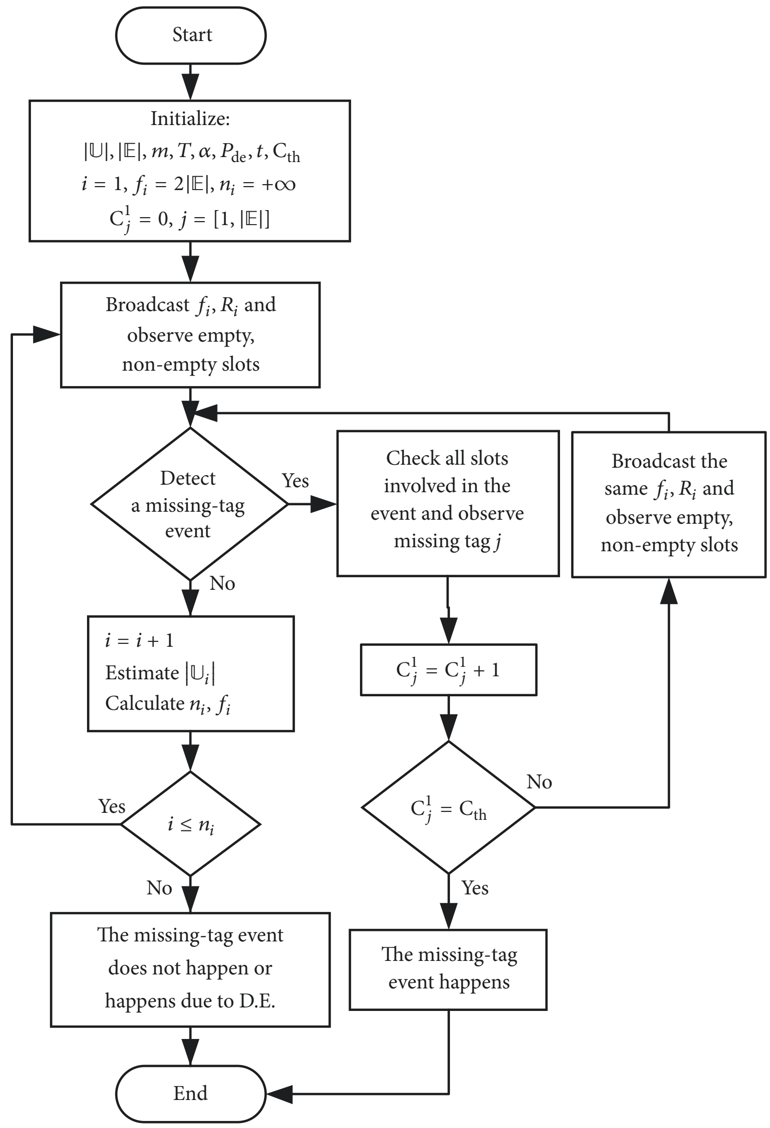

Figure 3: Flowchart of mRUN1 protocol.

requirements but also improve the performance efficiency of the protocols. To do this, our protocols first estimate the number of unexpected tags $|\mathbb{U}|$ that may result in incorrect observations in each frame. In particular, if we denote by p^i_{01} the probability that an expectedly empty slot is observed as nonempty in the i-th frame, it can be calculated as

$$p^i_{01} = (1 - P_{\mathrm{de}})\left(1 - \left(1 - \frac{1}{f_i}\right)^{|\mathbb{U}|}\right), \quad (5)$$

where P_{de} is defined as the detection error probability, while $[1 - P_{\mathrm{de}}]$ is the probability that the detection error does not happen in that slot. This equality is held thanks to the random responses from tags over the frame. The expected number of those slots in the i-th frame denoted by $\mathrm{E}[X^i_{01}]$ can also be computed as

$$\mathrm{E}\left[X^i_{01}\right] = (f_i - k_i)(1 - P_{\mathrm{de}})\left(1 - \left(1 - \frac{1}{f_i}\right)^{|\mathbb{U}|}\right), \quad (6)$$

where k_i is the number of slots out of the f_i ones that is expectedly nonempty. Based on (6), the estimate of $|\mathbb{U}|$ before the i-th round can be found using the observed values of X^i_{01} over the previous frames as follows:

$$|\mathbb{U}_i| = -\frac{1}{i-1}\sum_{l=1}^{i-1}\frac{\ln\left\{1 - X^l_{01}/(1 - P_{\mathrm{de}})(f_l - k_l)\right\}}{\ln\{1 - 1/f_l\}}. \quad (7)$$

When this estimate does not change by more than a predefined threshold t% in c consecutive frames, the estimate is understood as the real value of $|\mathbb{U}|$.

