Operational Considerations in Simulation and Deployment of RFID Systems

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Abstract — **Large-scale radio frequency identification (RFID) deployment is needed for efficient item identification in supply chains. To reduce cost and save time, simulations are often carried out before actual implementation, especially when RFID is used in regions in which strict regulations and standards must be adhered to. However, due to the unpredictable environmental effects on radio propagation simulation, simple results can be misleading and questions have been raised over the validity of many wireless simulations. This paper reviews, from the point of RFID antenna deployment, the sources of error in wireless simulations reported in some publications. Also, this paper offers important EMC information relevant to RFID system deployment.**

I. Introduction

Radio frequency identification (RFID) has received much attention since it has been discovered that RFID can lead to fully automated item identification and tracking systems in the supply chain. Due to the many advantages that RFID can offer, many major supply chain companies, such as Wal-Mart and Tesco [1], have begun to exploit RFID in their warehouses and supply chains. Wal-Mart has mandated the use of RFID in its supply chains by its top 100 suppliers [2].

The strengths of an RFID system over a conventional Barcode system are discussed in [3, 4], and are widely accepted. Though RFID has its own shortcomings in potential privacy invasion, regulations on RFID ethics have been drafted to avoid public dissatisfaction [5].

However, RFID has yet another challenge, the EMC of RFID system. A common supply chain RFID system runs within the frequency range of 860 – 960 MHz in the UHF band, depending on which country the RFID system is being deployed. In most cases, the band RFID is using is also known as the unlicensed Industrial, Scientific and Medical (ISM) band. Normally, there are other electronic equipment, intentional or non-intentional radiators, that are operating in this band. Unlike some of the other signaling equipment permitted to use the band, RFID antennas use comparatively intense RF power, to energise passive tags within their interrogating zones and hence can interfere with nearby electronic equipment operating in the band of interest. Due to this reason, RFID is subjected to very strict regulations around the world.

Designers of RFID systems must be aware of the strict regulations to avoid system incompatibility with local limits. The provision of Listen Before Talk (LBT) as used in Europe imposes great challenge for antenna positioning. Hence, a good simulation of RFID deployment is essential. It enables visualization of RFID deployment prior to actual implementation. However, a simulation result depends on the complexity of the model used for the simulation. A simple simulation will often give wrong ideas while a complex simulation will consume too much computational time to be feasible. Several papers in the literature have investigated the validity and credibility of wireless network simulation [6]-[8]. Of particular interest is [6], where several common simulation assumptions, which contribute the most to simulation inaccuracy, are raised. In this paper, common simulation errors, such as inappropriate simulation model, neglecting antenna gain and misinterpretation of simulation results, will be discussed in the context of RFID, along with the exploration of the challenges in RFID simulations. A simulation program has been written to compare with the practical measurement results obtained, and several suggestions have been offered to minimise the possible sources of error.

RFID EMC related background information is discussed in the next section, followed by the brief introduction of EPCglobal C1G2 RFID protocol and its proposed transmit mask in a dense reader environment. Section 4 will be the major part of this paper, looking into several common sources of error in wireless simulation, and suggesting ways to minimise them. Section 5 offers some insight into multi-channel interference simulations and Section 6 provides the conclusions of this paper.

II. RFID EMC Background

The regulatory status for using RFID in the UHF spectrum around the world can be summarised into two categories: governed under Frequency Hopping Spread Spectrum (FHSS), and governed under Listen Before Talk (LBT). By the end of 2005, it is expected that 50 countries, representing 83% of the global GNI (Gross National Income) will have RFID regulations [9]. It is essential to understand the differences between each regulation before an RFID simulation on deployment is carried out, especially on the allocated bandwidth and the maximum allowable radiated power.

A. Frequency Hopping Spread Spectrum (FHSS)

An example under this category is the USA FCC Title 47 Part 15.247, with operation within the band 902-928MHz [10]. It allows a maximum transmit power of 1 W with a maximum of antenna gain of 6 dBi, giving a maximum total radiated power of 4 W EIRP (Effective

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Isotropic Radiated Power). It is adopted mainly in North and South America.

B. *Listen Before Talk (LBT)*

An example under this category is the European ETSI 302 208 [11] that has been adopted by some European countries. It allocates the frequency band of 865 to 868 MHz for RFID deployment. This frequency band is then divided into 15 sub-bands or channels; each spans a total of 200 kHz. When a reader is operating at the maximum total radiated power, which is 2 W ERP (Effective Radiated Power) or equivalently to 3.2 W EIRP, only 10 sub-bands are available, while the remaining 5 are utilized as guard bands in which low ERP is allowed.

