WHITE PAPER SERIES / EDITION 1

AUTO–ID LABS

BUSINESS PROCESSES & APPLICATIONS
SOFTWARE & NETWORK
HARDWARE

AUTOIDLABS-WP-HARDWARE-018

The Reader Collision Problem in RFID Systems

Kin Seong Leong, Mun Leng Ng, Member, IEEE, Peter H. Cole

Auto-ID Laboratory, Department of Electrical & Electronic Engineering, The University of Adelaide

{kleong, mng, cole}@eleceng.adelaide.edu.au

www.autoidlabs.org

Abstract

In a multi-reader environment, RFID system performance will be limited by the reader collision problem. RFID readers use different channels to minimise collision. However, with limited channels, the in-channel collision will happen. Using a path loss model, this paper predicts the safe distance between the readers before collisions occur in a same channel. This paper also explores the complication caused by the introduction of Listen Before Talk (LBT) in the European Regulation, makes suggestions on how reader collision problems and LBT effects can be minimised.

1. Introduction

Radio Frequency Identification (RFID) systems are gaining popularity since some big companies in the USA, such as Wal-Mart, had mandated the use of RFID tags in their respective supply chains. With increasing interest in deploying RFID system on large scale, problems emerge, and one of them is the reader collision problem. Reader collision problems mainly occur in a dense reader environment, where several readers try to interrogate tags at the same time in a same vicinity. The read results can be unsatisfactory with read times and an unacceptable level of misreads. In Europe, the fear of RFID disrupting non-RFID devices operating in the same frequency band as RFID systems has prompted the introduction of the concept of a “Listen Before Talk” (LBT) provision for RFID systems, causing some uncertainties over the feasibility of RFID global deployment.

The objectives of this research are to report an analysis on the reader collision problem and provide some solution to RFID deployment regarding the reader collision and the LBT problems for the benefit of those eager to set up RFID systems. After this introduction, the second section introduces some relevant terminologies and proposes the model used throughout this document. In the third section, a simple two-reader environment is described and the potential interference between the two readers are analysed. The forth section discusses the “Listen Before Talk” policy mandated in Europe and the impact of it in a multiple reader area. The fifth section contains some experimental results, and an analysis of those results. The sixth section provides some recommendations to resolve reader collision, followed by conclusions in the seventh section.

AUTO–ID LABS

2. Theoretical background

2.1 Free Space Path Loss

For a pair of lossless antennae in free space with optimum orientation we may write the power transfer ratio in the form

$$\frac{P_r}{P_t} = g_t g_r \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (1)$$

where P_t is the transmitted power, P_r is the available received power, g_t is the transmitter antenna gain, g_r is the receiver antenna gain and d is the separation distance between antennae.

For some purposes it is desirable to separate the effects of antenna gain and distance between antennae, and give the name *free space path loss* to the factor $\left(\frac{\lambda}{4\pi d}\right)^2$ in the above equation. By expressing this factor in dB we have the free space path loss expression:

$$\mathrm{PL(dB)} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) \qquad (2)$$

Using the frequency of f = 915MHz, $\lambda = c/f$ = 0.33m, for a separation d = 1m, PL(dB) = 31.61dB.

2.2 Terrestrial or Within Building Path Loss

When we consider propagation between a transmitter antenna and a receiver antenna, we can, as we have done above, hopefully remove the transmitter and receiver antenna gains from the propagation loss, and call the remaining factor the path loss. The path loss will no longer be expected to have a simple d^{-2} variation. Its form must be discovered empirically. There are different path loss models but the model we use is in the following form:

$$\mathrm{PL(dB)} = \mathrm{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) \qquad (3)$$

where d_o is a reference distance chosen by the author of the model, n is a value that depends on the surroundings and building type and d is the separation distance between two antennae. We chose for convenience d_o = 1m. We will also then make the assumption PL(1) to be approximately 32 dB. This assumption comes from the fact that the 1m in building path loss will (provided we are in the same room and room reflections are not huge) be approximately the same with the free space path loss.

