[Practical Paper] Problem and solution of delay in UHF RFID

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Abstract—RFID (Radio Frequency Identification) is important hardware for the ubiquitous society. There are some RFID technologies and the UHF (Ultra High Frequency, 860-960MHz) RFID is one of the key technologies because the access distance is longer than other technologies.

The UHF RFID tag does not have a battery generally. Power for tag is supplied from a reader as a radio wave. So a high power output is required for a reader. In Japan, high power reader (1W, 36dBm output) for UHF RFID can be used since April 2005. However, high power reader causes the interference problems. One of them is that a reader is interfered by the output of another reader while it is receiving the response from a tag. The distance between readers is estimated about 1.6km under the Japanese regulation.

Since January 2006, low power reader (10mW, 13dBm output) can be used. At the same time, carrier sense mechanism called LBT (Listen Before Talk) is introduced to prevent interference between RFID readers. If all the channels are used, a reader must wait until one of other readers releases a channel in the LBT mechanism.

We show the problem of the UHF RFID system caused by the LBT that readers are influenced by other readers and do not keep realtime capability when readers work simultaneously. We also show the solution for this problem. The name of the solution is the "cycle-divide method" which can keep the realtime capability by changing the session ID and suspending the transmission of the non-realtime reader's cycle.

Keywords: Radio Frequency Identification, anti-collision, realtime system, non-realtime system, time sharing

1 INTRODUCTION

RFID (Radio Frequency Identification) is important hardware for the ubiquitous society in which everything is connected easily via "Everyone anytime and anywhere anything" network. There are some RFID technologies and the UHF (Ultra High Frequency, 860-960MHz) RFID is one of the key technologies because the access distance is about 3m without battery and it is longer compared with other technologies such as 2.4GHz RFID. So it is expected to be applied to logistic management system and so on.

The UHF RFID tag does not have a battery generally. Power for tag is supplied by a reader as a radio wave. So a high power output is required for a reader. In Japan, high power reader (1W, 36dBm output) for UHF RFID can be used since April 2005. However, high power reader causes the interference problems described in Section 2. One of them is that a reader is interfered by the output of another reader while it is receiving the response from a tag. The distance between readers is estimated about 1.6km under the Japanese regulation.

Low power reader (10mW, 13dBm output) can be used since January 2006. At the same time, carrier sense mechanism called LBT (Listen Before Talk) is introduced to prevent interference between RFID readers. In the Japanese LBT, 9 and 14 channels are defined for high power and low power respectively and if all the channels are used, a reader must wait until one of other readers releases a channel.

It is easy to imagine that some readers must wait and cause read failures by the LBT when more than 9 readers work at the same time [1-3]. It means that the realtime RFID readers such as gate monitor cannot detect the RFID tag when other non-realtime readers such as stock control work simultaneously. In this paper, we discuss about the interference between realtime readers and non-realtime readers [4-6], and propose the solution.

2 PROBLEM IN UHF RFID

2.1 Interferences in UHF RFID

One of the key features of UHF RFID is the communication distance. The tag without the battery (passive tag) can be accessed from 3m distance. It means that the response (reflected wave) from a tag is extremely small and the transmission wave of very far reader may cause the interference as described above.

There are four interference paths. Figure 1 shows the interference paths and the interfered distance [3].

・ Route<1>: reader-reader interference
  A reader is interfered by the command of another reader while it is receiving the response from a tag. Interference distance is estimated about 1.6km

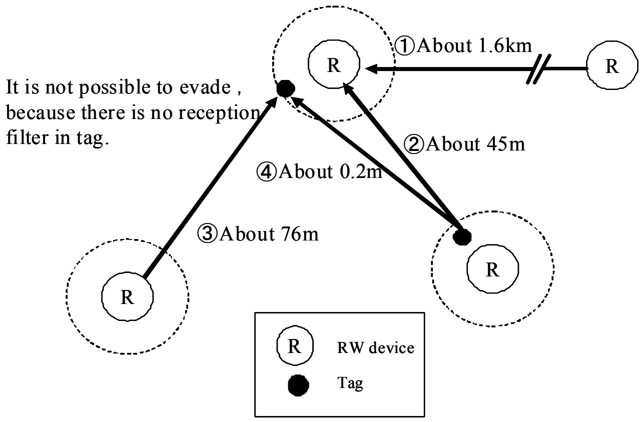

Figure 1: Interference distance between systems

- Route<2>: tag-reader interference
  A reader is interfered by the response of a tag that is owned by another reader while it is receiving the response from the owned tag. Interference distance is estimated about 45m.
- Route<3>: reader-tag interference
  A tag is interfered by the command of another reader while it is receiving the command from the owner. Interference distance is estimated about 76m.
- Route<4>: tag-tag interference
  A tag is interfered by the response of another tag while it is receiving the command from the owner. Interference distance is estimated about 0.2m.