A small extract from the ETSI 302 208 best describes the essence of "Listen Before Talk". "Prior to Transmission, the interrogator must listen for the presence of another signal within its intended sub-band of transmission. The listen time shall comprise a fixed period of 5 ms plus a random time of 0 ms to 5 ms in 11 steps. If the sub-band is free the random time shall be set to 0 ms" [11]. The threshold to determine the presence of another signal within the intended sub-band is shown in Table 1 below.

ERP (W)	ERP (dBW)	Threshold (dBW)
Up to 0.1	Up to -10	≤-113
0.1 to 0.5	-10 to -3	≤-120
0.5 to 2.0	-3 to 3	≤-126

TABLE I: TRANSMIT POWER AND CORRESPONDING VALUES

III. RFID PROTOCOL

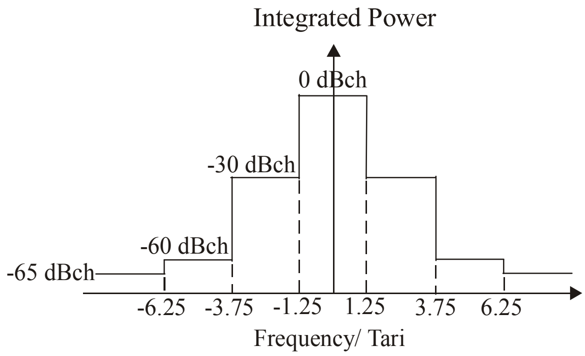

Fig. 1. Transmit Mask for Dense-Interrogator Environments [12]: dBch is defined as decibels referenced to the integrated power in the reference channel.

The operation of an RFID system is also standardised to encourage wide spread deployment. EPCglobal has produced "EPC Radio-frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for Communication at 860 MHz – 960 MHz" [12], in short EPC C1G2, as the standard operational protocol. This comprehensive protocol includes the detailed air interface between readers and tags and also standard commands for tags interrogation. The section in the protocol which is closely related to this paper is on the transmit mask for dense-interrogator environments as shown as Fig. 1. A more relaxed transmit mask is used for low reader density surroundings [12] but is not presented here, as the focus of this paper will be in a dense reader environment. Also, it is stated in this protocol that odd-numbered channels should be used for tag backscatter while even-numbered channel will be used for reader interrogation.

IV. SOURCES OF SIMULATION ERROR

A good simulation program should be able take into account the EMC regulations and protocol standards discussed in Section 3 and Section 4. Also, the common sources of simulation error of a wireless system as outlined in [6] and [7] must be minimised.

A. *Simulation Model*

The term "path loss" is widely used in the literature and is carefully explained by the authors in [13]. Often the path loss model in a simulation is considered as a simple function of distance. It is only true for free space propagations, and is used for satellite communication simulations [14]. A typical RFID deployment zone is a warehouse filled with commercial products and logically a more complex model is required. Also, the focus will be on far field only. The near field effect only extends to approximately 0.5 m and is assumed negligible here. Hashemi has categorised all the path loss models found in literature, apart from the simple free space path loss, into four groups [15]. The authors have studied these four categories carefully and have supplemented those studies with their own work. It is found that a path loss model with variable environmental factor, n, is most suitable for the case of RFID as shown in Equation (1) below:

$$\mathrm{PL(dB)} = \mathrm{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) \qquad (1)$$

where d_0 is an arbitrary reference distance, n is the environment factor, d is the separation distance between two antennas and PL(d_0) is the free space path loss for a distance d_0. The n value takes into consideration, path obstruction, reflection, absorption and other attenuation effects introduced by the presence of objects inside a building. However, Equation (1) does not consider the fact that the n value will increase as the distance increases, and hence is modified as shown as Equation (2) below and is explained in detail (includes the selection of d=8 as boundary), in [13]:

$$\mathrm{PL(dB)} = \begin{cases} \mathrm{PL}(d_0) + 10n_1\log\left(\frac{d}{d_0}\right) & 0 \le d < 8m \\ \mathrm{PL}(d_0) + 10n_2\log\left(\frac{d}{d_0}\right) & d \ge 8m \end{cases} \qquad (2)$$
$$n_2 > n_1$$

The comparison with various models and experimental results are plotted in Fig. 3 that shows a path loss model in free space, three models based on Equation (1) with n = 2, 3 or 4, one model based on Equation (2) and also the practical measurements from experiment. It can be seen that Equation (1), with n = 2 and PL(d_0) set to the value for free space, is actually the same as free space path loss.