The value of n should be obtained through experiment, and it varies from building to building. A more hostile environment will have a higher n value and the path loss will be higher for a same distance if compared with an environment with a lower n value. We assume that in a practical case we need to take into account, in addition to the path loss, the transmitter and receiver antenna gains to determine propagation loss between antenna terminals.

Rappaport has collected path loss data on buildings with data classified into losses between the same or different building levels [1]. The focus of this paper is on a one-level warehouse. Based on Rappaport's data for the same building level, we have proposed a piece-wise linear model, which is shown in Figure 1,as the darkest line in the graph. The dotted lines in the graph are a guidance lines with slope corresponding to $n \approx 4$ and $n \approx 2.5$. Also, the piece-wise linear line has been drawn to pass through the 32 dB at 1m point. This is very sensible in the sense that with a shorter separation distance, there will be fewer or probably no obstacles and hence a friendlier environment and free space path loss will apply. As the distance increases, more obstacles will appear and the environment will be a more hostile one, with higher n.

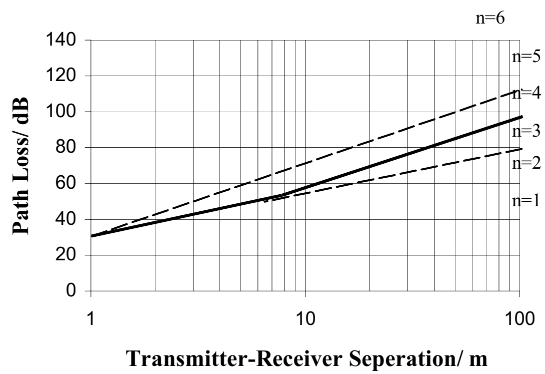

Fig. 1: Path loss against distance

For the theoretical calculation in section 3 and 4 of this document we chose $n = 3.5$, when the separation is more than or equal to 8m, and we chose $n = 2.5$ when the distance is less than 8m. i.e. we are using approximation equations:

$$PL(dB) = \begin{cases} 32 + 25\log\left(\frac{d}{1}\right) & 0 \le d < 8m \\ 23 + 35\log\left(\frac{d}{1}\right) & d \ge 8m \end{cases} \qquad (4)$$

3. Two-reader Interference

In this section, a scaled down version of reader collision is discussed, where the collision involves only two readers, and the readers are assumed to transmit and receive in the same channel of a multi-channel frequency band. Consider the case where there are 2 readers, A and B, using a same channel, channel C. It is assumed that Reader A and Reader B are identical, the antennae for both of them are the same and have the same gain. Also, both of the antennae are facing each other. Reader A uses channel C to interrogate a tag and the tag will have in-band backscattering to response to Reader A. If we have a transmitted power of 0 dBW and an antenna gain of 6 dBi, we will have a total of 6 dBW EIRP.

Figure 2 shows a rough idea on how the interrogation between Reader A and the tag occurs. The paths 1 and 2 are the signal paths. At 1m away, the path loss as obtained using equation 4 is 32dB. Hence the total path loss is approximately 64dB (2 x 32dB).

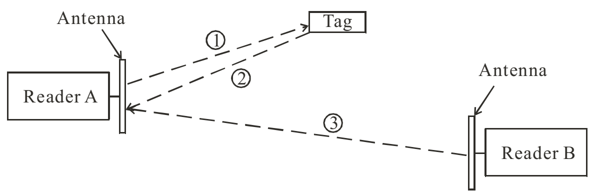

Fig. 2: Interference caused by Reader B

The tag antenna has a gain of approximately 1.5. However, we have to take in consideration a probable tag misalignment, that is the tag antenna is not positioned in the most optimal way. In our case, we assume the tag has a unity antenna gain.