It is necessary to prevent these interferences. Especially reader-reader interference is the key because the distance is about 1.6km which can easily cover a factory or a building.

The key concept to prevent reader-reader interference is to separate radio wave. There are two same ways to separate, the first one is to change the frequency and the second one is to change the time slot. The technologies to prevent interference are called anti-collision, and the followings are summaries of the anti-collision technologies [7-10].

1. **Frequency hopping method**

This method is classified into the method of changing the frequency. In the United States, the bandwidth for RFID is 26MHz (902-928MHz) and it is possible to assign about 100 channels. The reader changes the frequency dynamically to reduce probability of the collision (the readers use a same channel).

2. **LBT (Listen Before Talk)**

This method is classified into the method of changing the time slot. The reader must confirm that the channel is not used by sensing carrier (Listen) before using channel (Talk). If the channel is used, the reader waits until the channel is released. This solution is suitable for the countries which wide bandwidth is not assigned to. For instance, the bandwidth for RFID is 3MHz (865-868MHz) under the European regulation. Japan also adopts this method.

3. **Subcarrier method**

This method is classified into the method of changing the frequency. A slight electric wave from the RFID tag has a big influence on interference. In the Class1-Generation2 standard that EPC Global proposes, the subcarrier method is included.

This method modulates the subcarrier, changes the frequency of up-link signal and down-link signal, and has evaded the interference between readers.

4. **Down-link and up-link channel division method**

This method is classified into the method of changing the frequency. This method changes sending and receiving frequency. A reader transmits a command as a down-link signal and changes the frequency for the up-link signal. A response from a tag is carried on the up-link frequency. So the frequency of the down-link and up-link is changed and prevent the interference. For instance, the interference is reduced by allocating one channel for down-link, and three channels for up-link.

2.2 LBT and the problem

In Japan, the discussion to introduce UHF RFID has been started in the Ministry of Public Management, Home Affairs since 2004. Radio Law was revised in April 2005 and January 2006 as mentioned above. Table1 shows the overview of the regulation for the UHF RFID in Japan.

The LBT mechanism is introduced since January 2006, so reader-reader interference problem was solved. In the LBT for the high power RFID, we can use 9 channels and sense carrier 5 to 10 milliseconds before transmission, then start transmission maximum 4 seconds, sleep 50 milliseconds before next transmission.

It is possible to prevent interference between readers by sensing carrier and waiting for a channel release, however, the reader must wait when all channels are used. As a result, delay may happen, and the possibility to fail to read in realtime comes out. It is important for the realtime RFID system to evaluate this delay and to find a solution

It thinks about correspondence by the above-mentioned each method by actual use. It is a situation in which two or

Table1: Standard of 950 - 956MHz Band passive type RFID

	High power type	Low power type
Output	air electric power: 1W or less air gain: 6dBi or less	air electric power: 10mW or less air gain: 3dBi or less
Frequency	952 - 954MHz	952 - 955MHz
License	Premises wireless station	Specified low power radio station (The license is unnecessary.)
Channel	9 Channels (200KHz)	14 Channels (200KHz)
Carrier sense	5 - 10ms, -74dBm	10 - 15ms, -76dBm
Transmission time	Continuousness 4 seconds, 50ms stop	Continuousness 1 second, 100ms stop
Access distance	About 3m	About 50cm

more medium-scale buildings where a lot of RFID readers were set up in each floor have built. To simplify the model, assume that each floor is a big one room and it is not partitioned by the wall.

Two or more readers transmit in each of these floors and the transmission command of the per-device is transmitted to the RFID tag that reflects the floor and the wall and exists on the entire floor when there is a device. Then, the R/W device in the same floor controls timesharing by the carrier sense. In this case, the frequency channel need not be changed, and it is possible to unite them with the same channel. It is necessary to give a different frequency because the interference between R/W devices is generated even if the shielding effectiveness is applied to the ceiling and the wall when there is a hierarchical relationship of the floor. Moreover, when such two or more buildings are side-by-side, the interference problem between buildings remains and it doesn't become an effective solution only by the frequency dividing and timesharing.

