HYBRID OPTIMIZATION TECHNIQUE FOR RFID NETWORK PLANNING TO IMPROVE WAREHOUSE MANAGEMENT EFFICIENCY

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A thesis submitted in fulfillment of the requirement for the award of the Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering
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AUGUST 2017
In the name of

ALLAH

Most Gracious,
Most Merciful

To my loving parents Prof. Dr. Muhsin Elewe and Suhaila Hamdi.

My dear wife Huda Abdulali.

My joyful and precious daughter Jud.

And my darling Rana, Hiba and Rafid
ACKNOWLEDGEMENT

Alhamdulillah, all praises to ALLAH the most gracious and merciful, for the strengths, blessing, protecting and guiding the author throughout in completing this thesis. The author would like to thank all the precious people that provide the greatest support with a significant strength and stay behind the author, very closely and lovingly, in order to support the author for bouncing back to face all the challenges.

The author would also like to express his deepest gratitude to the main supervisor, Prof. Dr. Khalid bin Hasnan for his continuous support, tremendous level of patience and admirable guidance that enable the author to have the excellent atmosphere for doing research. In addition, Special appreciation goes to my co-supervisor, Dr. Azli Bin Nawawi for his invaluable help of constructive comments and suggestions throughout the thesis works have contributed to the success of this research.
RFID Network Planning (RNP) strategy based on the functional parameters is often deployed in large scale applications to efficiently track assets and can lead to significant revenue gain. The placement of RFID readers to support warehouse design is often done on a trial and error basis which is time consuming and results in less than optimal coverage. For this reason, this research has developed a RFID network planning model that can improve warehouse management. The mathematical model of the RFID network planning is concerned with two major issues. The first one was to specify the reader parameters. The parameters of the RFID network planning (RNP) problem specified in each optimization technique were adjusted to improve the quality of the solutions. The second issue was to specify the objective functions of RNP problems. The fundamental gap highlighted in this research was the effect of network topology, which represents the most important factor in hard optimization problems of network planning. The present methodology correlated the RFID Network Planning with topology network design. Optimizing the network topology design can be formulated as set of functions employed with a Monte Carlo Algorithm in order to optimize the warehouse management. The main methodology process was by integrating the RFID multi-objective network planning with the network topology design to improve the capability of reader distribution. The sequence of operation started with Monte Carlo simulation (MCS) which was used to generate tag placements based on network topology design modules as a method to evaluate the deterministic indicators in NP-hard problems. The generated data are utilized as an input representation to apply into firefly algorithm based on Density-Based Algorithm (DBSCAN) to find the optimal network solution. The current work has produced much superior results for large scale and multivarience facility shapes. The results show the effectiveness of the method in L-Shape RNP and standard benchmark in addition to two types of standard warehouse design. The optimization results indicate reduction of power consumption by 31% due to the reduction the number of readers and propagation range. It also indicates the high reliability of this method to work with complex tags distribution in large scale area.
Strategi Perancangan Rangkaian RFID (RNP) berdasarkan parameter fungsi sering digunakan dalam aplikasi berskala besar untuk menjadikan aset secara efisien dan boleh membawa keuntungan hasil yang ketara. Penempatan pembaca RFID untuk menyokong reka bentuk gudang sering dilakukan cara cubaan dan ralat yang memakan masa dan menghasilkan laporan yang kurang optimum. Penyelidikan ini telah menghasilkan model perancangan rangkaian RFID bagi mengoptimalkan pengurusan gudang. Model matematik perancangan rangkaian RFID menangani dua isu utama. Yang pertama ialah menentukan parameter pembaca. Parameter yang bermasalah semasa perancangan rangkaian RFID (RNP) yang terdapat dalam setiap teknik pengoptimuman telah dilaraskan untuk meningkatkan kualiti penyelesaian. Isu kedua dalam model matematik perancangan rangkaian RFID adalah untuk menentukan fungsi objektif masalah RNP.

