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Dense RFID Reader Deployment in Europe using Synchronization

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***Abstract*—For a dense RFID reader deployment, such as in a warehouse, where hundreds of readers will be positioned in a building, the interference between all these readers must be studied carefully to avoid disruption of operations. Strict RFID regulations and standards have been imposed, trying to address the problem of reader collision and also the problem of RFID devices interfering with other devices operating in the same and nearby frequency bands. However, these guidelines and regulations are not entirely friendly for dense RFID reader deployment; in some cases it is not possible to have a feasible RFID system while adhering to these regulations. Hence, this paper proposes the synchronization of RFID readers to enable successful dense RFID reader deployment. A case study targeted at European operations is presented in this paper to illustrate the actual synchronization of RFID readers in real applications. Some fine-tuning methods are also suggested to further improve the performance of readers in a high reader density population area.**

***Index Terms*—Radio frequency identification, RFID, synchronization, dense reader.**

I. INTRODUCTION

Radio Frequency Identification (RFID) has received much attention recently as it is widely believed that RFID can revolutionize supply chain management, replacing barcodes as the main object tracking system. Several major supply chain operators and retailers, such as Wal-Mart in the USA, have deployed RFID systems in some of their supply chains [1]. Initial test runs of RFID deployment show encouraging results [2], and hence large scale RFID deployment is planned. However, before any successful deployment can be achieved, some RFID issues have to be resolved. One of them is the RFID reader collision problem, which is the focus of this paper.

The term "reader collision(s)" is discussed extensively in [3] and [4]. In this paper, reader collision is simply defined as the phenomenon where an interrogation signal from a certain reader disrupts the communication between a tag and another reader, and this reader collision problem is potentially magnified in a dense reader environment, such as in a warehouse. Various regulatory and standardization bodies have tried to regulate the operations of RFID readers. In this paper, the ETSI 302 208 as introduced by the European regulatory body and the EPC Class 1 Generation 2 as recommended by EPCglobal are used as the basis of RFID reader operations. However, as will be discussed in more detail in the later part of this paper, the restrictions that are put on the operation of RFID readers are very strict, making it quite impossible to have an uncoordinated large scale deployment of RFID readers. Hence, this paper introduces the idea of RFID reader synchronization, to enable good RFID performance in a dense reader environment, while adhering to strict regulations.

The next section introduces the ETSI 302 208 and EPC Class 1 Generation 2 Protocol and their impact on RFID reader deployment. Section III explains the concept of RFID reader synchronization and how it adheres to strict regulations. Section IV suggests possible ways in implementing a RFID synchronization system. A case study on RFID reader synchronization is presented in Section V. Ways of fine-tuning RFID reader positioning is discussed in Section VI. Variation of possible reader synchronization schemes is presented in Section VII, followed by conclusion in Section VIII.

This paper is the extended version of [5]. It expands from the basics of RFID synchronization as introduced in [5] to the actual implementation methods and variations.

II. BACKGROUND

A. ETSI 302 208

ETSI 302 208 is a European regulation governing the operation of RFID readers [6]. It allocates the frequency band of 865 to 868 MHz for RFID deployment. This frequency band is then divided into fifteen sub-bands or

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Based on "Synchronization of RFID Readers for Dense RFID Reader Environments", by Kin Seong Leong, Mun Leng Ng, Alfio R. Grasso, Peter H. Cole, which appeared in the Proceedings of the International Symposium on Applications and the Internet 2006, Phoenix, Arizona, USA, January 2006. © 2006 IEEE.

TABLE I.
TRANSMIT AND THRESHOLD POWER

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

channels, each spanning a total of 200 kHz. However, when a reader is operating at the maximum radiated power, which is 2 W ERP (Effective Radiated Power), only ten sub-bands are available, while the remaining five are utilized as guard bands or for lower power readers. ETSI 302 208 also introduces the concept of “Listen Before Talk”. An extract from the ETSI 302 208 best describes the essence of “Listen Before Talk”. It says “Prior to each transmission, the receiver in the interrogator shall first monitor in accordance with the defined listen time 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” [6]. The threshold to determine the presence of another signal within the intended sub-band is shown in Table I. The measurement method is defined in the standard.