Recently, the skyscraper might increase, it be adjacent between buildings, and the factor of interference increases. It becomes impossible to secure realtime of the delay in the interference workaround until present depending by application for which realtime like the gating arrangement is necessary.

3 MODELING OF SIMULATION

3.1 Operation overview of Gen2

The UHF RFID technology called Class-1 Generation-2 (alias Gen2) [11] settled on by EPC global is now a main stream, though there is various kinds of UHF RFID. Figure 2 shows the operation overview of the protocol of the Gen2 and the above-mentioned Radio regulation.

Reading tag is often executed two or more times. It is called a cycle here. LBT of 50 milliseconds is needed between cycles. Next, the processing that is called a round following initialization is repeated at each cycle. Initialization can be divided roughly into initialization according to the processing system of the reader and the initialization of tag (session initialization). A round is composed of the round initialization and slots. In addition, a slot can be divided into the inquiry and the reading to tag. When the corresponding tag does not exist, the reading time becomes unnecessary.

The number of slots is decided during the round initialization. Tags decide the slot number to respond randomly according to the number of slots. If there are multiple tags in the same slot, the reader does not detect response, so tag reading process is just skipped and they are read in the next round.

The formula that the reader puts out the electric wave is shown by the next expression.

T(cycle) = T(system dependent part) + T(session initialization) + N_R ×{T(round initialization) + T(inquiry) × N_S +T(tag reading) × N_T} ･････ (1)

N_R: Number of rounds in a cycle
N_S: Number of slots in a round

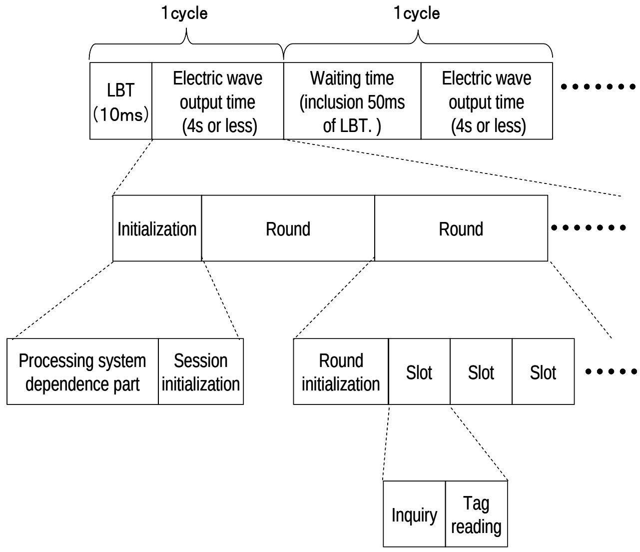

Figure 2: Operation overview of Gen2

N_T: Number of tag to read

The transmission rate by one channel (200 kHz) becomes about 40kbps, and Table 2 shows typical values for each T.

T (processing system dependence part)	about 10ms
T (session initialization)	about 2ms
T (round initialization)	about 1.5ms
T (inquiry)	about 0.8ms
T (tag reading)	about 6ms

If there is one round in which there are 16 slots:

T (cycle) = 12ms + (1.5ms + 0.8ms × 16) + N_T × 6ms
= 26.3ms + N_T × 6ms ･････ (2)

Multi-cycles are necessary for practical use. In that case, the number of reading times is given by the following expressions.

N (the number that can be read)
= T (can be read) / (T (cycle) + T (LBT)) ････ (3)

T (can be read): time that tags pass the accessible area, i.e. reader repeats cycles during this period.

T (LBT): 10 milliseconds for the first cycle, and 50 milliseconds for the second and the following cycles.

Table 2: Typical Values for each T

	Number of bits	Time* (msec.)	Gen2 Command
System dependent part	-	10.0	-
Session initialization	50	2.0	SELECT
Round initialization	27	1.5	QUERY
Inquiry	9	0.8	QREP
Response	34	0.9	
Tag reading	23	1.1	ACK
Response	144	4.0	

* Including interval time between commands

3.2 Model of gate monitor (realtime processing)

Accessible distance of a UHF RFID is 2-3m. The gate monitor must complete reading while a person or a thing moves such a distance. For instance, the passing speed of a person is about 5km per hour, and it is assumed about 10km per hour in the band conveyer, 5km/h and 10km/h mean 1.4m/sec and 2.8m/sec respectively. Therefore, T (can be read) is about 1 to 2 seconds.