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<td>Radio Frequency Identification</td>
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<td>RNP</td>
<td>Rfid Network Planning</td>
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<td>PSO</td>
<td>Particle Swarm Optimization</td>
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<tr>
<td>DOE</td>
<td>Design Of Experiments</td>
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<tr>
<td>GA</td>
<td>Genetic Algorithm</td>
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<tr>
<td>UTHM</td>
<td>Universiti Tun Hussein Onn Malaysia</td>
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<tr>
<td>QoS</td>
<td>Quality Of Service</td>
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<tr>
<td>EPC</td>
<td>Electronic Product Code</td>
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<tr>
<td>LF</td>
<td>Low Frequency</td>
</tr>
<tr>
<td>HF</td>
<td>High Frequency</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
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<tr>
<td>RSSI</td>
<td>Received Strength Signal Indicator</td>
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<td>TDS</td>
<td>Tag Data Standard</td>
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<td>FFA</td>
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<td>Cov</td>
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<td>Rmax</td>
<td>Maximum Interrogation Range</td>
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<td>Ractual</td>
<td>Actual Interrogation Range</td>
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<tr>
<td>Xn</td>
<td>summation of tags in x-positions</td>
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<tr>
<td>Yn</td>
<td>summation of tags in y-positions</td>
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<tr>
<td>Pr</td>
<td>Power input at receiving antenna</td>
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</table>
\( P_t \) - Power output at transmitting antenna
\( G_t \) - Transmitting antenna gain
\( G_r \) - Receiving antenna gain
\( R_S \) - The propagation domain
\( T_S \) - The working domain
\( \beta_0 \) - The Attractiveness
\( G_t \) - Transmitter(Reader) Antenna Gain
\( G_r \) - Receiver (Tag) Antenna Gain
\( D \) - Distance Between Transmitter And Receiver
\( \Lambda \) - Radio Wavelength
\( N_t \) - Readers number
\( N_T \) - Number Of Tags
\( M \) - Number Of Readers
\( \text{dist( )} \) - Function To Compute Distance
\( R_{i, j} \) - Positions Of \( i \)th And \( j \)th Reader Respectively
\( r_{i, j} \) - Interference Range Of \( i \)th And \( j \)th Reader Respectively
\( b_1 \) - location width
\( l_1 \) - Storage location front
\( b_2 \) - aisle width
\( L_r \) - Aisle length
\( B_r \) - aisle width
\( r_{\text{max}} \) - Maximum propagation distance
\( L_m \) - Path loss in meter
\( L_{db} \) - Path loss in decibels
\( \lambda \) - Wavelength (m)
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<tr>
<td>$c$</td>
<td>Speed of light (299,792,458 m/s)</td>
</tr>
<tr>
<td>$f$</td>
<td>Frequency (Hz)</td>
</tr>
<tr>
<td>$t$</td>
<td>Tag</td>
</tr>
<tr>
<td>$k$</td>
<td>Number of groups</td>
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CHAPTER 1

INTRODUCTION

The Radio-frequency identification (RFID) tag is a small electronic chip data carrying device used to attach with items for identification and tracking. RFID technology has been used in order to identify items wirelessly. Essentially, its architecture provides an Identification Code (ID), a reader that obtains a code from the tags and the middleware that receives the collected set of IDs to use them for tracking and monitoring materials. This technology can be used to track persons, animals, items. Additional applications include warehouse logistics, personal documents (passports, driving licenses), public transportation cards, building access control, and it is one of the main parts in Internet of Things paradigm (IoT) (Suriya 2013).