Furthermore, once a sub-band has been selected, the RFID reader is permitted to use that sub-band for up to 4 s. After use, it must free the sub-band for at least 100 ms. A reader can however, listen to another sub-band for 5 ms and if free use that new sub-band.

B. EPC Class 1 Generation 2 Protocol

“EPC Radio-frequency Identification Protocols Class 1 Generation 2 UHF RFID Protocol for Communication at 860 MHz – 960 MHz” [7], in short EPC C1G2, is the standard protocol developed by EPCglobal for RFID devices for use within the supply chain. This protocol outlines the air interfaces and commands between an RFID reader and an RFID tag. It also includes the spectrum management of RFID operation. Frequency hopping or frequency agile systems are the suggested techniques. An allocated frequency band, as allowed by local regulatory body, is divided into sub-bands or channels. A reader will only use a certain channel for communication, not the entire allocated frequency band.

EPC C1G2 covers both dense reader mode and multiple reader mode; multiple reader mode is for an environment where the number of simultaneously active readers is modest relative to the number of available channels while dense reader mode is for an environment where the number of simultaneously active readers is comparable to or more than the number of available channels.

This document only focuses on dense reader mode. In dense reader mode, for narrow bandwidth (European 200 kHz) channels, it is suggested in this protocol that odd-numbered channels should be used for tag backscatter while even-numbered channels will be used for reader interrogation. For a wide bandwidth channel (USA FCC 500 KHz channel [8]), all available channels can be used for reader interrogation, as tag backscatters will be located at the boundaries of these channels.

TABLE II.
MIN. DISTANCE BETWEEN ANTENNAS [9]

Channel Difference	Antenna Projecting Horizontally		
	Front (m)	Side (m)	Back (m)
0	1400	350	210
1	180	45	30
2	130	25	15
3	95	20	10

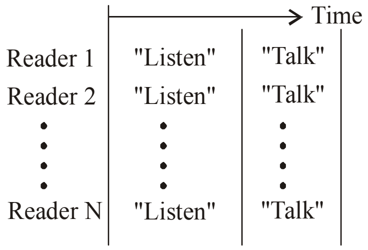

Figure 1. Synchronization of all readers: All the readers start to “Listen” at a same time and finish “Listen” at a same time too.

C. Problem in dense reader environment

With the implementation of ETSI 302 208 and EPC C1G2, it is clear that when a reader is operating at a certain sub-band or channel, this reader will effectively prevent other readers from using that channel within an unacceptably large area. Ref. [9] and [10] have presented detailed discussions and analysis on this matter and Table II, as extracted from [9], summarizes the minimum distance (calculated using a piece-wise path loss model with variable environmental factor) between two antennas connected to readers before one antenna operating at a certain channel will prevent the other antenna from using that channel. It should be noted that these results are obtained using a 0 dB isotropic receiving antenna, and do not represent any real life situation, as a typical RFID antenna will be a directional antenna. Nonetheless, the data presented in Table gives sufficient evidence that a low threshold value for the LBT as specified in ETSI 302 208 is severe enough to impede the reader deployment in a dense RFID reader system.

III. READER SYNCHRONIZATION

Under the concept of reader synchronization, all the RFID readers in a certain area, for example all the readers in a warehouse, are networked together through a central control unit. The connection method can be the common Ethernet connection, or equivalent, and will be discussed in the next section.

Since all the readers are linked together, physically or wirelessly, they can be directed to carry commands at a same time. Also, they can be assigned channels dynamically, so that the spectrum management is optimized while the reader collision is minimized.

European regulation allows ten channels when maximum radiated power, 2 W ERP, is used. Following the recommendation of EPC C1G2, under dense reader mode, five of them, the even-numbered channels, are used for reader interrogation. All the readers are "Listen Before Talk" compatible. They are configured to start to "Listen" at the same time, and then at the end of the listen period, they can all synchronously start to "Talk", as shown in Fig 1. This is due to the fact that according to ETSI 302 208, if there is no signal detected in the intended channel of interest, the "Listen" time is fixed. Hence, all the readers, which start "Listening" at the same time, will start "Talking" at the same time. If a reader is turned on at a different time, or if a reader looses synchronization that reader can be made to start again in synchronism with the rest of the readers, after the last reader has finished its "Talk" session.

