Performance Evaluation of an Arbitration Scheme for RFID Readers

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***Abstract* – The interrogation range of an RFID (Radio Frequency IDentification) reader can be restricted by its sensitivity and powering availability depending on distance. The RF Shower amplifies the signals transmitted by neighboring RFID readers and then transmits them again to expand the interrogation zones of the readers. However, since multiple readers may have the exactly identical interrogation zone by the Shower, collision between readers becomes severe. To solve this problem, an arbitration mechanism for multiple readers is needed. This paper presents an arbitration algorithm and its simulation results.**

I. INTRODUCTION

Recently, the 860-960 MHz UHF-band passive RFID technology has been spotlighted. The EPCglobal Class 1 Generation 2 [1] and the ISO/IEC 18000-6 [2] standards are the most well-known protocols. With these protocols, since tags are passive, a reader receives information from a tag by transmitting a continuous-wave (CW) RF signal to the tag. On the other hand, battery-powered mobile and portable computing devices are becoming important platforms in modern society. The coupling of the RFID technology and mobile technology helps to widely and rapidly diffuse the RFID technology into our everyday life. Generally, a mobile RFID reader has weaker transmission power than stationary ones to reduce the energy consumption and prolong battery life. Inevitably, the **interrogation zone** of the mobile RFID reader, the finite area around the reader where it can communicate with tags, is also scaled down.

For diminishing those difficulties, we have developed an RFID signal repeater, called the **RFID Shower** which supports both the EPCglobal Class 1 Generation 2 and the ISO/IEC 18000-6 Type B standards simultaneously. The main functionality of an RFID Shower is to amplify the signals transmitted by neighboring readers and then to transmit them again. Similar to a reader's interrogation zone, the area around an RFID Shower where tags can receive the Shower's repeated signal and their replies can be correctly decoded by the reader in the area, is called the Shower's interrogation zone or simply the **Shower zone**. In a Shower zone, a reader's interrogation zone is expanded to the Shower zone.

Unfortunately, the Shower System suffers from an unattractive side effect: collisions between readers in the same Shower zone. When multiple readers may exist in the same Shower zone simultaneously, their interrogation zones are perfectly overlapped. A tag cannot choose a single frequency for communication due to its very low functionality. Instead, it responds to all communications over a wide range of frequencies. Thus, if a tag in the interrogation zone (i.e. the Shower zone) receives signals from more than one reader at the same time, it cannot decode the information in the signals although the readers are using different channels.

To avoid this collision, we have to allot the readers different times to operate. An arbitration algorithm for the readers to enable efficient, successful interrogations in a Shower zone is proposed in our previous study [3]. In the paper, we have assumed that the arbiter is embedded into the Shower and the communication protocol between the arbiter and readers employs the RFID protocol itself considering simplicity and production cost. Thus, the arbiter operates as a special RFID tag. However, it contains more sophisticated RF circuits than ordinary tags and has a power source. Thus, it can recognize arbitration requests transmitted by distant readers in the Shower zone. All RFID communication for arbitration is transmitted over a specific channel. The channel is referred to as the **arbitration channel** and has to be announced to all mobile RFID readers beforehand. Although a Shower can amplify multiple signals in distinct channels simultaneously, the readers in the Shower zone can transmit signals over only one channel at a time because tags are not capable of differentiating between the channels. Thus, the readers use a common channel, called the **Shower channel**, to interrogate tags in the same Shower zone.

In this paper, we focus on overall performance evaluation of the arbitration algorithm. We employ Ziegler's DEVS (Discrete EVent Systems Specification) [4] formalism to specify the arbitration algorithm. The DEVS formalism provides a formal framework for specifying discrete event models in a hierarchical, modular manner. Several realizations of the formalism have been proposed. DEVSim++ [5] realizes the formalism in C++. We employ DEVSim++ for modeling and simulation in this paper.