On the other hand, the number of tags can be assumed several pieces on the gate. For instance, one person passes the gate with a few items.

So we assume following values in the following simulation.

T (can be read) = 1 second
T (cycle) = 50 milliseconds

50 milliseconds for T (cycle) means that there are 4 tags and the system reads them in one round which has 16 slots.

In the simulation, gate passing events are given by the Monte Carlo method, and the state of the readers are updated every ten milliseconds. For instance, a reader changes in the state of LBT when a gate passing event is generated. It changes in the state of ACTIVE if there is an open channel after ten milliseconds. The state of LBT is continued when there is no open channel. Time in the state of LBT is measured when a reader changes in the state of ACTIVE, ten milliseconds are subtracted, and then the delay by LBT is obtained. The state of ACTIVE is continued during T (cycle). After T (cycle), the state is changed to LBT2 if the time is within T (can be read). In the state of LBT2, a reader waits for 50 milliseconds. A reader repeats ACTIVE state and LBT2 state during T (can be read).

After an event (i.e. a human pass the gate), the next event is generated evenly within the fixed time as following.

T (mean time) ×2 – T (can be read)

For instance, 1800 events per hour means T (mean time) is 2 seconds, and if 1 second is assumed for T (can be read), then the next event is generated within 3 seconds. In this simulation, event distribution within 3 seconds is uniform and share 9 channels by all the gate readers. Because the carrier sense level is –74dBm in the Japanese regulation and it is equivalent to 1.6km away from high power reader (1W, 36dBm output).

3.3 Model of stock control (non-realtime processing)

The many tags are read simultaneously when the inventory is executed in the stock control in bulk. It causes two differences compared to the gate model. The first is that the reader works eventually because an operation is done by human. So we introduce T (interval) instead of T (can be read). T (interval) is the interval time for the next operation and the event of the next operation is given by 2 times of T (interval) by the Monte Carlo method.

The second is T (cycles). The slots per rounds are assumed 16, and the typical T (cycles) are followings.

T (cycle) = 161 ms (20 tags and 2 rounds)
T (cycle) = 235 ms (30 tags and 3 rounds)

If there are many tags, some tags may respond in the same slot. In this case, a reader can know there are some tags to read and expand the number of slots from 16 to 32 or more for the next round. So T (cycle) may be more than several hundreds milliseconds. In the simulation in chapter 4, T (cycles) are changed from 100 milliseconds to 500 milliseconds.

4 SIMULATION AND PROBLEM

4.1 Simulation results of gate monitor

As mentioned, LBT may cause delay for each read cycle if there are many readers. The delay is calculated in this simulation with following parameters.

Number of gates:	15 - 150
T (cycle):	50 milliseconds
T (mean time):	2 seconds
(Traffic = 1800 events / hour)	
T (can be read):	1 second

Traffic that passes the gate is given by the Monte Carlo method by using these parameters, and the relation between the number of gates and the amount of traffic was simulated.

The delay time is expressed at the probability distributions because traffic is given based on the probability by the Monte Carlo method. Figure 3 shows the relation between the delay time and probability distributions. The figure shows that, in case of 40 gates, the delay time is less than 100 milliseconds with 98% events while remained 2% events may wait for more than 100 milliseconds.

In this simulation, T (cycle) is 50 milliseconds, typical T (LBT) is 50 milliseconds, and T (can be read) is 1 second, so it is easy to understand that expected cycles are 10 per event. So number of total cycles an hour is 18000. Probability of 98% means that 360 cycles are delayed more than 100 milliseconds.