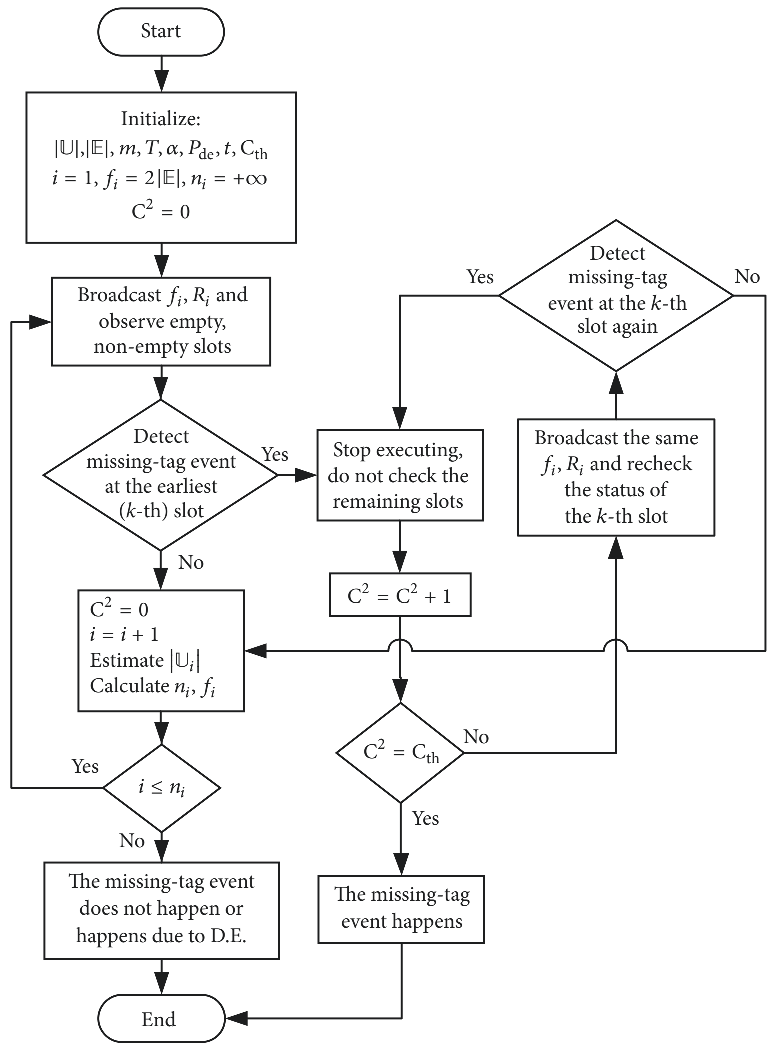

Figure 4: Flowchart of mRUN2 protocol.

Given the estimate of $|\mathbb{U}|$, we now find the optimal values of f_i and n_i. In particular, we first denote by P_{fp} a probability that slots, which expectedly include a particular missing tag, are observed as nonempty after n executed frames. The probability can be written as

$$P_{\mathrm{fp}} = \left\{ \left[1 - P_{\mathrm{de}}\right] \left[1 - \left(1 - \frac{1}{f}\right)^{|\mathbb{U}|+|\mathbb{E}|-m}\right]\right\}^{n}. \quad (8)$$

Here, $[1 - (1 - 1/f)^{|\mathbb{U}|+|\mathbb{E}|-m}]$ is the probability that at least one tag in our system responds during the slot that expectedly includes the missing tag's response. Since the proposed protocols are required to detect the missing-tag event with a probability greater or equal to α when $m \geq T$, the following condition should be satisfied:

$$1 - P_{\mathrm{fp}}^{T} \geq \alpha, \quad (9)$$

or equivalently,

$$f \geq \frac{1}{1 - \left[1 - (1-\alpha)^{1/nT} / \left(1 - P_{\mathrm{de}}\right)\right]^{1/(|\mathbb{U}|+|\mathbb{E}|-m)}}. \quad (10)$$

In this case, f can be numerically selected as the minimum value satisfying (10) to improve the performance efficiency of the proposed protocols in terms of time slots consumption, given the estimate of P_{de}. In this paper, we assume that the detection error probability P_{de} is known a priori thanks to a certain method using measured transmission data. The method could be based on, for example, expectation-maximization (EM) approach [33]. Studies that try to improve the estimation accuracy of P_{de} will be investigated in future works. Consequently, given the frame size f, the total number of slots used to detect a missing-tag event denoted by S is written as

$$S = \frac{n}{1 - \left[1 - (1-\alpha)^{1/nT} / \left(1 - P_{\mathrm{de}}\right)\right]^{1/(|\mathbb{U}|+|\mathbb{E}|-m)}}. \quad (11)$$

To find the optimal value of n that minimizes the executed time for a detection of the event, we can set the differentiation of S with respect to n to be 0 and use Newton-Raphson searching method.