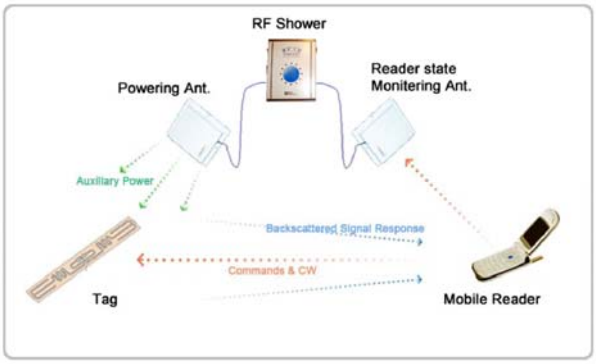

FIGURE 1 – THE RFID SHOWER

II. THE DEVS FORMALISM

For specifying a target system by using the DEVS formalism [4], the system must be repeatedly decomposed into primitive components. Dynamic behavior of each component is specified by atomic DEVS. An atomic model M is defined as

$$M = \langle X, Y, S, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$$

where

- X : input events set.
- Y : output events set.
- S : sequential states set.
- δ_{int} : S→S : Internal Transition Function
- δ_{ext} : Q×X→S : External Transition Function
  where Q is the total state of M given by
  $Q = \{(s,e) \mid s \in S \text{ and } 0 \le e \le ta(s)\}$
- λ : S→Y : Output Function
- ta : S→ $R_0^{+\infty}$: Time Advance Function

Then, several component models are connected together to from a new model by coupled DEVS. Since the latter model can be employed as a component in a larger model, the target system can be specified in a hierarchical, modular fashion. A coupled model DN is defined as

$$DN = \langle D, \{M_i\}, \{I_i\}, \{Z_{i,j}\}, select \rangle$$

where

D : set of component names

For each i in D

M_i : DEVS for component i in D

I_i : set of influences of i

For each j in I_i

$Z_{i,j}$: $Y_i \rightarrow X_j$: i-to-j output translation function

select : subset of D → D : tie-breaking function

The complete description of definitions for the atomic and coupled DEVS models can be found in [4].

III. MODEL DESCRIPTION

This section describes the development of a Shower based UHF-band RFID system model in a hierarchical, modular manner using the DEVS formalism. First, the overall system model is decomposed into three components: a ReaderSet model, a Shower model, and a TagSet model. The ReaderSet model is partitioned into Reader models. Each instance of the Reader model corresponds to a distinct RFID reader. The Shower model is decomposed into a Channel model and an Arbiter model. The Channel model represents a generic UHF-band RFID channel. In case of the Shower model, it corresponds to the arbitration channel. The Arbiter model is the central arbiter embedded in the Shower. The TagSet model is further divided into a Channel model and a Tags model. The Channel model corresponds to the Shower channel in this case. The Tags model represents the group of the RFID tags in the Shower zone.

Fig. 2 shows the hierarchical construction of the mobile RFID system model. Each terminal node (represented by a box) is specified by atomic DEVS while each internal node (represented by an oval) is specified by coupled DEVS. Since the Tags model represents a population of RFID tags, there is only one instance of the Tags model although a lot of tags may exist in a Shower zone.

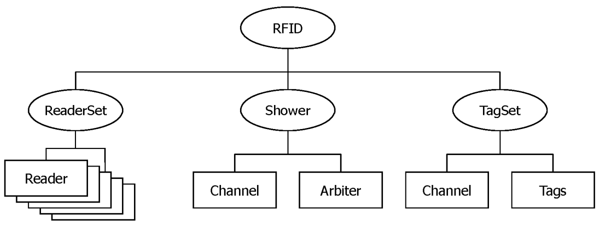

FIGURE 2 – HIERARCHICAL CONSTRUCTION OF THE MODEL

To specify the behavior of the atomic DEVS models, their operation scenarios are investigated. When a user requests an interrogation, the reader first checks whether another reader is requesting arbitration. This can be examined by clear channel assessment (CCA) on the arbitration channel. If the channel is found to be busy, the reader waits for a random period before trying to assess the channel again. Otherwise, the reader transmits an arbitration request to the arbiter. (Although we assume that the readers support CCA capability in this paper, the arbitration scheme can properly operate with no use of CCA.)

When the arbiter receives an arbitration request from a reader, it grants channel access to the reader via the arbitration channel if either i) the Shower channel is idle or ii) there is no reader that has been already granted to access the Shower channel but does not yet start to transmit signals. The latter condition is caused by the **hidden arbitration** capability of the arbiter. Namely, the arbiter decides beforehand the next reader which will use the Shower channel, while another reader is using the Shower channel, for reducing the time consumed in performing arbitration. Then, the next reader performs CCA on the Shower channel, and starts to access the channel when it becomes idle. The latter condition means that the next reader has been already decided. If none of the two conditions is satisfied, the arbiter transmits a WAIT message to the reader to request again after waiting for a random period. Note that a multiple reader-to-tag collision may occur in the arbitration channel, when multiple readers simultaneously assesses that the channel is busy. However, an arbitration transaction is very shorter than general RFID transactions. The overhead caused by the collision is negligible considering the hidden arbitration.