Applying RFID system provides various benefits such as the reduction in labor, time savings, efficient handling process and reducing out-of-stock (Polycarpou, et al., 2012; Nawawi 2015). Therefore, the application of RFID technology has steadily increased and the need to detect assets in a large area is becoming essential. Large scale RFID usage exhibits in supply chain management as one of the affordable tools for automotive inventory management system and product receiving (Qiang, Yu, Yiping, and Wenshneg, 2006). It is used as a network planning technique that monitors the network to provide sufficient coverage for the services requirement including assigning frequencies, transmitter locations and parameters of a wireless communications system (Hasnan et al., 2013). In sum, RFID reader’s position represents the backbone network which can represent a strategic base in RFID Network Planning (RNP).
1.1 Background of Study

Radio frequency identification (RFID) is one of the Automatic Identification and Data Capture (AIDC) technologies which enable the automatic collection and storage of data in a computer system (Suriya 2013). Accordingly, RFID technologies have been adopted by industry, luggage tracking systems in airports, antitheft systems, electronic toll collection systems, and in the academic world such as modern academic library etc. (Castro and Wamba 2015). The obstacles that arise in the area of RFID system design rely on large and complex environments such as the efficient organization and smooth running of warehouses, which is considered as a non-deterministic polynomial problem (NP problem) (Ren et al., 2011).

RFID offers desirable benefits in many RNP network cases. Warehouse facility is one of the essential fields of RFID application. Warehouse layout improvement takes place by tracking the stored items and identifying the movement history and material location. The tagged items can also be organized based on the operations study during the picking and putting away of the items to find the shortest path to optimize the warehouse facility layout. Supply chain management obtains another benefit. The mechanism of rapid scanning and the real-time data based on RFID systems introduced the feasibility of travel time estimation, positioning and theft prevention. The supply chain based on real-time-information enables sharing between the manufacturer, distributor, supplier and retailer and reduces the administrative errors and vendor fraud (Aysegul, et al., 2008) (Porter 2003).

The large-scale problems based on RFID network planning (RNP) observe crucial functional parameters for Quality of Service (QoS). RFID Network Planning (RNP) strategy assigns frequencies, transmitter locations and parameters for a wireless communication system (Hasnan et al., 2015). Most studies investigate the use of RFID to find the optimal evaluation of objective functions in NP hard problem. These objective functions mainly involve minimum number of readers needed to cover an entire region, the interference between two or more RF reader fields that may overlap and interfere with each other, and signal propagation that represents the minimum power
required at a RFID tag antenna (Elewe et al., 2016). However, the structure of the network is strictly related to the topography of the environment and effective geometrical parameters (Di Giampaolo et al., 2010). Therefore, Network design is noticeably affected by RFID at the edge effects and deployment of the RNP mathematical model which must be able to address universal concepts in order to obtain a successful numerical simulation (Maneesilp et al., 2013).

One of the successful numerical simulation optimization techniques is firefly algorithm. Firefly algorithm is a type of swarm intelligence algorithm based on the reaction of a firefly to the light of other fireflies (Niknejad & Petrovic 2013). Firefly algorithm was one of the evolutionary computing models for solving multimodal optimization problems that have nonlinear and multi-dimensional components (Prakash and Aravindhababu, 2015). This algorithm appears to be an effective tool due to the high potential power in solving optimization problems. It also seems to be a favorable optimization tool due to the effect of its intelligent function (Pal et al., 2012). This algorithm can be used in large and complex environments with indoor working areas. It also exhibited better capability in topological network design. However, the obstacle in using the swarm intelligences in real application is the weakness to detect the topological differences in RNP network design. Therefore, there is a need for a flexible method able to work with a variety of design topologies.

This research focuses on solving the RNP network problem by implementing hybrid firefly algorithm (FA) based on RFID objective function. The present method was designed to discover and cluster the tag groups in a spatial database in order to specify the appropriate number of required readers and to enhance the operation of the system. It was applied in warehouse topological model based on novel mathematical formula in order to investigate the impact of topological network design based on multi-objective RFID network planning. The present work provides the ability to run experiments with less cost and robust capability in topological network design of different boundary conditions. The pre-processes reflect flexibility in reader’s distribution and numbers. This approach can be used in conceptual design stage of RFID Network Planning (RNP) to specify the warehouse design and material organization and serve Internet of Things (IoT) application.
1.2 Problem Statements