As the n value increases, the path loss increases for a fixed distance.

The practical measurement is set up as shown in Fig 2. A room with metallic cupboards and cabinets, and wooden tables is chosen as an experimental site to represent a typical storage area (experiment will be carried out in actual warehouse in future). This room is divided into a grid system, with markers positioned 1 m apart. Two antennas of known gain are used as the transmitter and receiver. These two antennas are directly facing each other (with each at exactly the same height) in order to obtain an orientation with maximum directivity. Several measurements are taken at various positions for a chosen separation, and the means are used as the final result.

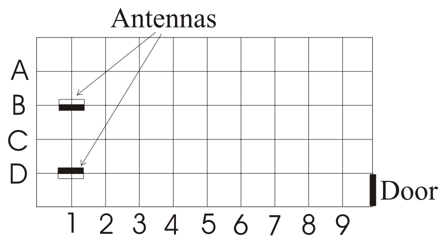

Fig. 2. Experiment Grid for Signal Strength Measurement: For measurement more than 8 m, the receiver antenna is moved out of the room through the door shown. The antennas are facing each other with maximum gain attained for all measurements.

The measurement shows several things. The first is that within the room, the path loss is less than the free space path loss generally by a few dB. This we attribute to reflections within the room, which would be expected to produce this effect. Secondly, the practical measurement results follow an approximately free space path loss pattern until the first wall is encountered along the measuring path. As the distance increases, more major obstacles appear along the path of measurement, and the practical measurement results have shown path losses higher than a free space path loss.

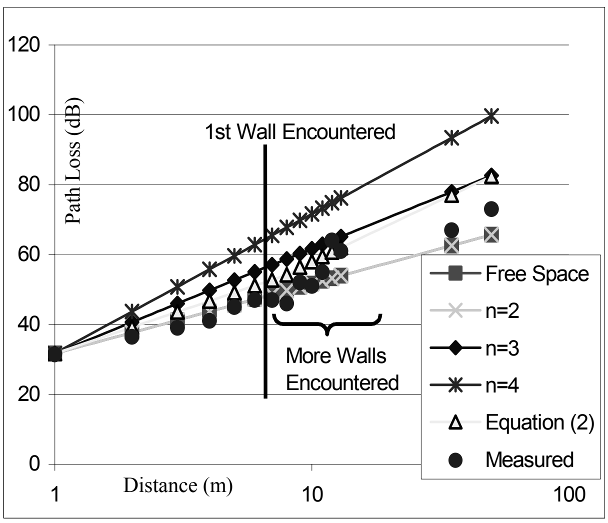

Fig. 3. Plot of Path Loss using Different Models Together with Measured Results.

Equation (2) best mimics the measured results. However, the n value changes from location to location. On-site measurement must be carried out to determine the best n for that certain area before the values of n are used in simulations. Walls have been shown to have a great impact on the value of n. Within a room, one fixed n value can be used, but n must be increased when a wall is encountered as the distance increases.

B. *Radiation Pattern of Antenna*

The quality of communication between any two antennas is dependent on the angle of orientation between them [6]. This is the case when neither of the antennas are isotropic radiators. A typical RFID antenna is 6dBi gain directional antenna and an example of the radiation pattern of a typical RFID antenna is as shown in Fig. 4. Despite the fact that in actual RFID deployment, it is very difficult to ensure all stationary RFID antennas are mounted in the fashion intended, with exact orientation, elevation and angles, the radiation pattern of any type of antenna to be deployed must be acquired and fed into RFID simulation program as accurately as possible. Experience shows that even two antennas of a same model manufactured by a same company will have a slightly different gain pattern. Though this is the case, the difference is small and hence, the simulation program can assume the same gain pattern.

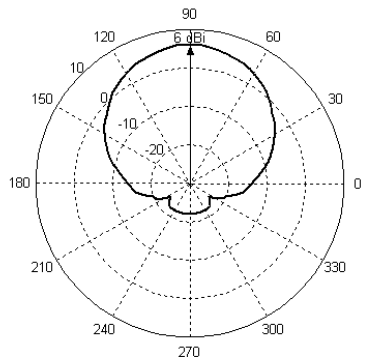

Fig. 4. Polar Plot of the Antenna Gain of a Directional Circularly Polarised RFID Antenna with a Gain of 6 dBi.

