Evaluation of a new RFID system performance monitoring approach

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Abstract— **Several performance monitoring approaches allowing the detection of RFID system defects have been proposed in the past. This article evaluates 3 of these approaches using a SystemC model, SERFID, of a UHF RFID system. SERFID can simulate the EPC C1G2 standard for the UHF tag-reader communication and also allows a realistic bit error injection in their RF channel.**

RFID;monitoring;on-line test; SystemC.

I. Introduction

In critical domains, RFID system failures can have catastrophic consequences. Monitoring RFID systems is thus a must in order to perform on-line detection of failures. However, defects detection is even more interesting than failures detection, since it may prevent failure occurrences. Therefore, the goal of our project [1] is to propose on-line methods to detect defects in HF or UHF RFID systems. These defects can result from hardware malfunctions (aging effects are particularly sensitive to harsh environments), medium disturbances (for example, electromagnetic bursts), or software bugs.

In our previous papers [1][2], we proposed a new monitoring technique for RFID systems, called *read rate profile*. This monitoring is based on the individual on-line evaluation of each tag read rate. This new test method was evaluated using an UFH RFID real industrial system application. Some errors (tag displacement or rotation…) were manually injected in the hardware system to analyze the quality of our proposed on-line test method. Our first conclusions, based on these few hardware fault injections, were very encouraging in comparison with existing methods. Nevertheless, performing an exhaustive evaluation of our method is very difficult because (1) the fault injection in such complex real RFID systems is really time consuming, (2) the accuracy of the fault injection is very difficult to control, (3) the statistical evaluation of a new test requires a lot of results to be statistically significant. Indeed, to thoroughly evaluate our test approach, we should be able to measure the two following complementary parameters: (1) the *Defect Level* (the percentage of application inventories that are defective but not detected), and the *Yield Loss* (the correct inventories incorrectly binned as "bad" due to the test inaccuracy).

In [3], we present a SystemC [4] model of an HF RFID system, and then we used it to perform the robustness analysis of HF RFID systems using realistic fault injection. Thus, our new contribution in the present paper is to propose a SystemC model of UHF RFID system to evaluate our test approach by means of software fault injection and simulation. In this study, we focus on the evaluation and comparison of several monitoring approaches (the classical ones and our approach) using software fault injection applied in the RF channel.

The outline of the paper is the following. The next section provides two short overviews on (1) existing RFID system simulators and on (2) the RFID system monitoring approaches. In section 3, we present the SERFID simulator. The fault free simulation results are discussed and compared to real application results. In section 4, we evaluate the different monitoring approaches using software fault injections.

II. State of the Art

A. RFID system simulators

Several RFID simulators have been proposed in the literature [5][6][7], but none of them focuses on the robustness evaluation. These simulators allow simulating (1) the communication protocol between the tags and the readers (called "air protocol") or (2) the interactions between the readers and the middleware. Designers generally use these simulators to perform a functional verification of their systems. For instance, Rifidi [5] only fits with RFID high level deployment issues; fault simulation with Rifidi would be unrealistic. RFIDSim [7] is a complete RFID simulator; nevertheless its main goal is to evaluate RFID protocols and tag hardware characteristics are not modelled.

We present in [3] a SystemC model of an HF RFID system to evaluate the system global robustness using software fault injection and simulation. This model (or simulation tool) is called SERFID (Simulation and Evaluation of RFID Systems). SERFID has been developed using the SystemC library which is adapted to both hardware and software components modelling. All digital functions in readers and tags have been modelled using the Transaction Level Modelling with Distributed Time (TLM-DT) [8]. In order to model global and local environment effects, the RF links between tags and readers have been divided into 2 parts: (1) a local RF link,

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which is specific to a couple of tag-reader and (2) a global RF link, which is a common RF environment for all the tags and the readers. This distinction allows the injection of global defects affecting all the tags and the readers and the injection of local defects affecting only one tag and one reader.