RNP network planning in storage facilities is faced with many challenges. RFID is one of the robust solutions which involve a set of activities used to design the access part of a wireless network. This method used different algorithms to satisfy the coverage and capacity requirements. The strategy of applying RNP depends on the functional parameters in designing the placement of RFID readers. These functional parameters involve the optimal tag coverage, readers collision avoidance, cost efficiency and good load balance (Bhattacharya and Roy, 2010; Chen, Zhu, Hu, and Ku, 2011; Nawawi 2015; Ahmed 2015) Maximizing the performance of functional parameters results an optimal coverage and readability of the warehouse facility area and enhance the warehouse processes (Polycarpou, et al., 2012). The major obstacles to optimize the objective functions of the network planning involve the network of warehouse topology which refers to the layout of the warehouse (Di Giampaolo 2010), the reliably of RFID readers for reading RFID tags based on the reader location in warehouse space correlated with the relative position of the RFID tags and the propagation range of reader radio wave signal (D'Mello et al., 2008). The RFID system is considered an excellent tool for enhancing the warehouse operation; therefore the optimization of RFID readers setup based on warehouse layout improves the warehouse financing. Also, the optimal choice can be achieved by hybridization the Artificial intelligence (AI) to develop the supply chain management (SCM) industry. However, the RNP network planning still suffers from following issues:

i. Low effectiveness of RFID multi-objective network planning based on asymmetric topological network design. The RFID readers in terms of asymmetric topology is often done on a trial-and-error basis, which is very time consuming and generally results in less-than-optimal coverage. It is tangibly affected by the network features and the deployment of the storage area network. The challenge is how to identify the cause-effect relations between the composed functional features based on tags distribution (Di Giampaolo 2010; Chuang and Tsai 2015).
ii. Poor performance in placement of RFID readers positioning in large facility due to the complexity of the RFID system which results less-than-optimal coverage for deploying a set of RFID readers based on huge number of tags distributes in large scale and asymmetric area. The challenge is how to organize the tags positioning data based on the property of the tags density in order to specify the RFID readers number and position.

iii. The performance of range detection was not satisfactory for an RFID system due to differences in the reliability of reader propagation range correlated with non-uniform tags distribution in the working area. Reader propagation range determines the tag coverage range, reader collision avoidance, cost efficiency and good load balance. Therefore, RFID systems that operate in the specific area must be adjusted based on the needed propagation range covered by the identified tags. The challenge is how to optimize the objective functions of network planning in order to increase the RFID system performance (Suriya 2013; Nawawi 2015).

1.3 Research Objectives

The main aim of this work is the integration of multi-techniques in order to investigate analytical information based on realistic warehouse information. To achieve this aim, a set of objective functions and computation methodologies were designed and implemented in the form of integrated architecture for RFID network planning (RNP) problems. These objectives were:

i. To construct a new mathematical model based on the functionality of the warehouse topology.

ii. To propose an innovative technique that can be used to discover the clusters in a spatial database. This method can be used to specify the appropriate number of required readers to enhance the operation of the system.
iii. To apply a proper optimization technique which is useful in finding the optimum solution based on nonlinear and multi-dimensional components for efficient planning of RFID readers propagation range deployment.

1.4 Research Scope

The scope of this study covers the following:

i. Passive RFID tag is considered in this research. This kind of tag has no internal power source and it is powered by radio waves from readers.

ii. Isotropic radiator antenna is considered in this research.

iii. Several case studies of RNP conditions and scenarios were used. It covers the state of art conditions, L-shape and warehouse design condition.

iv. The study utilizes the standard dataset presented in Benchmark Instances of coordinates of RF tags in 50m * 50m working area.

v. Matlab software was used for running the simulation.

vi. The evolutionary computing method is considered one of the swarm intelligence algorithms.

1.5 Significance of the Study

The research is significant in theoretical and real world perspectives. The solution concept for addressing the difficulties of the Network Planning (RNP) was investigated through extensive computer simulation-experiments. The research has developed a new optimization method for RFID Network Planning (RNP) that can improve accuracy, iteration time and more cost efficient. The desirable RFID characteristics for the intended Network Planning are tag coverage, interference, economic efficiency and load
balance. The desirable performances are capable to achieve optimum number of readers and positioning in order to present practical solutions of difficult logistical equipment tracking in warehouses and supply chain management.