IV. ACTUAL IMPLEMENTATION

A. Connectivity

In actual implementation, RFID readers must be able to communicate with each other to enable synchronization of RFID readers. There are basically two ways in connecting all the readers; either using wired (physical) connection or using wireless connection.

A physically connected system or wired system cannot support mobile readers. Also, a wired connection may suffer from data latency in the network. Ref. [11] shows that time synchronization in a wired network is possible, but will require additional hardware and system reconfiguration. In the best case, the time difference achievable can be better than 1 μs. A wired system is often considered as a more reliable and a more secure communication method than a wireless communication.

A wireless system signals through an RF link. It can use one of the five guard bands, mentioned in Section II (A), for sending a synchronizing signal. A synchronizing signal can be a signal with a special pattern. A wireless system can also use any existing wireless protocol such as Bluetooth technology. It supports mobile readers but is inevitably vulnerable to interference (signal integrity problem), and unauthorized signal sniffing (security problem).

Both connectivity methods have their own advantages and disadvantages. The decision in choosing either of these two methods is largely dependent on the positioning of the LBT sensor, which is discussed below.

B. Positioning of LBT Sensors

An LBT sensor of an RFID reader is responsible for detecting signals in the channel of interest prior to transmission in that channel. This LBT sensor must have a power sensitivity level better than –126 dBW as specified in [6]. If not, this LBT sensor will not be able to function efficiently in determining whether there exists a signal with a power level higher than the power level specified in regulations in the channel of interest. An LBT sensor can be the RFID antenna used for transmitting and receiving signals in the communication with RFID tags. A LBT sensor can also be a separate antenna connected to an RFID reader.

Also, several RFID readers could share an LBT sensor within a close vicinity. This is also known as a centralized system. A localized system is where each and every RFID reader has its own LBT sensor.

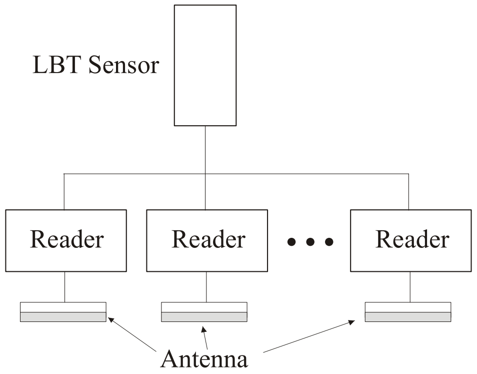

Figure 2. Centralized LBT system, where readers are connected to one LBT sensor in a nearby surroundings.

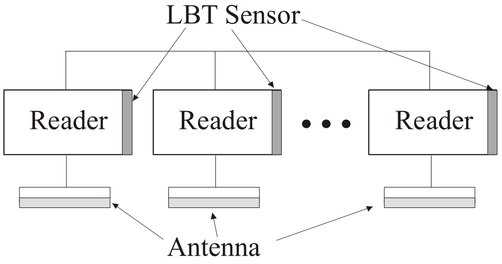

Figure 3. Localized LBT system, where each reader has its own LBT sensor.

A centralized LBT system is as shown in Fig. 2. The LBT sensor will constantly monitor all the channels allocated for RFID operation, and dynamically assign available channels to all the readers connected to it. The central control system has to be configured during the initial setup of the system. A fine-tuned centralized LBT system offers high reliability. However, it requires additional network hardware, to connect all the readers to the LBT sensor. Also, a centralized LBT system will not be able to be implemented effectively when mobile readers are dominant in the surroundings. Although the readers can communicate with the centralized LBT sensor through a wireless link, it is very difficult for the centralized LBT sensor to estimate the position of mobile readers, and hence is not possible to allocate the best channels for mobile readers. For example, if two mobile readers operate simultaneously in an enclosed area, there is a probability that the two readers move near to each other at some time. The centralized LBT sensor may at that time allocate very nearby channels to those two readers and serious interference between those two readers may occur.

Also, if two nearby areas are running on different RFID wireless networks and they are un-coordinated, interference with each other will occur, and in the worst case, cause a complete system shut down. The coordination of wireless networks in different premises will be time and cost consuming.