3.3. Expected Detection Time Slots. Here, the expected detection time slots of two protocols mRUN1 and mRUN2, respectively, denoted by D_1 and D_2 are analyzed. Let g be the probability that a missing-tag event is detected at a given time slot among f slots. Then, g can be computed as

$$g = P_{\mathrm{de}}\left[1-\left(1-\frac{1}{f}\right)^{|\mathbb{E}|}\right] + \left[1-\left(1-\frac{1}{f}\right)^{m}\right]\left(1-\frac{1}{f}\right)^{|\mathbb{E}|+|\mathbb{U}|-m}. \quad (12)$$

In (12) that the first term represents for the case where at least one tag in $\mathbb{E}$ responds at the considered slot, while the detection error happens here. The second term describes another situation where at least one missing tag maps to the slot in the precomputed frame, and the others do not select this slot in the executed frame. Therefore, if we denote by D the number of time slots used for the first detection of a missing-tag event, the average value of D denoted by $\mathrm{E}[D]$ can be calculated for given values of f and n as follows:

$$\mathrm{E}[D] = \sum_{j=1}^{fn} jP\{D=j\} = \sum_{j=1}^{fn} jg(1-g)^{j-1}, \quad (13)$$

where $P\{D = j\}$ is defined as the probability that the first missing-tag event is detected at slot j.

Since mRUN1 executes all slots of each frame, the expected number of slots in mRUN1 (D_1) can be calculated as follows:

$$D_1 = \left(\left\lfloor \frac{\mathrm{E}[D]}{f} \right\rfloor + 1\right) f + (\mathrm{C}_{\mathrm{th}} - 1) f, \quad (14)$$

where $\lfloor a \rfloor$ represents the largest integer smaller than or equal to a.

On the other hand, mRUN2 stops executing the remaining slots in each frame when a missing-tag event is detected. Therefore, D_2 is written as

$$D_2 = \mathrm{E}[D] + (\mathrm{C}_{\mathrm{th}} - 1)\left(\mathrm{E}[D] - \left\lfloor \frac{\mathrm{E}[D]}{f} \right\rfloor f\right). \quad (15)$$

4. Numerical Results and Discussions

In this section, we evaluate the performance of the proposed protocols mRUN1 and mRUN2 with different system parameters via computer simulations. Similarly to [25], the numbers of unexpected tags and expected tags are set to 1000 and 100, respectively. The required probability α is set to 0.9. The detection error is assumed to happen at any slots with responses. The threshold T for a missing-tag detection is set as same as the number of missing tags m. The simulation results are obtained by Monte Carlo method with the number of simulation runs of 1000. The obtained results are compared with those of the conventional RUN and also the recently published two-phase Bloom filter-based missing-tag detection protocol (BMTD) [22] to show the merit of the proposed ones. It is noted in BMTD that a Bloom filter is exploited at the reader to first deactivate the unexpected tags and then test the membership of the other expected ones.

Before showing the performance of the proposed protocols, we investigate physical-layer perspectives of the detection error to validate our assumption in Section 2. In particular, we consider the transmission within a time slot assuming the Rayleigh fading channel model with AWGN. The Signal-to-Noise Ratio (SNR) is set to be 10dB, while the threshold γ_{R} is supposed to be 3dB higher than the noise power. We then plot in Figure 5 the detection error probability P_{de} with respect to the number of transmitting tags. It is interesting to observe that the probability is quite significant in our model especially when the number of tags in the slot is small. It implies that this phenomenon should be taken into account when designing missing-tag event detection protocols. In this paper, to highlight the importance of the protocol design, we adopt a simple detection error model where the average detection error probability is the same at each nonempty slot. The more practical model will be investigated in future works.

We now plot in Figure 6 theoretical and simulation results of the number of slots used in our proposed protocols for a given number of missing tags. The detection error probability P_{de} and the threshold C_{th} are supposedly 0.01 and 2, respectively. Note that they can be also set to other possible values. We can see that the theoretical result matches with the simulation one, which confirms the correctness of our analysis. It is also validated that the proposed protocols execute fewer time slots when the number of missing tags increases. Moreover, mRUN1 uses more time slots for a missing-tag event detection than mRUN2. This is because while mRUN2 only deals with the event, mRUN1 needs to identify the involved missing tags. Besides, the validity of our analysis can be confirmed again in Figure 7 where the number of slots is replotted with respect to the detection error probability, and the same behaviour of the performance of the proposed protocols is observed as that in Figure 6.