The reader which is using the Shower channel is referred to as the **active reader**. The active reader transmits interrogation signals to tags. But its transmitter power is insufficient to activate distant tags, the Shower amplifies the signal. During the time that a tag respond to the reader, the Shower transmits a continuous wave RF signal to the tag at a constant RF power level, and the tag modulates the impedance of its RF load attached to the tag antenna terminals. The reader then receives the data back from the tag as a variation in a reflection of its transmitted power. Fig. 3 illustrates the procedure.

By investigating the input/output behavior of each model in Fig. 3, its atomic DEVS specification can be constructed.

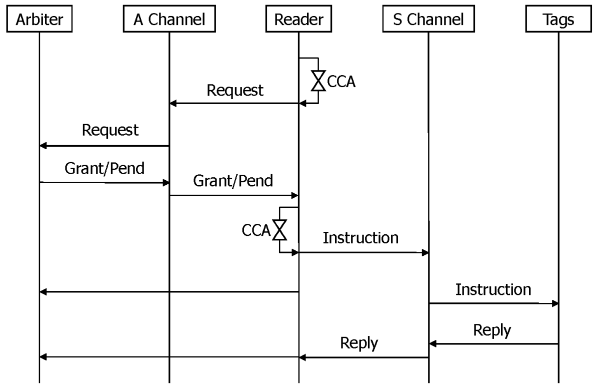

FIGURE 3 - A TYPICAL OPERATION SCENARIO

Fig. 4 depicts the overall structure of the RFID Shower system model. The component models are connected together through the input/output ports. A behavior of an individual model is specified by atomic DEVS definition, and an aggregation of the behaviors constitutes the overall behavior. To explain atomic model development used in this paper, the development of the atomic model Reader, which models the behavior of an RFID reader, is described.

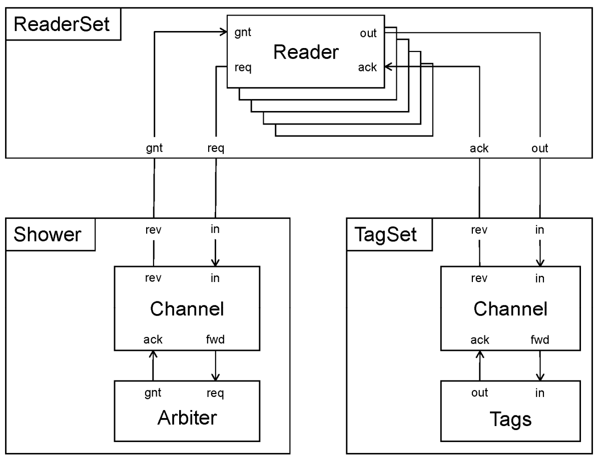

FIGURE 4 – STRUCTURE OF RFID SHOWER MODEL

The Reader model has two input ports (gnt, ack), and two output ports (req, out). These ports are connected to the Shower model and the TagSet model. The Channel model in the Shower model stands for the arbitration channel, while the Channel model in the TagSet model represents the Shower channel. The req port, connected to the arbitration channel, is used to send arbitration request messages to the Shower model. The result is informed via the gnt port. The out port, connected to the Shower channel, is used to transmit interrogation request messages to the TagSet model. Response of the TagSet is delivered via the gnt port.

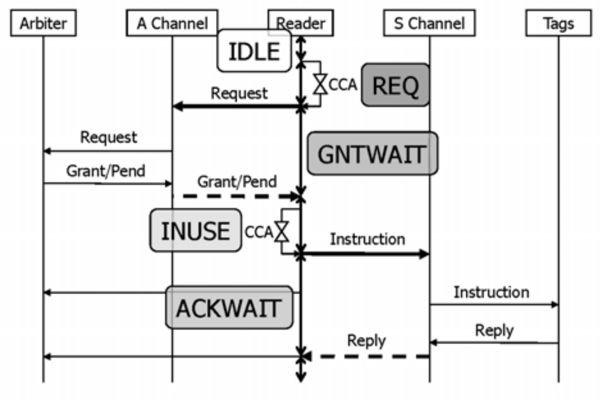

FIGURE 5 – PHASE DECOMPOSITION OF THE READER MODEL

As explained earlier, an atomic DEVS model alters its state when it receives an input or output event. Thus, to investigate the behavior of the Reader model, appearances of input/output events of the model should be analyzed. According to the typical operation scenario in Fig. 3, the Reader model receives two input events and two output events. If we assign different phases before and after every event, the Reader may have five phases (phases are a part of the sequential states set S, and the phase expresses an abstraction of contiguous states with respect to modeling objective). Since an initial state is required considering a user may randomly interrogate tags, there are six phases in the Reader model.