A localized LBT system is as shown in Fig. 3. Each reader has its own LBT sensor. The LBT sensor can either be a separate antenna (Fig. 3), or be the same

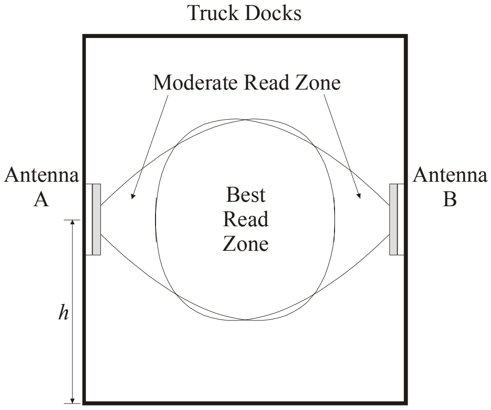

Figure 4. A typical antenna setting at dock door, with *h* being the height of the antenna from the base of a dock door.

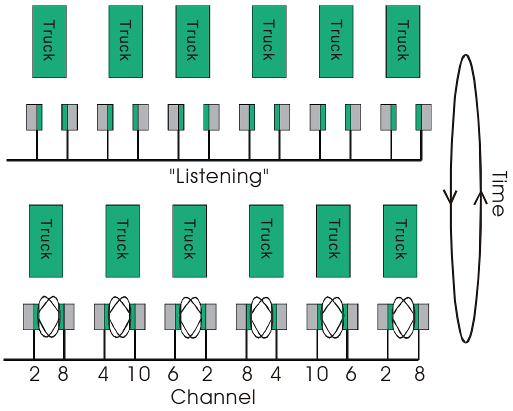

Figure 5. Alternating of "Listening" and "Talking" mode.

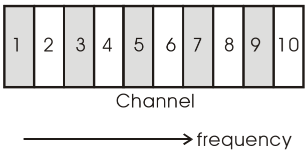

Figure 6. Channeling of the allocated frequency spectrum.

antenna a reader uses to establish communication with an RFID tag within its interrogation zone. As compared to centralized LBT system, a localized LBT system with wireless connectivity enables relatively easy new reader integration into an existing system, with no additional cabling or setup needed. However, a localized LBT system has the problem with management of channel sharing, signal interference and possibly creation of unwanted shielding.

In actual fact, the connectivity of readers and the positioning of LBT sensor are closely related. In [12], a wired system and a centralized LBT are linked together as one configuration, while a wireless system and a localized LBT are linked together as another configuration.

C. Antenna Positioning

The positioning of RFID interrogation antennas depends primarily on the application. Detailed operational considerations for the deployment of RFID system are presented in [13]. In this paper, only one example will be given, which is the dock door situation, as it will be used in the case study in the next section. A dock door is usually 2 to 3 m in length and approximately 3 m in height. The most effective way to create an RFID interrogation zone is to position two antennas at the sides of the dock door, face-to-face and with an height elevation, *h*, as shown in Fig. 4. The height elevation, *h*, mainly depends on the average height of objects being shipped through the dock door. A normal choice of *h* is between 0.5 to 1 m. Also, antenna A and antenna B normally will be using different channels for tag interrogation.

However, if antenna A and antenna B are operating at the same time, and a tag is located in the middle of the dock door, the tag may be "confused" by the interrogation signals from both of the antennas with the result that the tag is misread. This effect is known as the tag confusion problem. The discussion of this issue is outside the scope of this paper but a simple solution to this is to alternate the operation of antenna A and antenna B every query cycle.

V. CASE STUDY

A case study on dense RFID reader deployment at the dock doors of a warehouse is presented here. As shown in Fig. 5, the dark colour rectangles represent trucks loading or unloading goods at the dock doors of a warehouse. Each door is around 3 m in width, and has two RFID antennas facing each other for tag interrogation.

Since all the readers are synchronized in a way described in Section III, they will start "Listening" at a same time and will be assigned a channel for interrogation at the end of "Listen" period. The assignment of channels will be geographically influenced. Two readers assigned to be operating in the same channel will be as far apart as possible. Also, the neighbouring antennas will be using channels as far apart as possible. As illustrated in Fig. 6, the spectrum is split into ten channels, all five of the odd-numbered channels are reserved for tag backscattering while all five of the even-numbered channels are assigned for reader interrogation. Fig. 5 shows how the channel assignment is done. The antenna on the furthest left is using channel 2 for interrogation. The next antenna on its immediate right is using channel 8, which is six channels away. Channel 10, though is the furthest channel away, is not chosen. This is because the arrangement of {2, 8, 4, 10, 6} gives best channel separation between every channel.