1.6 Organization of Thesis

This thesis is organized as follows. Chapter 1 provides a brief description highlighting the aims of each chapter. Each chapter is developed to be self-contained, but there exists cohesion among the chapters in order to ensure the free flow of presentation and understanding of the thesis content. It should also be borne in mind that mathematical notations and definitions are introduced at various points to render consistency and better understanding of the presentation.

Chapter 2 provides a review on the existing researches related to the subject of this thesis. This includes a general review on RFID system and RFID Network Planning (RNP). The background covers most of the RFID system components and the technology that could impact the effectiveness of a network planning indoor environment. The presented models specify the Pattern Radiation, Gain Values and Polarization. Also, it presents the algorithms that were employed in order to determine the best locations for readers and technical gaps and challenging issues.

Chapter 3 presents a clear roadmap of this study to guide the reader to achieve a quick grasp of the detailed research framework. Also, it discusses the detailed design and development of the proposed approaches of RFID Network Planning (RNP) which includes DBSCAN algorithm (Density Based Spatial Clustering of Applications with Noise), firefly algorithm (FA) and Monte Carlo simulation (MCS).

Chapter 4 provides the validation and testing results, detailed analysis, and discussion that carried out for the performance evaluation and implementation of the use of standard measurement approaches. The performance of the proposed method was benchmarked against the best up-to-date techniques on NP-hard solutions found in the literature.
Chapter 5 concludes by emphasizing the major contributions, significant findings, and recommended future directions of the present study.
CHAPTER 2

LITERATURE REVIEW

This chapter focuses on the important theories and knowledge related to the research topics. This includes two categories; the first is a general review on RFID technology such as radio frequency specifications, components of RFID system and independent RFID parameters. The second category is the overview of RFID Network Planning (RNP). This part involves the warehouse layout design, the optimization techniques and the Network Planning (RNP) parameters. Also presented are the related works and models that are strongly related to this research. The critical findings in this chapter were the foundation for developing the research methodology.

2.1 RFID Background

RFID technology has been used to improve operational efficiency and productivity in warehouses (Mitrokotsa et al., 2006) (EPC Standard 2004). A warehouse is typically designed into functional areas based on material flow. The items are typically stored based on size and the storage locations are easily accessible and general material flow in a warehouse depends on the role of the particular warehouse. These roles are considered as the base of RFID objective functions. Therefore, the achievement of these objective functions is the access to RNP network planning. This chapter will
provide all the necessary concepts and formulas of RFID system which enable the researcher to develop a new methodology to optimize the RNP network planning.

2.2 Radio Frequency Identification

Radio Frequency Identification (RFID) is a technology containing several areas of expertise and study. It is believed that the birth of RFID can be traced back to the early 20th century, when Radio Detection and Range (Radar) was invented, where the reflected wave is used to detect an object. The first patent on RFID was by Harris in 1960, entitled “Radio Transmission Systems with Modula table Passive Responder”. In this patent, Harris presented several ways of communication between a reader and a passive responder (tag) (Ali et al. 2014). RFID was first applied in friendly transport aircraft so that these aircraft were not misidentified as the enemy. It was British technique called Identification Friend-or-Foe (IFF) system (Landt et al., 2005).