4.1. False-Alarm and True-Alarm Probabilities. In order to show the efficiency and reliability of missing-tag event detection protocols, the performance of the proposed protocols is now evaluated via the so-called false-alarm and true-alarm probabilities denoted by P_{fa} and P_{ta}, respectively. In particular, we suppose that among N_m times of detection of the missing-tag event, N_m^{ta} times are caused by the real missing tags, while N_m^{fa} times are due to the detection error where $N_m = N_m^{\mathrm{ta}} + N_m^{\mathrm{fa}}$. Then, P_{fa} and P_{ta} can be, respectively, calculated as

$$P_{\mathrm{fa}} = \frac{N_m^{\mathrm{fa}}}{N_m}, \quad P_{\mathrm{ta}} = \frac{N_m^{\mathrm{ta}}}{N_m}. \quad (16)$$

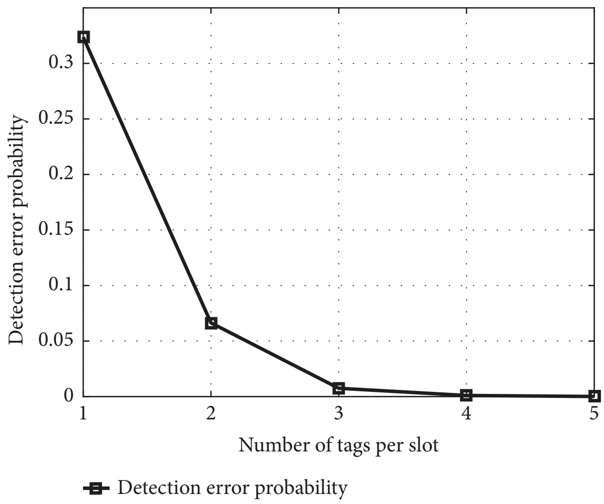

FIGURE 5: Detection error probability P_{de} versus the number of tags in a slot.

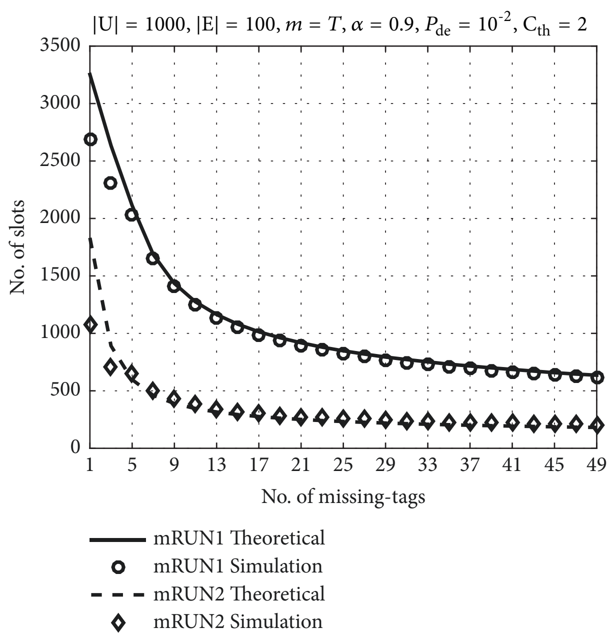

FIGURE 6: Theoretical and simulation results of the number of slots with respect to the number of missing tags.

We then plot in Figures 8 and 9 the probabilities P_{fa} and P_{ta} of mRUN1 and mRUN2, respectively, versus the detection error probability P_{de} in 1000 times of a successful detection of missing-tag event, given different values of C_{th}. We can see that when P_{de} is small ($P_{de} < 0.01$), the proposed protocols easily achieve a perfect performance with almost 100% true-alarm detection even with small values of C_{th} ($C_{th} \leq 2$). Nevertheless, as P_{de} increases, the probability that the status of a slot is wrongly observed increases. Therefore, the number of times of false-alarm detection also increases. In this case, we can evidently see the usefulness of larger values of C_{th} in improving the reliability of the proposed protocols. It is believed that, for a given value of the detection error probability, we always select a suitable value of C_{th} that helps the protocols to meet a predefined requirement of the true-alarm probability. Table 1 describes an example of selecting optimal values of C_{th} corresponding to the detection error probability for given $P_{ta} = 0.95$.

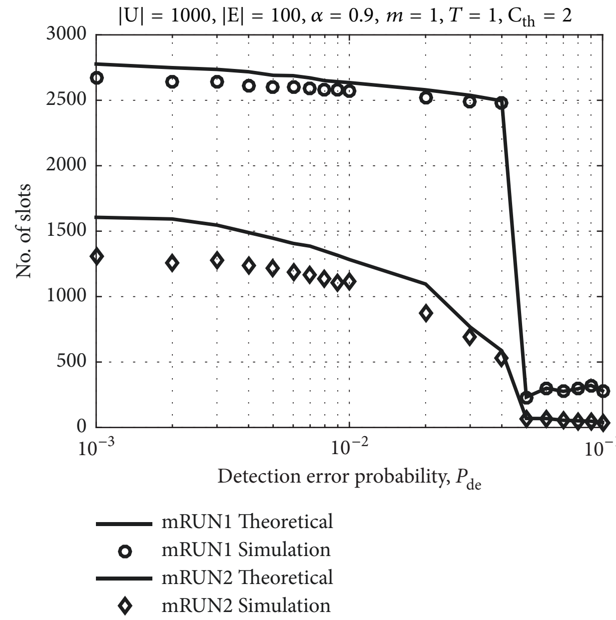

FIGURE 7: Theoretical and simulation results of the number of slots with respect to the detection error probability.