VI. SYNCHRONIZED RFID SYSTEM FINE-TUNING

Fine-tuning of a synchronized RFID system, as presented in this section, can be carried out to further reduce the tendency of reader collision. The fine-tuning methods discussed below include the reduction of output power, the reduction of overall reader talking time, the use of external sensors, the use of RF opaque or absorbing materials, and the frequent rearrangement of channels allocations.

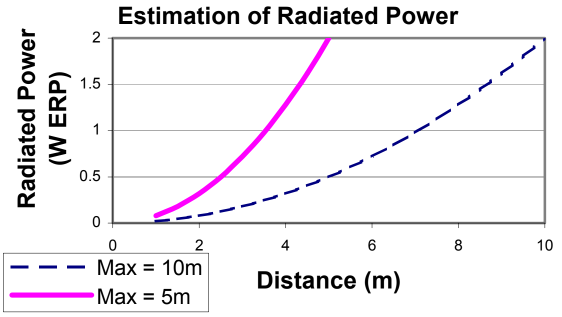

Figure 7. Estimation of required radiated power given that maximum read range corresponds to maximum radiated power.

A. *Reduction of output power*

Although up to 2 W ERP can be used in single or small population reader environment, in dense reader populations this higher power may not be necessary. Currently, a state of the art reader can read up to 10 m. However, normal reading operations do not require such a read range. In the case study presented in Section V, the dock doors of the warehouse are around 3 m in width. Since two antennas are positioned facing each other in every dock door, the read range required is also around 1.5 ~ 2 m. By reducing the radiated power of readers, the minimum distance between two antennas using the same channel can also be reduced, which is beneficial in a dense reader environment.

Fig. 7 gives an approximation on the reduction of output power. In the far field region, using the Friis equation, the power received is the inverse function of the square of distance (r^2). If the maximum read range corresponding to maximum radiated power (2 W ERP) of a RFID reader is known, we can compute the required radiated power for a shorter read range. For example, if the maximum read range of a reader is 5 m using 2 W ERP (shown in Fig. 7), and if only a read range of only 2m is required, the required radiated power can be lowered to 0.32 W ERP. This estimation may not be accurate in real life due to complex electromagnetic propagation phenomena, such as reflection caused by the surroundings objects, but it demonstrates that power reduction is a viable option.

B. *Reduction of overall reader talking time*

While it is possible to talk for 4 s, reader applications should be configured to talk for only the time necessary to capture tag data. There is no optimum talking time. It depends on the application and also the surroundings of the deployment zone. On-site fine-tuning and measurements are needed before the reduction of talking time can be carried out.

C. *Use of external sensors*

Sensors can be used to turn RFID readers on only when tags are approaching to further reduce reader interference in that area. This will free up the channels allocated for those antennas, and also to avoid unnecessary interference to other surrounding reader antennas. For example, external sensors can be attached to the dock door in the case study in Section V. When the dock door is not in use, the designated RFID readers would be switched off, as shown in Fig 8. Optionally, the central control unit can then as shown dynamically shift the channels assigned for the antennas at door 3 to door 4.

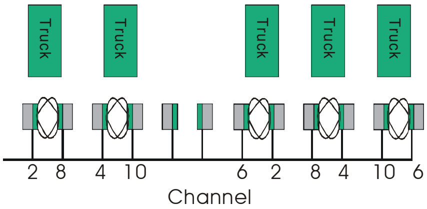

Figure 8. Using sensors in RFID system. Both the antennas at dock door 3 are switched off when the absence of truck 3 is detected.

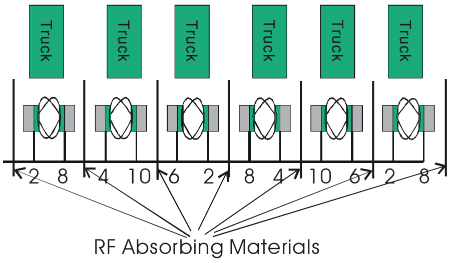

Figure 9. Use of RF absorbing materials. The antennas facing each other at the same door is at least 4 channels away.