If we further assume that the efficiency of the tag is 10%, the signal will suffer another 10dB loss. All the losses (path loss + tag efficiency-tag antenna gain) summed up to be 74dB. Since Reader B is also using the same channel, channel C, the interrogation signal sent by Reader B will interfere with the in-channel backscattered signal from the tag. The question is how near Reader B need to be to interfere with the backscattered signal.

The comparison is made between (a) Path loss of path 1 and path 2, tag antenna gain, and tag efficiency loss, and (b) Path loss of path 3. This comparison is only applicable in the situation as described in this section. As a common term used throughout this section, the losses in both (a) and (b) are called Total Loss. If we look at path 3 as shown in Figure 2 and using equation 4 to calculate path loss, a distance of around 28.7m is needed to have path loss, or total loss in this case, of 74dB.

Table 1 shows some result on the minimum distance for Reader B to interfere with the tag reply. Again, all this results are computed using equation 4, and equation 4 takes into consideration in-building propagation loss. It is very natural to also raise the question of what will be the case, if we only consider free space propagation loss. The results obtained using free space propagation loss model are attached as column 4 in Table 1 below:

Distance of Tag/ m	Total Loss/ dB	Minimum Distance for B to Interfere/ m	Distance in Free Space to give the same loss/ m
1	74	28.7	130.7
2	89	76.9	735.2
5	109	286.5	7352.5
10	144	2865.1	413460.5

Table 1: The effect of tag distance on multi-reader interference

We continue to make the assumption that free space path loss is not applicable in our case, and that at the distances emerging from these calculations, at least some obstacles will be present, and a within building propagation loss model is appropriate. It is discovered that, if a tag is located 10 meters away from an interrogating reader, the antenna of the other readers must be around 2865m away. Since the read range of a state of art reader in the market can have a read range of around 10 m when reading a passive tag, to put the next reader more than 1 km away is not sensible. Section 6 in the later of this paper provides ideas in solving this problem.

4. "Listen Before Talk"

In the European Regulation as outlined in ETSI EN 302 208-1 V1.1.1 (2004-09) [2], a reader must "listen" and confirm that a particular channel is not occupied before it can use that particular channel to interrogate any tag. The transmit power and the corresponding threshold values are extracted from the above-mentioned ETSI document and integrated into Table 2.

ERP/ W	ERP/ dBW	Threshold (ERP)/ dBW	Path Loss/ dB	Distance/ m
Up to 0.1	Up to -10	≤-113	103	193.1
0.1 to 0.5	-10 to -3	≤-120	117	485.0
0.5 to 2.0	-3 to 3	≤-126	129	1068.0

Table 2: Transmit power and corresponding values

Similar to the calculation done in Table 1 in Section 3, the Distance column in Table 2 is computed using equation 4, where we consider an in building propagation model with n value set to 3.5. As mentioned before, the value of n changes from different building to building. However, the distance for different value of *n* still can be obtained from Figure 1.

The main point here is if we are going to deploy readers in a large scale, most likely the system will not work in optimal operation mode. This is due to the fact that LBT will effectively shut down many of the channels, though those channels might have been, in the absence of the LBT provision, freely available for interrogation between readers and tags. This problem is not exactly a reader collision problem but it is also covered in this paper because LBT problem will be very serious in a dense reader environment, or a place where reader collision is a serious issue.

5. Experiment Results

An interrogating RFID antenna was set to transmit query signal while a measuring spectrum analyser was moved away from the transmitting antenna. The strength of the received signal was recorded versus the distance away from the transmitting antenna. Removing antenna gain from the measured values gives us the values of path loss. The transmitting and receiving antenna used in this experiment both have a gain of 6dBi. Figure 3 is plotted using logarithmic scale, and we have a straight line approximation of:

$$PL(dB) = 31 + 40 \log\left(\frac{d}{1}\right) \quad \text{for } d > 8\text{m}$$

The results resemble the model based on equation 4 and also strengthen the belief that reader collision must be solved for large scale RFID deployment.