TABLE 1: Optimal selection of C_{th} in mRUN1 and mRUN2, given $P_{ta} = 0.95$ and $m = T = 5$.

P_{de}	C_{th} (mRUN1)	C_{th} (mRUN2)
1.2×10^{-4}	1	1
7×10^{-3}	2	2
2×10^{-2}	3	3
4×10^{-2}	4	3
6×10^{-2}	5	3
8×10^{-2}	6	4

4.2. Performance Comparison with the Conventional RUN and BMTD. In order to show the merit of the proposed protocols, we now compare the performance of mRUN1 and mRUN2 with that of the conventional RUN and BMTD protocols. In particular, we present in Figures 10 and 11 the numbers of slots used in all the protocols with respect to the number of missing tags (P_{de} is set to 2) and the detection error probability (both m and T are set to 5), respectively, given $C_{th} = 2$. It is seen that although more slots are executed in mRUN1 and mRUN2 to handle the detection error, they are significantly reduced when the number of missing tags or the probability increases. In Figure 11, the performance of the four protocols is observed to be almost the same when P_{de} reaches 0.1.

On the other hand, we plot in Figure 12 the true-alarm and false-alarm probabilities of the four protocols with respect to the probability P_{de}, given $m = T = 1$ and $C_{th} = 2$. We can see that even when P_{de} is small (10^{-3}), the conventional

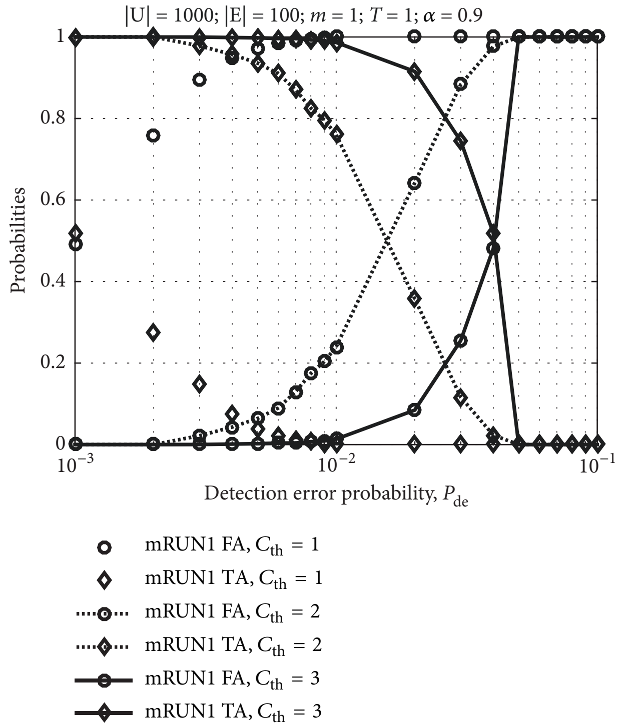

Figure 8: True-alarm and false-alarm probabilities with respect to the detection error probability of mRUN1.

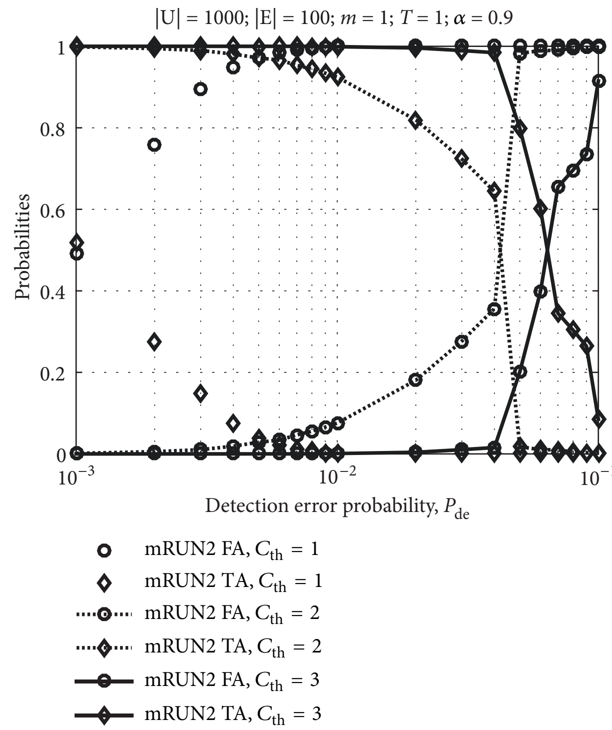

Figure 9: True-alarm and false-alarm probabilities with respect to the detection error probability of mRUN2.