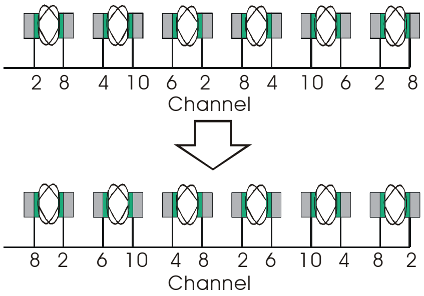

Figure 10. Channel switching within antennas.

D. *RF opaque or RF absorbing materials*

Another effective, but more expensive, way to reduce reader interference and collision, is to utilize RF opaque or RF absorbing materials to contain the interrogating signal within the designated zone of interrogation. For the case study presented in Section V, the use of such materials is shown in Fig. 9. Although there will still be some signal leakage through the door openings, it would not have caused much interference. This is due to the fact that the signal strengths at the sides of the antenna are relatively weak as compared to the front of the antenna. According to [9], the gain at the side of a typical RFID antenna is approximately 20 dB less than the gain at the front of the antenna.

E. *Frequent rearrangement of channels*

Interrogating Channels can be switched around every cycle of “Listen Before Talk”. This is to prevent the jamming of the interrogation signal by any external noise.

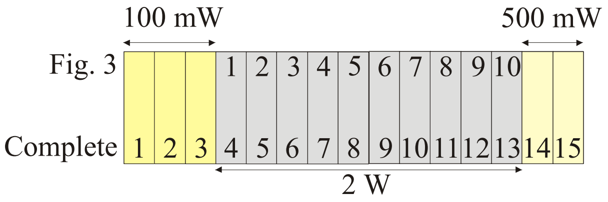

Figure 11. The complete frequency band allocated for RFID operation as compared to Fig. 3.

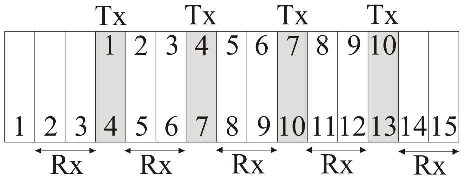

Figure 12. Variation in the separation of Transmitting (Tx) and Receiving (Rx) channel of a RFID reader.

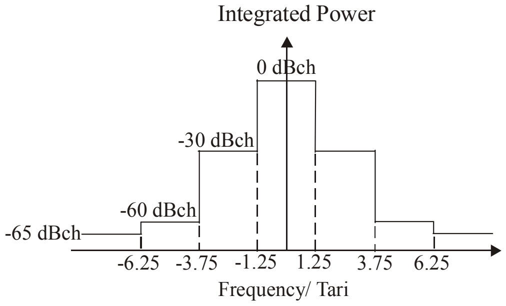

Figure 13. Transmit mask for dense-interrogator environments [7].

Fig. 10 shows a simple example on how the switching is done. There are other more complex switching methods involving higher artificial intelligence in the central control unit, depending on the noise received from the surrounding environment, but these await full development.

VII. VARIATION OF SYNCHRONIZATION

In the previous sections, suggestion on the implementation of a real life RFID reader synchronization system are presented, together with some deployment options, such as the connectivity of all the readers. Also, fine tuning methods are presented. In this section, some of the interesting variations of RFID reader synchronization schemes are presented. These variations may not be readily incorporated into the suggested methods mentioned in previous sections, but are presented here for future reference and for completeness.

A. Separation of transmitting and receiving channels

For the RFID full power operation (2 W ERP) as governed by ETSI 302 208, only ten channels are available, as shown in Fig. 6. However, as discussed in Section II, there are actually fifteen channels available for RFID in total. Five of the fifteen channels, though used as guard bands, can be used for RFID operation with reduced maximum allowable radiated power. There are three channels located lower in frequency than the normal ten channels, which can only be operated below 100 mW ERP, while there are two channels higher in frequency than the normal ten channels, which can be operated below 500 mW ERP. The complete frequency range for RFID operation, with respective regulated power level is as shown in Fig. 11.

The channel numbering system shown in Fig. 6 is included in Fig. 11, along with a new channel numbering system to simplify the discussion hereon. Channel 4, 7, 10 and 13 are assigned to be the reader transmitting channels while the tag reply channels are the four channels beside the transmitting channels [14]. For example, transmitting channel 4 uses channel 2, 3, 5, and 6 for tag reply.