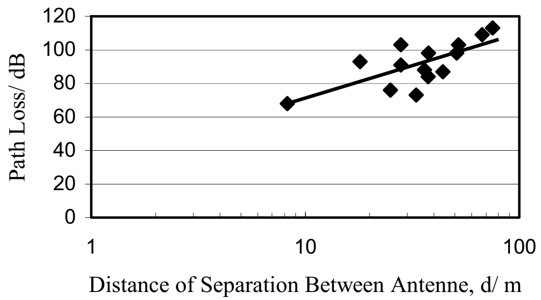

Fig. 3: Results from experiment

6. Recommended Readers Configurations

6.1 Proper Readers Arrangement

Throughout this paper, it is assumed that the antennae of two different readers are facing each other directly. In other words, the interference caused by other readers will be maximised and also the LBT impact will be the worst. However, by manipulating the placement of the antennae, the interference between 2 interrogating readers with near to each other antennae can be minimised.

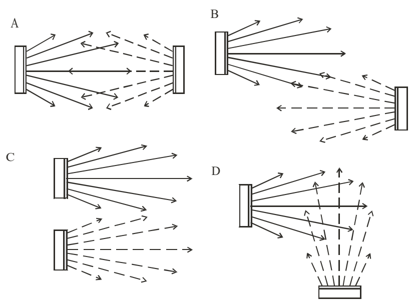

Fig. 4: Configuration of antennae

Type A configuration as shown in Figure 4 is the worst settings possible and has been discussed extensively throughout this paper and the minimum distance between the two antennae has been shown in Table 1. For configuration Type B, the minimum distance will be reduced. Configuration C will not help much because of the side lobe problem. Configuration D will not solve the problem either, it only minimises the interference between readers. A complete treatment of readers' arrangement is not included in this document due to pages constraint. The important point is by just arranging the antenna position and orientation, interference and LBT effect can be reduced but not minimised to a very low level. Hence, readers synchronization as described below, is required.

6.2 Readers Synchronisation

This method is to synchronise all the readers in a particular area. For example, synchronization of all the readers in a warehouse. All the readers have an absolute sense of time and may be linked using local area network system. They are set to "Listen" at the same time and since all readers are "Listening", all the channels will be unoccupied. Following the ETSI EN 302 208-1, if any reader finds that, a channel it begins to examine is unoccupied, its "Listening" period is fixed. Hence, in a synchronized system, all the readers may start to "Listen" in a fresh channel at a same time, finish "Listening" at a same time, and also start to interrogate tags at a same time as shown in the following Figure 6:

Using this way, readers can avoid the LBT problem completely. The collision problem can be minimised using proper readers separation and use of alternate channels for transmitting and receiving.

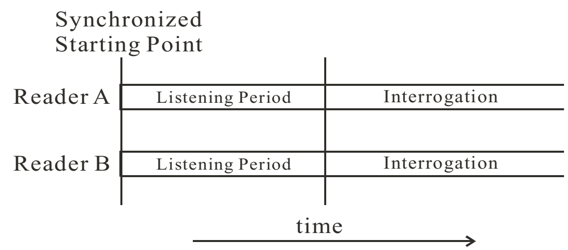

Fig. 5: Readers synchronization

7. Conclusion

We have introduced 2 methods that can be used to minimise the problem of reader collision and LBT effect. We also had carried a detailed analysis on RFID indoor propagation model. There are rooms for extension in this research field. In the future, we will identify blind zones in a multi-reader environment, in which a tag will not be able to be detected by any reader. This efforts aims to create a complete guide to allow fast and successful deployment of large scale RFID system and to maximise its potential and benefits.

References

[1] T. S Rappaport, Wireless Communications – Principles and Practice, Prentice Hall, Second Edition, 2002.

[2] ETSI EN 302 208-1 V1.1.1 (2004-09), www.etsi.org.