RUN is obviously unreliable ($P_{ta} \approx 70\%$) while our protocols achieve almost 100%. This is because the detection error has been taken into account in our proposed protocols while it is completely ignored in RUN and BMTD. Although P_{ta} decreases when P_{de} increases, mRUN1 and mRUN2 always outperform RUN and BMTD in terms of achieving a required reliability with an optimal selection of C_{th}.

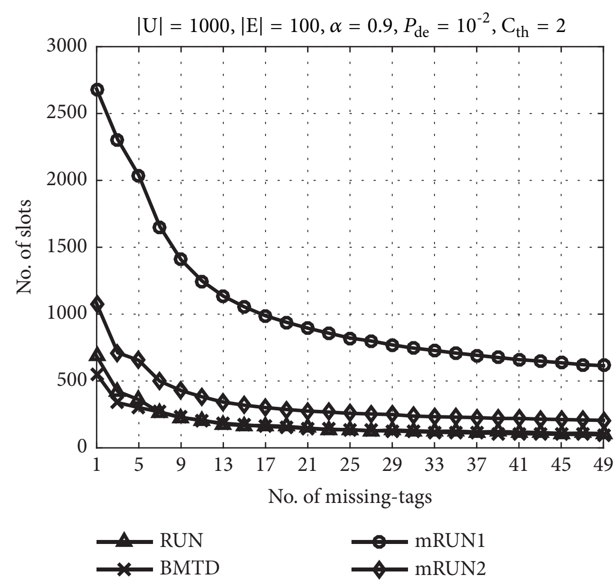

Figure 10: The numbers of slots with respect to the number of missing tags of conventional RUN, BMTD, proposed mRUN1, and mRUN2.

5. Conclusions

This paper investigated the missing-tag event detection issue in RFID systems taking both the unexpected tags and the detection error into account. Two protocols mRUN1 and mRUN2 were proposed using multiple Aloha-based reading rounds and tracking counters supposedly available at the reader. While mRUN2 only dealt with the event, mRUN1 identified specific missing tags involved in the event. Computer simulations were performed. The obtained results showed the validity of our analysis as the theoretical number of slots executed in the proposed protocols matched with the simulation one. The performance of the proposed protocols was also compared with that of the conventional RUN and BMTD protocols. The comparison showed that although more slots were executed in mRUN1 and mRUN2 than the conventional protocols, they would be almost the same in all the protocols when the detection error probability or the number of missing tags kept increasing. Moreover, the proposed protocols presented a better performance than the conventional ones in terms of giving much more smaller false-alarm, but higher true-alarm probabilities. The results demonstrated the efficiency and reliability of the proposed protocols. In future works, we plan to consider the impacts of more practical detection error model on the protocol design where the positions of tags and different fading channels are taken into account.

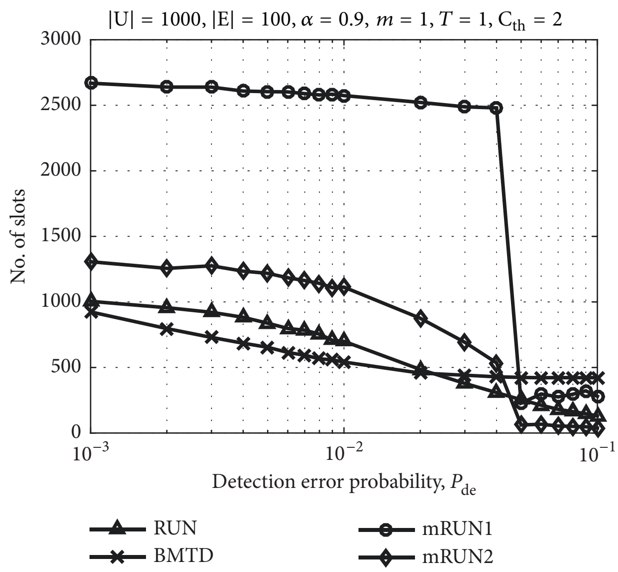

Figure 11: The numbers of slots with respect to the detection error probability of conventional RUN, BMTD, proposed mRUN1, and mRUN2.