B. On-line testing methods

The classical RFID monitoring methods are based on reader performances monitoring. Many performance parameters can be observed to detect failures and defects. The classical performance parameters are the *Average Tag Traffic Volume* (ATTV) and the *Read Errors to Total Reads* (RETR) [9]. ATTV allows determining unusual tag traffic which is a symptom of a faulty system. For instance, if between 8:00am and 11:00am a reader usually reads 100 tags/hour every day and if one day, during the same period, the same reader reads only 50 tags/hour, then it can be assumed that a failure or a disturbance has occurred. RETR consists of counting erroneous reads over the total (correct and faulty) read attempts of a specific reader. High RETR means there is probably a problem: a faulty antenna, an improper placement of antennas, signal interferences in the range of RFID frequencies, low signal strength or software dysfunction. The evolution of this RETR can also be analyzed.

In [1], we propose a new monitoring method based on the read rate monitoring of each tag. The real case study we used to analyse and evaluate this approach is a UHF RFID system (900MHz) detecting boxes arranged on a pallet. Figure 1. illustrates this RFID system. To detect most of the tags, the pallet goes through a rotating conveyor which is centred into the RFID reader field.

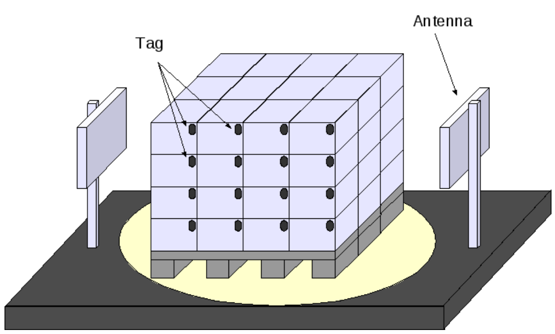

Figure 1. RFID system case study configuration

With our monitoring approach, the he tags ordered read rates –called profile- are compared to a reference –called *limit profile*– to check the health of the system. An example is given on Figure 2. . The "+" curve represents the limit profile. For each inventory, a new profile which is a new ordered list of the tag read rates is calculated. The "-" curve represents a fault free profile: in this case, every tag read rates are above the limit profile. The "." curve represents a faulty profile: in this case, some read rates are under the limit profile.

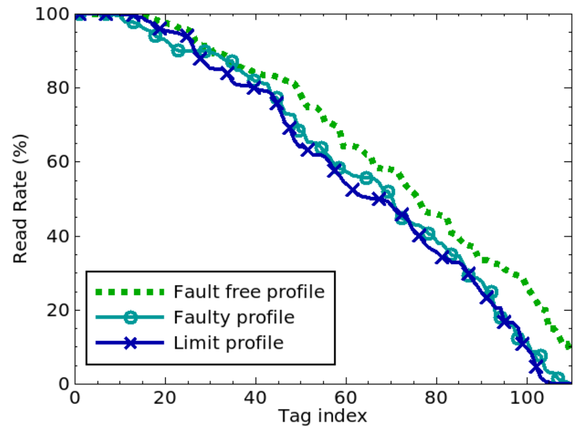

Figure 2. Limit, fault free and faulty profiles

III. SERFID SET UP

A. SERFID: from HF to UHF RFID

We modified our previous HF RFID simulator SERFID to model the UHF RFID systems. First, the HF power attenuation model has been replaced by a UHF attenuation model [12]. Secondly, we replace the HF RFID ISO 15693 protocol [10] by the UHF RFID EPC Class 1 Gen 2 protocol [11]. SERFID implements all the timings defined by the standard. This means that waiting times between slots, frames, data and also bit-rate of transmissions are simulated. Thus, the simulator can evaluate the application inventory time depending on the reader configuration (i.e. number of cycles, antenna selection…). Our monitoring approach is a non intrusive approach adding no additional test operations (and so no additional times) to the application inventory. However, the simulator could also evaluate the additional times for all the required additional test operations. Finally, an Ethernet interface has been plugged to the SystemC simulator so that SERFID can be controlled by a distributed middleware, as real readers usually are. Figure 3. illustrates a SERFID high level view containing several readers and tags; and one middleware. The middleware is a program which commands the inventory execution and performs the on-line monitoring. In the following, the same Java middleware is used for simulation and real RFID system control and monitoring. Thus, SERFID allow us to validate and to optimize our Java implementation of the monitoring approach.