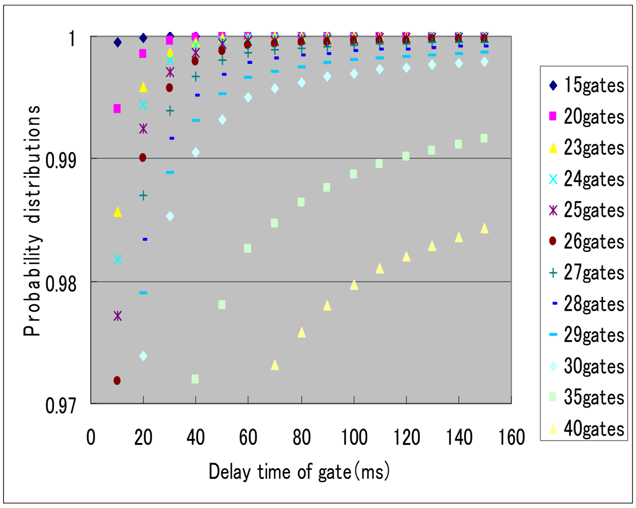

Figure 3: Relation between the delay and probability distributions

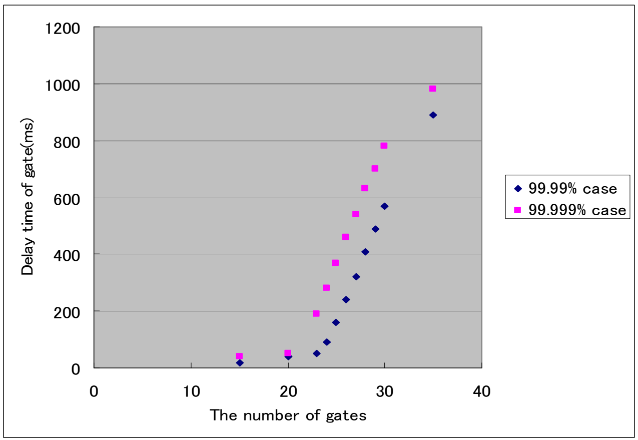

Figure 4: Relation between number of gates and delay time

In the system on practical use, probability of 99.99% or more is needed. Naturally, when the range of probability is expanded, delay time grows, too.

Figure 4 shows the relation between the number of gates and the delay at the probability of 99.99% and 99.999%. For instance, the delay times for probability 99.99% and 99.999% are 160 milliseconds and 370 milliseconds at the 25 gates respectively. It is shown that delay time rapidly stands up on the boundary of about 25 gates in Figure 4.

Figure 5 shows the relation between the number of gates and probability at the expected cycles of 60 to 80 percent. As described, the number of expected cycles is 10 per event. The number of expected cycles decreases by the delay, and it is shown as a probability distributions. The expected cycles of 60 percent means 6 cycles per event. The figure also shows that the boundary of the influence is about 25 gates.

4.2 Simulation results of gate monitor and stock control

Consider that there are two systems in a same building.. The first one is a gate monitor system discussed above and the second one is a system that reads tags in bulk like an inventory control system. T (cycle) for the second system is a several hundreds milliseconds typically.

The simulation conditions are:

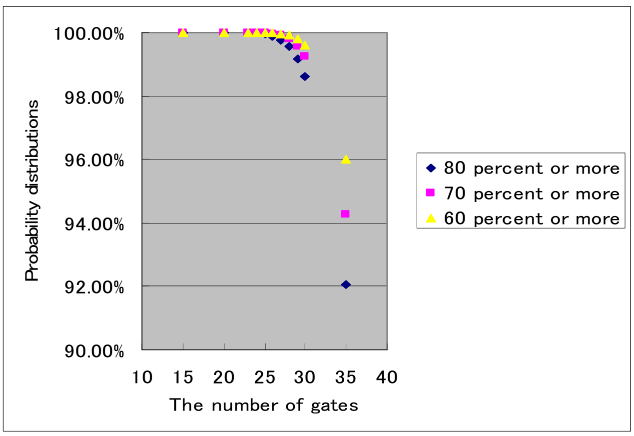

Figure 5: Relation of number of gates and the probability

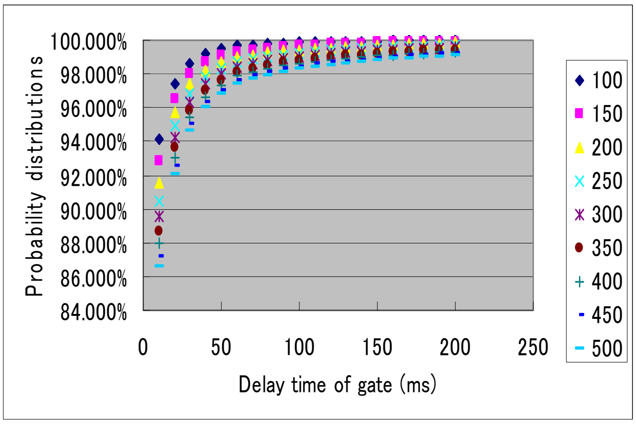

Figure 6: Delay time and probability distributions

Gate monitor system (same with 4.1):

Number of gates:	25
T (cycle):	50 milliseconds
T (mean time):	2 seconds
T (can be read):	1 second

Stock control system:

Number of stock controls:	5
T (cycle):	100 - 500 milliseconds
T (interval):	500 milliseconds

Figure 6 is similar with the Figure 3 in case of 25 gates, with changing T (cycle) of stock control from 100 milliseconds to 500 seconds.