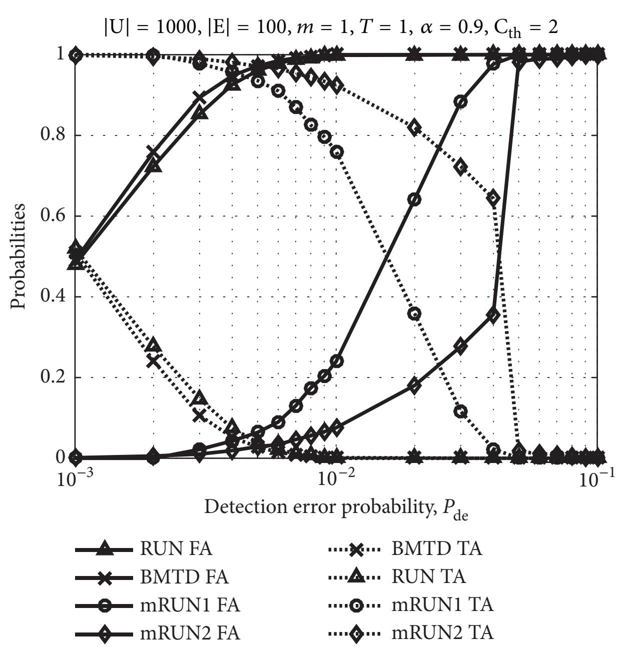

Figure 12: False-alarm (FA) and true-alarm (TA) probabilities (in solid lines and dash lines, respectively) with respect to the detection error probability of conventional RUN, BMTD, proposed mRUN1, and mRUN2.

Data Availability

Our work focuses on theoretical perspectives with computer simulations, and no data sets were generated during the work.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work is supported by Hanoi University of Science and Technology, Vietnam, through a Project no. T2017-PC-115.

References

[1] D. Zhang, H. Huang, and M. Jo, "Future RFID technology and applications: visions and challenges," *Telecommunication Systems*, vol. 58, no. 3, pp. 193-194, 2015.

[2] V. Gazis, M. Gortz, M. Huber et al., "A survey of technologies for the internet of things," in *Proceedings of the 11th International Wireless Communications and Mobile Computing Conference, (IWCMC '15)*, pp. 1090–1095, Croatia, August 2015.

[3] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of things: a survey on enabling technologies, protocols and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.

[4] M. Robert, "A 5-cent breakthrough," *RFID Journal*, p. 2295, 2006, http://www.rfidjournal.com/articles/view.

[5] M. Bolic, D. Simplot-Ryl, and I. Stojmenovic, *RFID Systems: Research Trends and Challenges*, Wiley & Sons, 2010.

[6] Z. Han, Y. Xu, and R. Wang, "The summarize of medium access control protocol in RFID," in *Advanced Technologies in Ad Hoc and Sensor Networks*, vol. 295 of *Lecture Notes in Electrical Engineering*, pp. 335–343, Springer, Berlin, Germany, 2014.

[7] R. Das, "Global RFID market tops $5.5 Billion," 2009, http://marketinfogroup.com/global-rfid-procurement-market/, http://www.convertingmagazine.com/articles/CA6653688.html.

[8] M. S. Humphreys, "Shoplifting-in 100 words," *The British Journal of Psychiatry*, vol. 202, no. 2, p. 128, 2013.

[9] A. D. Smith, A. A. Smith, and D. L. Baker, "Inventory management shrinkage and employee anti-theft approaches," *International Journal of Electronic Finance*, vol. 5, no. 3, pp. 209–234, 2011.

[10] E. C. Jones and C. A. Chung, *RFID in Logistics: A Practical Introduction*, CRC Press, Boca Raton, Fla, USA, 2007.

[11] C. T. Nguyen, V. X. Phan, N. X. Quyen, T. M. Hoang, and A. T. Pham, "Performance evaluation of missing-Tag algorithms in CDMA-based RFID systems," in *Proceedings of the 6th IEEE International Conference on Communications and Electronics, (IEEE ICCE '16)*, pp. 131–135, Vietnam, July 2016.

[12] "Preliminary national retail security survey findings," 2012, https://nrf.com/news/national-retail-security-survey-retail-shrinkage-totaled-345-billion-2011.

[13] C. T. Nguyen, K. Hayashi, M. Kaneko, P. Popovski, and H. Sakai, "Probabilistic dynamic framed slotted ALOHA for RFID tag identification," *Wireless Personal Communications*, vol. 71, no. 4, pp. 2947–2963, 2013.

[14] Z. Qian and X. Wang, "An overview of anti-collision protocols for radio frequency identification devices," *China Communications*, vol. 11, no. 11, pp. 44–59, 2014.

[15] T. Li, S. Chen, and Y. Ling, "Identifying the missing tags in a large RFID system," in *Proceedings of the 11th ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc '10)*, pp. 1–10, September 2010.

[16] W. Luo, S. Chen, T. Li, and Y. Qiao, "Probabilistic missing-tag detection and energy-time tradeoff in large-scale RFID systems," in *Proceedings of the 13th ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc '12)*, pp. 95–104, June 2012.

[17] C. C. Tan, B. Sheng, and Q. Li, "How to monitor for missing RFID tags," in *Proceedings of the 28th International Conference on Distributed Computing Systems (ICDCS '08)*, pp. 295–302, July 2008.