In the early 1990s, IBM engineers developed and patented an ultra-high frequency (UHF) RFID system. This system has become an independent platform for implementing and developing dozens of new classes of RFID applications. In 2005, Royal Philips Electronics produced the first engineering samples of an RFID chip compliant with (UHF) Electronic Product Code (EPC) Class 1 Generation 2 (G2) standard. NASDAQ: NXPI in 2015 presented UCODE product, UCODE DNA (ultra-high frequency) RAIN RFID tag IC to combine long-range read performance with cryptographic authentication. With this new tag, IC developers no longer have to choose between contactless performance and the need for security in their applications; UCODE DNA enables them to have access to both in a single RAIN RFID tag IC. The new tag IC is ideal for use in a wide variety of applications, such as electronic road tolling, electronic vehicle registration, license plate authentication, access control, asset tracking, brand protection, parking (EPCglobal, 2004).
2.3 Components of RFID System

A system is a set of interacting or interdependent component parts. Every system is delineated by its spatial component. An RFID system largely consists of tags (transponder), readers (transceiver) and middleware. These components working together based on specific software which is able to read the transferred the data and arrange the ID of each tag.

![RFID System Components](image)

Figure 2.1: RFID System Components (Elshayeb 2009)

RFID is considered as a nonspecific short range device. It can use frequency bands without a license. Nevertheless, RFID has to be compliant with local regulations (ETSI, FCC etc.)

2.3.1 RFID Tag

A tag is a piece of equipment that stores certain unique information. The tag contains a chip and antenna combined on a plastic base and covered by plastic sheet. Tags are usually used to label products and then communicate with a reader by radio waves. This tag can also be classified into two groups.
2.3.1.1 Passive RFID Tag

A passive tag is an RFID tag that does not contain an internal power source. The power resource is the reader which formed a magnetic field by radio waves when across coiled antenna. Passive RFID tags generally operate at three distinct frequencies as in Table 2.1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Symbol</th>
<th>Frequency</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low Frequency</td>
<td>LF</td>
<td>125 -134 kHz</td>
<td>0-0.5m</td>
</tr>
<tr>
<td>2</td>
<td>High Frequency</td>
<td>HF</td>
<td>13.56 MHz</td>
<td>0-0.8 m</td>
</tr>
<tr>
<td>3</td>
<td>Ultra High Frequency</td>
<td>UHF</td>
<td>856 MHz to 960 MHz</td>
<td>0-15m</td>
</tr>
</tbody>
</table>

It has almost unlimited applications in consumer goods and other areas. The passive tags can be read from 1 millimeter to more than 300 feet away (ISO 14443) (ISO 18000-6). Passive RFID tags are small, inexpensive, unlimited in life span because power does not have to be supplied as shown in Figure 2.2 (Ting et al., 2007).

Figure 2.2: Passive RFID Tags, a) Tag structure, b) Tag size (Ting et al., 2007).
It can be read only at a short distances, which means if tags are placed outside of the electromagnetic field, these devices do not work. It is also not possible to connect these devices with sensors that can use electricity for power.

2.3.1.2 Active RFID

Active RFID tag is a type of tag which has its own power source. The power is generated inside the tag to energize the circuits in the tag in order to send the information encoded in the tag's memory. The read range of active tag with fixed readers is commonly up one hundred meters and tags contain specific information and have abundant memories. The active RFID tags can also be used to detect temperature, humidity and brightness, and for this reason, they have been used in a wide number of industries as shown in Figure 2.3.

![Active RFID Tags](image)

Figure 2.3: Active RFID Tags, a) Tag size, b) Tag shape (Jin et al., 2006)

The major disadvantage of using active RFID tags is that the tag's life span depends on the battery, which limits the working life of the tag (Jin et al., 2006). Active RFID tags are also more expensive than passive RFID tags.
2.3.1.3 Sensor Tags

Sensor tags may contain on-board environmental sensors, and may log and store data without the aid of a reader. Sensor tags offer more than strict RFID functionality, and are typically not thought of as RFID. Many sensor tags may form a “sensor net” that monitors a physical area’s environmental properties. This may include temperature changes, rapid acceleration, changes in orientation, vibration, the presence of biological or chemical agents, light, sound, etc. Because they operate without a reader present, Figure 2.4 shows the sensor tags which is necessarily be semi-passive or active.

![Sensor tag image](image)

*Figure 2.4: Tag Sensor (Turner & Sherratt 2002)*

On-board power source and sensor functionality comes at a much higher manufacturing cost (Turner & Sherratt 2002).