Figure 7 shows the relation between T (cycle) of stock control and the delay in the gate system at the probability of 99.99% and 99.999%.

4.3 Summary of problem

According to the simulation results, the delay time is increased when the stock control system coexists with the gate system. It means that the number of reading cycles at the gate may decrease, and the reading accuracy at the gate where realtime processing is necessary worsens as the reading time of the stock control becomes long.

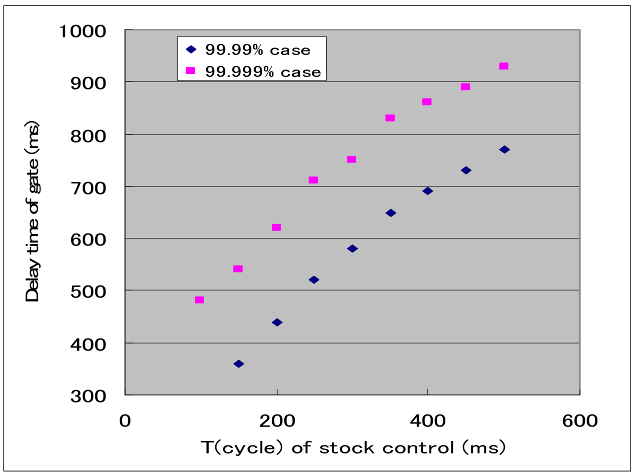

Figure 7: Reading time of gate delay time and stock control

4.4 Summary of problem

According to the simulation results, the delay time is increased when the stock control system coexists with the gate system. It means that the number of reading cycles at the gate may decrease, and the reading accuracy at the gate where realtime processing is necessary worsens as the reading time of the stock control becomes long.

5 SOLUTION AND VERIFICATION

As described in Section 3, a cycle consists of session initialization and one or more rounds. In the Gen2 standard, there are four sessions and some sessions can maintain the state during the fixed time even if the access by the reader stops. For instance, session S2 and S3 are able to maintain the state for two seconds or more.

Table 3: State maintenance (Gen2 standard) of the session

Session	Maintain the state
S0	less than 5seconds more than 500 milliseconds
S1	500 milliseconds
S2	2 seconds or more
S3	2 seconds or more

We propose the "cycle-divide method" to solve the reader-reader interference. The solution is that either of S2 or S3 session is used on the stock control side, and other sessions are used on the gate side. In addition, we stop the reader between rounds on the stock control, and restarts after LBT (Figure 8).

We assume that 8 tags can be read in each round and simulate with T (round) for stock control as 75 milliseconds. Again, we show the simulation parameters.

Gate monitor system (same with 4.1):
- Number of gates: 25
- T (cycle): 50 milliseconds
- T (mean time): 2 seconds
- T (can be read): 1 second

Stock control system:
- Number of stock controls: 5
- T (cycle) = T (round): 75 milliseconds
- T (interval): 500 milliseconds

Figure 9 shows the result. The "cycle-divide method" is our proposed method and Figure 9 shows the improvement by the proposed method. It shows that gate reader may wait for 600 milliseconds applying our method while it may wait for more than 900 milliseconds applying the earlier method when stock control readers use channels for about 500 milliseconds.

6 CONCLUSION

In this paper, we show the problem of the UHF RFID system caused by the LBT that readers are influenced by other readers and do not keep realtime capability when many readers work simultaneously.