C. *Simulation Result Interpretation and Analysis*

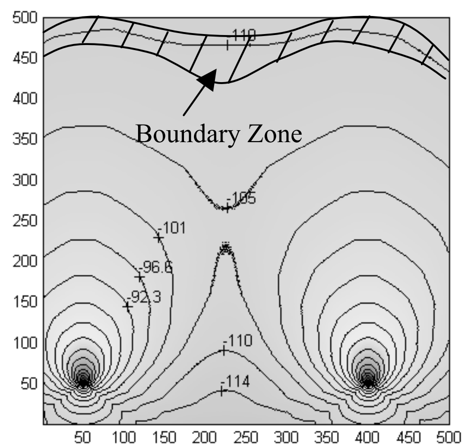

Fig. 5. Results From Simulation (Vertical and Horizontal Axes in m, Received Power in dBW).

Basically, a simulation program will use its simulation model to compute the strength of signal at a certain distance away from any transmitting antenna. There are many ways of presenting a simulated result, either numerically or graphically. Fig. 5 shows an example of simulated results in a graphical form. However, in real life applications, as shown in [6], the reception of a signal does not exhibit a sharp cliff. For example, the line in the top of Fig. 5 shows signal strength of –110dBW. This line does not represent a clear threshold line between a region with signal weaker than –110 dBW and region with signal stronger than –110 dBW. This is due to uncontrollable factors that present in real life scenario, such as fluctuation of path loss and antenna gain. However, a "boundary zone" (Fig. 5), rather than a boundary line, can be specified in the simulation result to give good estimate of the overall system performance before an actual deployment is carried out. The size of the boundary zone should reflect the previously measured uncertainties in the propagation loss which have already stated to be a few dB.

V. Multi Channel Simulation

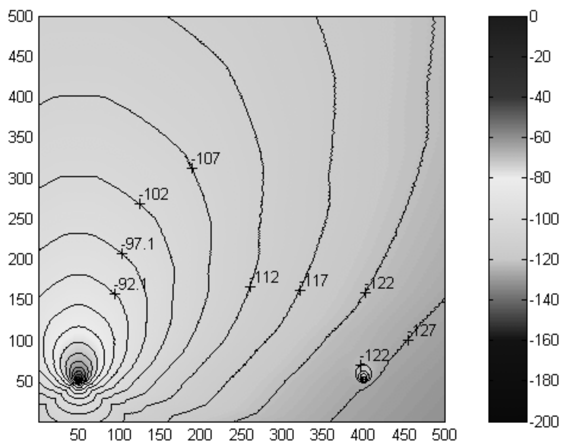

Fig. 6. Results From Simulation (Vertical and Horizontal Axes in m, Received Power in dBW): Antenna on the right is two channels away from the channel used by antenna on the left.

As discussed in Section 2 and 3, the operation of RFID interrogation is bounded by strict regulations and protocols. Hence it is essential for the simulator to simulate interference between channels, in both the case of FHSS or LBT. A simple and conservative way to give a rough estimation of inter-channel interference is available if all the readers are compliant to [12]. Referring to the transmit mask shown in Fig. 1, it can be seen that if a channel is being used for interrogation, the leakage to its immediate neighbouring channels must be below –30dBch. Since only even-numbered channels are used for interrogation, while the odd-numbered channels are reserved for tag backscattering, the leakage to the next neighbouring even-numbered channels must be below –60 dBch. Hence, if the simulation is focused on a particular channel, the interference from the next neighbouring even-numbered channels can be emulated by reducing the signal strength by 60 dB. For example, if the radiating antenna on the right in Fig. 6 is operating in the next immediate even-numbered channel, its maximum interference to the antenna on the left can be simulated by reducing its signal strength by 60 dB (Fig. 6).

VI. Conclusion

This paper has suggested ways of minimising common errors viz. ignoring multi-path propagation, antenna orientation and pattern, and variation of path loss as obstacles are traversed, in the simulation of RFID antenna deployments. Some errors are unavoidable, but the extent estimated from empirical measurements can be shown to be not severe. Hence it is essential not to interpret any simulation results without bearing all the possible errors and underlying assumptions in mind. This paper hopes to provide a clear view of the pitfalls for researchers interested in RFID simulator development. Also, this paper has highlighted EMC regulations which are essential in understanding the actual implementation of an RFID system, in order to produce a sensible simulator, which will definitely contribute to the vision of automating supply chains using RFID technology.

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