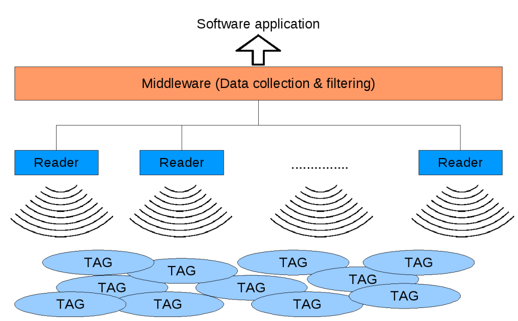

Figure 3. SERFID high level view model
with several readers and tags

B. *Simulation and test set up*

Thanks to the SERFID simulator and the middleware, we have obtained several read rate simulation results. These results which allow us to define the limits of the different monitoring approaches are presented in TABLE I. For each detected tag, the simulator (as the hardware reader does) returns a read rate (RR); i.e. the number of times the tag has been read during the inventory over the total number of read attempts. For illustration purposes, some of these RR are shown in TABLE I. These inventories, as they serve as references for our monitoring approach, have been performed without fault injection. Then, for each inventory, the *RETR* has been calculated. TABLE I. gives for several inventories (1, 2, i, j) obtained RETR, the average and the standard deviation of each RETR. In addition, we count the *ATTV* per pallet for each inventory and we determine the average and the standard deviation of this parameter. These values are also given in TABLE I. Each inventory in TABLE I. leads to a specific inventory profile and these inventory profiles allow us to compute the limit profile (defined in II.B).

Our simulator does not considered low level electromagnetic equations. Bit-Error-Rate (BER), which is modelled by direct bit flipping injection into the exchanged data, permits to model different electromagnetic environmental conditions. Of course, for complex RFID systems, the BER characterization of each tag-reader communication is very difficult to realize. Thus, our simulator allows us to evaluate the efficiency of different monitoring approaches for several possible BER configurations. In this case study, we chose BER to obtain similar average read rate profiles for simulation and experimental configuration (described in section II.B). Figure 4. shows the obtained simulation results and experimental results. We can observe that the read rate average profiles of the real RFID system (plain curve) and the simulated one (dotted curve) have similar shapes. In addition, the number of tags with 100% read rate and read rate around 10% are the same.

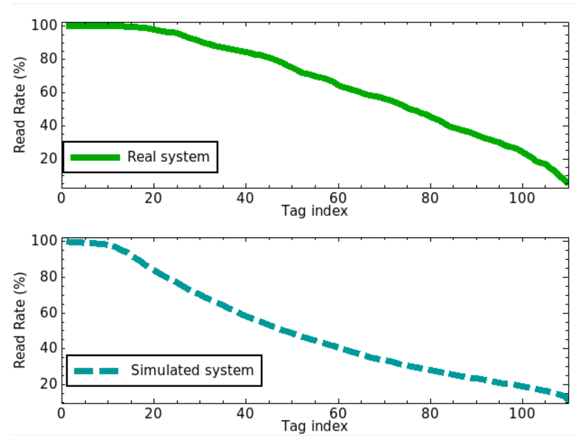

Figure 4. Real and simulated read rate profile

The global average inventory time (which consists of 100 successive inventories each separated by 1.5s waiting times) of the real RFID system is 160s and of SERFID is 176s. The difference is due to the fact that SERFID always implements the maximal allowed times defined in EPC Class1 Gen2 standard.