Fig.5 shows the phases. The IDLE phase is the initial phase of the Reader model, is transited to the REQ phase when a user requests to interrogate tags. During the REQ phase, the CCA operation is applied to the arbitration channel. If the channel is found to be idle (i.e. the channel is available), the Reader generates an arbitration request message, sends it to the Shower model through the req port, and becomes the GNTWAIT phase. When the arbitration result comes from the Shower via the gnt port, the Reader is transited to the INUSE phase, the REQ phase, or the IDLE phase depending on the result. In the INUSE phase, the CCA operation is applied to the Shower channel. If the channel is found to be idle (i.e. the channel is accessible), the Reader generates an interrogation request message, sends it to the TagSet model through the out port, and becomes the ACKWAIT phase. When the tag response comes from the TagSet via the ack port, the Reader is transited to either the STOP phase or the IDLE phase depending on the status of the response and the existence of further user requests. Fig. 6 illustrates the phase transition diagram of the Reader model. In the figure, '?' and '!' symbols represent an input and output event, respectively.

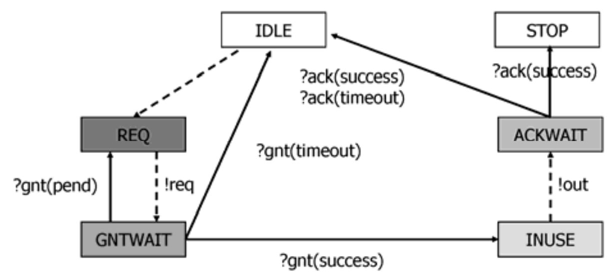

FIGURE 6 – PHASE TRANSITION OF READER DEVS MODEL

IV. SIMULATION RESULTS

To evaluate the performance of the arbitration scheme, the models developed in Section III are implemented in DEVSim++. For performance comparison, three cases are simulated: the Shower supports the arbitration mechanism and readers has CCA capability (CCA-Arbiter), the Shower supports no arbitration mechanism and readers has CCA capability (CCA-Only), and the Shower supports the arbitration mechanism and readers has no CCA capability (Arbiter-Only). We assume that each reader repeatedly tries to interrogate the tags while it completely reads full information from all the tag.

Fig. 7, Fig. 8 and Fig. 9 show the performance of the proposed arbitration scheme with varying numbers of RFID readers. Each point takes an average of the results from 10 statistically independent simulation runs. That is, each simulation run uses a distinct stream of random numbers.

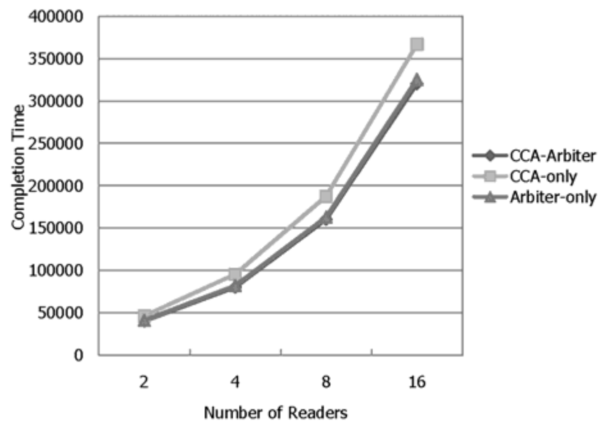

FIGURE 7 – RESULT OF COMPLETION TIME

In the first experiment, the average completion time is compared. The completion time denotes the time spent by each RFID reader to complete given user requests. It is mainly influenced by the number of arbitration trials. Thus, a longer completion time means larger arbitration overheads. Fig. 7 shows the result of the simulations. As can be clearly seen from the graphs, CCA-Arbiter and Arbiter-Only show very similar performance and outperform CCA-Only.