2.3.2 RFID Reader

An RFID reader is a network connected device (fixed or mobile) with an antenna that sends power as well as data and commands to the tags. The RFID reader acts like an
access point for RFID tagged items so that the tags' data can be made available to business applications. The working technique of reader is to receive the tag reflection signal as information and to send it through standard interface to the host computer (Sweeney 2006).

The antennas are the parts that are used to identify radio waves and to specify the range of zone of reading, both of which depend on the reader’s power and the frequency used. There are three basic kinds of RFID reader installations: hand-held, fixed reader installed in area, and fixed reader installed at chokepoint. The location of reader and the types of readers used play a major role in the selection of the type of reader. The electromagnetic field range that powers how the tagged item moves and broadcasts its data can be classified based on their applications on their usage as below (Sweeney 2006). The next sections will overview different types of RFID readers that are used in different applications.

2.3.2.1 Hand-Held Reader

A hand-held reader is a small lightweight device that is used to find tagged items easily and quickly as shown in Figure 2.5. It is used for specific things and users can grip the hand-held reader to look for what they want in complicated large areas.

![Figure 2.5: Hand-Held Reader](image-url)
The Received Strength Signal Indicator (RSSI) can specify the location and distance of the desired tagged items through measuring the displacement and signaling the destination.

2.3.2.2 Fixed Reader

A fixed reader is a stationary point reader located on a ceiling or wall to read internal data, location, or movement of objects in the area as shown in Figure 2.6. Fixed readers are mainly used with active RFID tags in which the reader receives information continuously based on the reader size (especially its antenna), and because of the big antenna size, the range and accuracy are greater than hand-held readers.

![Fixed Reader Image](image)

Figure 2.6: Fixed Reader

2.3.3 Middleware

Middleware is software to integrate various data received from several readers (Sweeney 2006). That means the middleware can connect two disparate applications represented by the reader and host computer as shown in Figure 2.7. The connection allows information to pass between instruments and the users can get data from the reader for display on the host computer. There are many applications in reality, such as
2.4 RFID Frequencies

Frequency is the number of occurrences of radio waves repeating per unit time. Understanding the relation between RFID and frequency can provide better knowledge about the application of RFID. Figure 2.8 shows the Radio Wave Frequency spectrum.
RFID systems operate at 4 major frequency ranges. As a rule of thumb, low-frequency systems are distinguished by short reading ranges, slow read speeds, and lower cost. Higher-frequency RFID systems are used where longer read ranges and fast reading speeds are required, such as for vehicle tracking and automated toll collection. The radio wave band is divided into several different categories. Radio wave propagation is the way the radio waves behave when they are transmitted from one point to another. The radio waves are also affected by the medium in which they travel. Phenomenon like reflection, refraction, diffraction, etc. also affects the behavior of the radio wave when they propagate through any medium. The Radio Wave Speed is equal to the speed of light since the radio wave also comes under the category of EM waves. The speed of the radio wave also depends on several factors when they are travelling through the medium. Microwave requires the use of active RFID tags. Table 2.2 shows different frequencies that are used for different applications.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Range</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-frequency 125 - 148 KHz</td>
<td>3 feet</td>
<td>Pet and ranch animal identification; car key locks</td>
</tr>
<tr>
<td>High-frequency 13.56 MHz</td>
<td>3 feet</td>
<td>Library book identification; clothing identification; smart cards</td>
</tr>
<tr>
<td>Ultra-high frequency 915 MHz</td>
<td>25 feet</td>
<td>Supply chain tracking; Box, pallet, container, trailer tracking</td>
</tr>
<tr>
<td>Microwave: 2.45GHz</td>
<td>100 feet</td>
<td>Highway toll collection; vehicle fleet identification</td>
</tr>
</tbody>
</table>
Because of these differing characteristics, the application is also different for each frequency range (Ward et al., 2006). LF is used is a frequency that is used in access control systems, and also in library management systems. The standardized air interfaces for these two application areas are very different. HF for access cards or liquid products, UHF for supply chain applications, and microwave frequency for toll booths on a highway.