Although the transmitting channels are reduced from a total of five down to four, the transmitting channels are placed two channels away rather than one channel away. From the transmit mask shown in Fig. 13, an improvement of 5 dB can be obtained. Hence with the reduction of interference between transmitting channels, readers can be placed nearer to each other.

B. Separation of RFID and non-RFID signals

Another variation of synchronization is to differentiate an RFID signal from a non-RFID signal. A method using signal recognition is presented in [15]. The idea is that all the RFID readers in a certain region can be treated as a single entity in the regulation as outlined in the ETSI 302 208. Hence, it is only required to avoid the signal interference between all the RFID readers and the rest of the short-range devices. If this concept is valid, the interrogation signals of RFID readers are not treated as a signal in a channel when a LBT test is carried out.

The main advantage of this method is that a lot of readers can be deployed in a small confinement area. However, reader antenna positioning can become more challenging, as all the readers can choose any channel for transmission as long as there is no other type of short-range device around.

VIII. CONCLUSION

This paper has identified synchronization of RFID readers as a mechanism to assist in RFID reader deployment in dense reader environments. Some implementation methods, and several fine-tuning methods are also presented in optimizing the performance of a synchronized RFID system. As compared to conventional unsynchronized RFID systems, a synchronized RFID system can offer more coverage, less reader collision or interference, while strictly following the European regulations and the EPC C1G2 recommendation, and can with variation of the normal operating procedure deal also with the effects of tag confusion. However, these benefits require the use of more complex hardware and hence can marginally increase deployment costs. Reader synchronization has not been tested in real situation, and hence will require future study in this area.

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Alfio R. Grasso received two degrees from The University of Adelaide, B.Sc., and B.E(Hons). He has spent the last 26 years working on various RFID technologies. His early work was with Surface Acoustic Waves (SAW) RFID devices, working for TABTEK Electronics. Over the past 15 years has been working with modulated backscatter systems, working for Integrated Silicon Design, Gemplus Tag Australia and TAGSYS Australia as Engineering Manager, Sales and Marketing Manager, Production Manager, Operations Manager, Standards Liaison and General Manager. He has worked in many different industry sectors such as Automotive, Mining, Waste Management, Library, Transportation, Sugar, Oil and Gas, and has managed a team of Engineers in the development of RFID systems at 13.56 MHz, 27 MHz, 433 MHz, 889-928 MHz, and 2.45 GHz.

Over the past 5 years he has contributed at International Standards Organisation meetings for sub-committee SC31, and was appointed the project editor for ISO 18000-6, the RFID air interface for item management at UHF (860 to 960 MHz). He has also worked with the Hardware Action Groups of both The Auto ID Center (at MIT, Boston) and EPCglobal, on the UHF Class 1 Generation 2 air interface.

He has had extensive experience in RFID site surveys, installation and commissioning and has conducted a number of training courses both in IC Design and RFID Systems. Working with SIEN (one of its founders), he was the chairman of the ISO 9001 sub-committee that successfully saw 7 companies in the SIEN Network achieve ISO 9001. He is also a consultant to EPCglobal Australia on the activities of the Hardware Action Group (HAG) and Software Action Group (SAG).

Peter H. Cole is the Professor of Radio Frequency Identification Systems in the Department of Electrical and Electronic Engineering at The University of Adelaide.

He completed his undergraduate and postgraduate studies at Sydney University in 1964, receiving degrees of B.Sc., B.E. and Ph.D., and then worked in the Center for Materials Science and Engineering and the Department of Electrical Engineering at the Massachusetts Institute of Technology. Since his return to Australia in 1967, he has lectured at the Universities of Sydney and Adelaide, and pursued research interests in the development and industrial applications of electromagnetic identification systems. He has had a particular interest in technology transfer to industry, and served for 15 years as Chairman of Directors of

Integrated Silicon Design Pty. Ltd., a University technology transfer company, working on both microelectronic design software and RFID systems. His recent interests have led to a close collaboration with the seven EPCglobal linked Auto-ID Research Laboratories, which include the Auto-ID Laboratory in the University of Adelaide, of which he is the Research Director.