[18] C. Shao, T. Kim, J. Yu, J. Choi, and W. Lee, "ProTaR: probabilistic tag retardation for missing tag identification in large-scale RFID systems," *IEEE Transactions on Industrial Informatics*, vol. 11, no. 2, pp. 513–522, 2015.

[19] R. Zhang, Y. Liu, Y. Zhang, and J. Sun, "Fast identification of the missing tags in a large RFID system," in *Proceedings of the 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON '11)*, pp. 277–286, Salt Lake City, Utah, USA, June 2011.

[20] T. Li, S. Chen, and Y. Ling, "Efficient protocols for identifying the missing tags in a large RFID system," *IEEE/ACM Transactions on Networking*, vol. 21, no. 6, pp. 1974–1987, 2013.

[21] X. Liu, K. Li, G. Min, Y. Shen, A. X. Liu, and W. Qu, "Completely pinpointing the missing RFID tags in a time-efficient way," *Institute of Electrical and Electronics Engineers. Transactions on Computers*, vol. 64, no. 1, pp. 87–96, 2015.

[22] J. Yu, L. Chen, R. Zhang, and K. Wang, "Finding needles in a haystack: missing tag detection in large RFID systems," *IEEE Transactions on Communications*, vol. 65, no. 5, pp. 2036–2047, 2017.

[23] H.-L. Shieh, S.-F. Lin, and W.-S. Chang, "RFID medicine management system," in *Proceedings of the International Conference on Machine Learning and Cybernetics, (ICMLC '12)*, pp. 1890–1894, Xian, China, July 2012.

[24] H. Tan, "The application of RFID technology in the warehouse management information system," in *Proceedings of the International Symposium on Electronic Commerce and Security, (ISECS '08)*, pp. 1063–1067, China, August 2008.

[25] M. Shahzad and A. X. Liu, "Expecting the unexpected: fast and reliable detetion of missing RFID tags in the wild," in *Proceedings of theIEEE Conference on Computer Communications (INFOCOM'15)*, pp. 1939–1947, IEEE, Kowloon, Hong Kong, April 2015.

[26] M. Shahzad and A. X. Liu, "Fast and reliable detetion and identification of missing RFID tags in the wild," *IEEE/ACM Transactions on Networking*, vol. 24, no. 6, pp. 3770–3784, 2016.

[27] C. T. Nguyen, K. Hayashi, M. Kaneko, P. Popovski, and H. Sakai, "Maximum likelihood approach for RFID tag set cardinality estimation with detection errors," *Wireless Personal Communications*, vol. 71, no. 4, pp. 2587–2603, 2013.

[28] C. T. Nguyen, K. Hayashi, M. Kaneko, and H. Sakai, "Maximum likelihood approach for RFID tag set cardinality estimation under capture effect and detection errors," *IEICE Transactions on Communications*, vol. E96-B, no. 5, pp. 1122–1129, 2013.

[29] P. Popovski, K. Fyhn, R. M. Jacobsen, and T. Larsen, "Robust statistical methods for detection of missing RFID tags," *IEEE Wireless Communications Magazine*, vol. 18, no. 4, pp. 74–80, 2011.

[30] EPCGlobal Inc, "Radio-frequency identity protocols C1G2 UHF RFID protocol for communications at 860 MHz," *Information Systems Management*, 2013.

[31] C. T. Nguyen, A. T. H. Bui, V.-D. Nguyen, and A. T. Pham, "Modified tree-based identification protocols for solving hidden-tag problem in RFID systems over fading channels," *IET Communications*, vol. 11, no. 7, pp. 1132–1142, 2017.

[32] Y.-C. Lai and L.-Y. Hsiao, "General binary tree protocol for coping with the capture effect in RFID tag identification," *IEEE Communications Letters*, vol. 14, no. 3, pp. 208–210, 2010.

[33] C. T. Nguyen, T. T. Hoang, and V. X. Phan, "A simple method for anonymous tag cardinality estimation in rfid systems with false detection," in *Proceedings of the 4th NAFOSTED Conference on Information and Computer Science, (NICS '17)*, pp. 101–104, Vietnam, November 2017.


Journal of Engineering
The Scientific World Journal
International Journal of Rotating Machinery
Journal of Sensors
Advances in Multimedia
Advances in Civil Engineering
Hindawi
Submit your manuscripts at
www.hindawi.com
Journal of Control Science and Engineering
Journal of Robotics
Journal of Electrical and Computer Engineering
Advances in OptoElectronics
VLSI Design
International Journal of Navigation and Observation
Modelling & Simulation in Engineering
International Journal of Aerospace Engineering
International Journal of Chemical Engineering
International Journal of Antennas and Propagation
Active and Passive Electronic Components
Shock and Vibration
Advances in Acoustics and Vibration