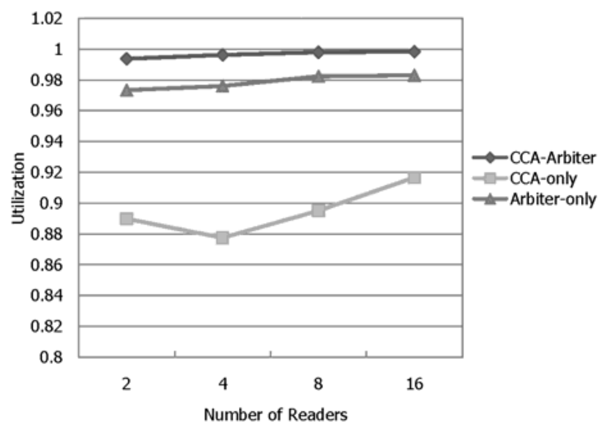

FIGURE 8 – RESULT OF UTILIZATION

In the second experiment, the utilization of the Shower channel is compared. The utilization of a channel indicates the ratio of its busy period to entire simulation period. Thus, higher utilization implies that the channel is used more frequently. Fig. 8 presents the result. As shown, CCA-Arbiter and Arbiter-Only outperform CCA-Only, and case CCA-Arbiter shows slightly better performance than case Arbiter-Only.

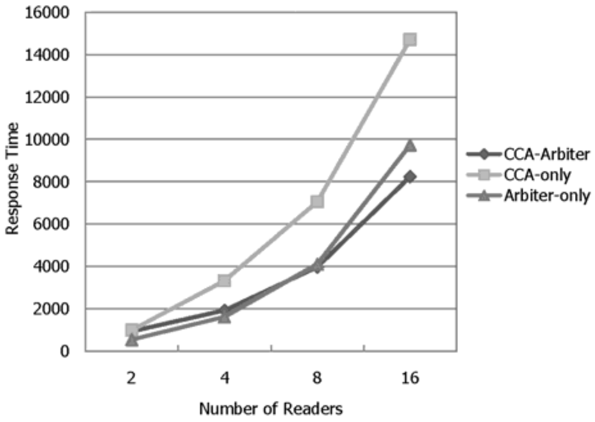

FIGURE 9 – RESULT OF RESPONSE TIME

In the final experiment, the average response time is compared. The response time is the elapsed time between the arrival of a user request and the beginning of the successful tag response. The simulation result is shown in Fig. 9. Similar to the prior two experiments, CCA-Arbiter and Arbiter-Only show very similar performance and outperform CCA-Only. Consequently, we can conclude that the arbitration scheme efficiently coordinates the interrogation of the readers in its Shower zone.

V. CONCLUSION

An RFID Shower is devised to widen the interrogation zones of RFID readers. Since collisions between the readers become severe under the Shower environment, an arbitration mechanism for the RFID readers is required to reduce the collisions.

In this paper, we evaluated the performance of the arbitration scheme proposed in [3]. To do this, a typical Shower-based RFID system model is presented and implemented by using the DEVS formalism. From various simulation experiments, we can conclude that the arbitration scheme efficiently coordinates the interrogation of the readers in the Shower zone. In the near future, we are planned to realize the proposed algorithm on the RFID Shower system and to validate the proposed model.

REFERENCES

[1] EPCglobal. EPC^{TM} radio-frequency identity protocols class-1 generation-2 UHF RFID protocol for communications at 860MHz - 960 MHz, 2004.

[2] ISO/IEC JTC 1. Information technology – radio-frequency identification for item management – part 6: parameters for air interface communications at 860 MHz - 960 MHz, 2004.

[3] Yeong Rak Seong, Ha Ryoung Oh, Jun Seok Park, Ho Jun Song, Byung Jun Jang, Sung Woo Bae, Hong Goo Cho, Eui Seok Song, Myoung Sub Jeong, and Juno Kim. Arbitration of UHF-band mobile RFID readers. In *Proceedings of the 6th Asia Pacific International Symposium on Information Technology*, pages 281–288, 2007.

[4] Bernard P. Zeigler. *Multifacetted Modeling and Discrete Event Simulation*. Academic Press, 1984.

[5] Tag Gon Kim. DEVSim++ user's manual: C++ based simulation with hierarchical modular DEVS models, 1998.