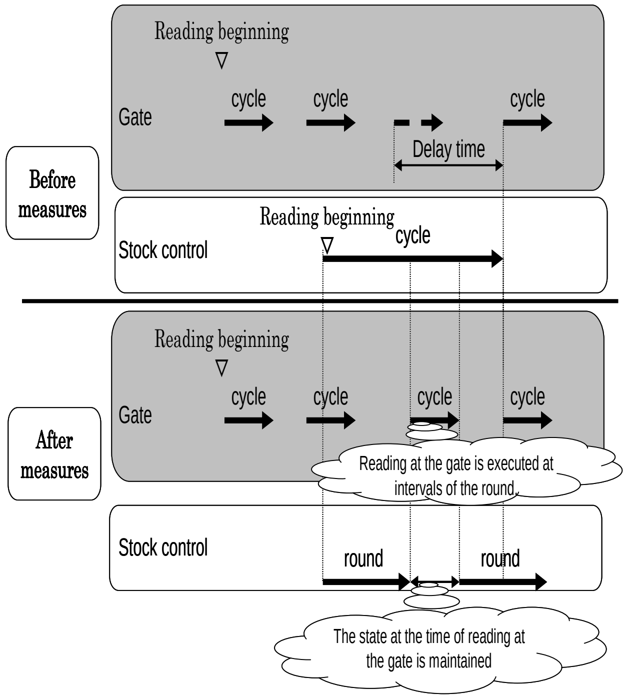

Figure 8: Sequence of the "cycle-divide method"

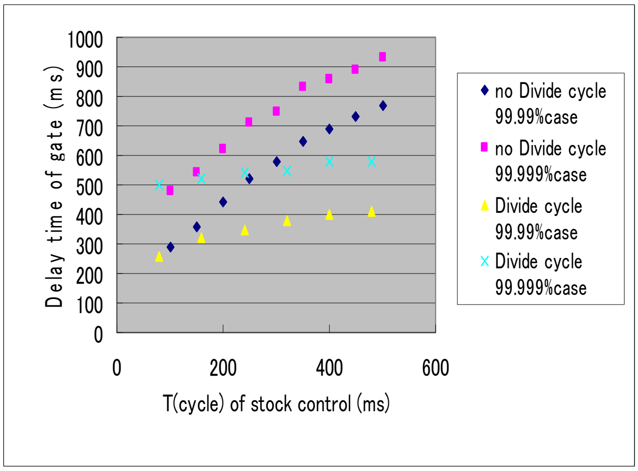

Figure 9: Delay relation between inventory system reading time and gate system

We also show the solution for this problem. Our solution named the "cycle-divide method" is very effective, and keeps the realtime capability by changing the session ID and suspending the transmission between rounds of the non-realtime readers.

REFERENCES

[1] M. Shimizu, "The Problem of wireless telecommunications in use of ID tag," and COMPUTER & NETWORK LAN, pp. 16-81, Ohm company, 2004.

[2] Y. Sogabe, T. Kamemaru, and A. Taira, “Interference evasion technology between readers of UHF band electronic tag,” Monthly EMC, No. 202, pp. 86-93, 2005.

[3] Y. Sogabe, H. Aikawa, T. Iwahashi, and T. Kamemaru, “The Collision Problem of UHF RFID Systems,” IEICE Transactions magazine, Vol. 89, No. 2, pp. 156-161, 2006.

[4] A. Taira, T. Kamemaru, A. Kurita, Y. Sogabe, and F. Ishizu, “Examination concerning UHF band RFID interference workaround,” 2005 IEICE, B-5-107, 2005.

[5] Y. Tanaka, A. Ninomiya, and H. Kobayashi, “Reader interference control method in UHF band RFID system,” 2006 IEICE, B-5-147, 2006.

[6] S. Arakawa, “Problem and measures (4) of UHF band RFID examination of workaround of the interference between electronic tag — reader/writer device,” 2006 IEICE, B-5-16, 2006.

[7] H. Mitsugi, “Decentralized interference evasion between RFID by channel selection with weight,” 2006 IEICE, AS-3-12, 2006.

[8] T. Ito, K. Nishikawa, H. Funakura, S. Arakawa, and T. Kamemaru, “Proof of the interference evasion method between adjacent systems by multistep floor LBT,” 2007 IEICE, B-7-126, 2007.

[9] T. Ito, K. Nishikawa, S. Arakawa, T. Kamemaru, and Y. Takahata, “Problem and measures of UHF band RFID —Method examination to making in realtime —,” 2006 IEICE, B-5-15, 2006.

[10] Telecommunication council, Telecommunication technological subcommittee meeting, Small electric power wireless system committee report (2005 fiscal year).

[11] Specification for RFID Air Interface EPC™ Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz – 960 MHz Version 1.0.9, Copyright notice 2004, EPC global Inc.

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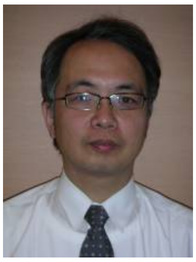

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