C. *Software fault injection*

The software fault injection consists of injecting parametric variations on the BER of the global or local RF links. As the fault free read rates are variable for each application inventory (see Table I), it is necessary to define what a faulty inventory is. So, we state that a faulty inventory is an inventory which contains at least one tag read rate decreased of at least 20%. Indeed, we observed in the experiments that the variations of the fault free read rates never exceed this limit. This point is also confirmed by the maximal standard deviation of the tag read rate given in Table I which is closed to 5%.For example, when the tag with id #1 has an average read rate equal to 98%, we consider as faulty every inventory with a read rate less than 78% for this tag and as fault free every inventory with a read rate greater than 78% for this tag. Using this definition we are able to create numerous faulty inventories to perform the evaluation (and comparison) of the monitoring approaches.

TABLE I. STATISTICAL RESULTS FOR FAULT FREE INVENTORIES

Tag ID	Inventory 1	Inventory 2	…	Inventory i	Inventory j	…	Average	Standard Deviation
1	100	97	…	99	96	…	98.85	1.68
….	….	….	…	….	….	…	….	….
61	28	44		38	48	…	40.15	5.32
62	40	40	…	40	44	…	38.44	4.89
63	44	54		35	42	…	37.99	5.10
…	…	…	…	…	…	…	…	…
110	27	20	…	19	14	…	17.59	3.94
Average Read Rate	51.02	50.15	…	49.77	51.02	…	50.56	0.50
RETR	48.98	49.85		50.23	48.98		49.44	0.50
ATTVs	110	110	…	110	110	…	110	0.00

IV. Evaluation of The RFID system Monitoring

TABLE II. shows the Defect Level – *i.e.* the percentage of application inventories that are defective but not detected – in different faulty cases for each monitoring method. The first column describes the injected faults and the approximate number of resulting faulty tags (as defined in III.C). We can see that, for these "soft faults", ATTV never detects faults. So, its DL is always 100%. In addition, Profile method has detected more faults than RETR. The Profile method DL is lower than RETR DL. This simulation result confirms what we previously observed and described in [1] on real measurements. Finally, Figure 5. shows the complementarities of these different methods. Even if the Profile methode DL is the best, the RETR permits to detect some defects not detected by the Profile method.

TABLE II. Defect level for different fault injections

Fault	Defect Level		
	for ATTV	*for RETR*	*for Profile*
10 BER increased by 0.35 (~4-5 faulty tags)	32/32 (100%)	5/20 (25%)	0/20 (0%)
5 BER increased by 0.5 (~2-3 faulty tags)	20/20 (100%)	15/20 (75%)	8/20 (40%)
10 BER increased by 0.3 (~3 faulty tags)	19/19 (100%)	13/19 (68%)	10/19 (53%)
2 BER increased by 0.5 (~1-2 faulty tags)	20/20 (100%)	18/20 (90%)	18/20 (90%)
5 BER increased by 0.3 (~2 faulty tags)	20/20 (100%)	18/20 (90%)	12/20 (60%)
Total	111/111 (100%)	69/111 (62%)	48/111 (43%)

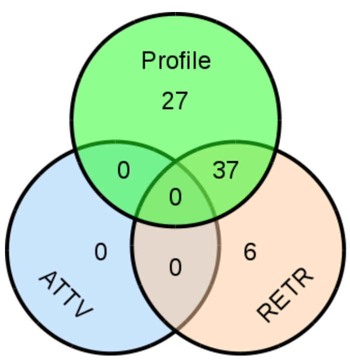

Figure 5. Set diagrams showing the complementarities of the 3 monitoring methods

V. Conclusions and Perspectives

Using our simulation tool SERFID, previous observations have been confirmed. Many different faulty cases have been simulated to allow comparison of classical monitoring methods and proposed one. The new proposed method, named Profile, detects more faulty configurations than previous methods. Because the combination of these different methods, like RETR and Profile makes the detection better, we conclude that these methods must be conjointly used.

In our future work, the results presented in this paper will be consolidated using other BER profiles (corresponding to other electromagnetic configurations) and using a higher number of fault injections; In addition, we will evaluate the proposed method for different RFID system configurations. Also, the yield loss for each method, i.e. the number of correct inventories incorrectly binned as "bad" due to the test inaccuracy will be thoroughly evaluated. The Profile method should require a special care on the Profile limit definition in order to limit the yield loss.

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