2.5 RFID Standards

RFID standard has become an important issue in application because without a globally accepted standard, companies are free to follow any encodation logic and may use whatever software and hardware specifications they choose. A globally accepted Tag Data Standard (TDS) results in greater efficiency and accuracy, and ensures that RFID tag data can be read across all retailers and industries. Big name retail stores have adopted RFID technology early on and are slowly streamlining the process with their suppliers. Full implementation of the technology will take time, and a TDS will only make that process easier for suppliers and retailers alike. Standards can be classified into two types:

Tag Data Standard (TDS) defines the Electronic Product Code (EPC), including its correspondence to GS1 keys and other existing codes. TDS also specifies data that is carried on Gen 2 RFID tags, including the EPC, User Memory data, control information, and tag manufacture information. It specifies what is contained in the memory portion of the RFID tag [book]. The EPC is a unique code number which has same structure in every tag. This code is divided into four partitions. The two-digit header number identifies the length, structure, type, version and generation of EPC. With 28 bits, the EPS manager is able to cover as many as 228 companies. Object class represents the stock keeping unit (SKU) when applied to retail products. This is related to retail application. A serial number shown in Figure 2.9 is used to identify each product; it can
share about 68 billion items (Ward et al. 2006). A Pure Identity EPC URI is the primary representation of an EPC as an Internet Uniform Resource Identifier (URI). The Pure Identity EPC URI is the form that is used to identify a physical object in documents, databases or computer programs, in the same way a URL identifies a website’s resource or location.

![EPC: Electronic Product Code](image)

Figure 2.9: Electronic Product Code (EPC)

Technology standard is a global Network system that combines the different EPC data structures. The independent standards are: ISO 11784 (Livestock), ISO 15693 (Smart Labels), and ISO 14443 (Contactless payments), and the ISO 18000 standards family is the most widely used. The reason these various standards exist is to eliminate some problems such as the weakness of the interoperability with various readers of different manufacturers. The unification of technology standards will improve the utility of RFID.

### 2.6 RFID Parameters

RFID systems, the parameters which are generally effect on the objects affected by interrogating RF waves. For that the next sections will describe the RFID working
parameters which can identify physical objects sufficiently and provide more understanding to optimize the RFID system.

2.6.1 RFID Objective Function

In order to obtain reliable and accurate network planning, a set of objectives must be satisfied such as tag coverage, load balance, economic efficiency, and interference. It indicates to the number of readers deployed in the network and their locations and radiated power of each reader (Bacanin et al., 2015) (Bacanin & Tuba 2015) (Hasnan et al., 2015). The following sections will give an insight into effective factors of presented parameters also, the most important types of each factor.

2.6.1.1 RFID Signal Coverage

RFID tracking system consists of a particular signal coverage which specifies the system performance. The signal coverage capability represents resolution location accuracy of the tag coverage in RNP design. This design depends on the RFID reader’s antenna which represents the device to transmit and/or receive electromagnetic radio waves. The number of RFID readers required is affected by the size and shape of the RFID reader’s antenna coverage patterns (Gangwar et al., 2014).

The critical characteristics of the antenna are the gain and directivity. The gain is defined as the ratio of the antenna radiated power density at a distance point to the total isotropic input radiated power of the antenna. It represents the actual efficiency of the antenna. The radiation pattern of the graphical antenna gain is drawn in a vertical and horizontal polarization or three-dimensional polar plots (Bolic, et al., 2010) (LIU et al., 2008). The antenna directivity is defined as the ratio of the antenna radiated power density at a distance point to the total isotropic radiated power density of the antenna.
The directivity of the isotropic radiator is spherical pattern and equal to one, as Figure 2.10 observes the reference antenna.

![Isotropic and Omni-directional antennas](image)

Figure 2.10: The Isotropic Directivity Radiator (Balanis, 2005)

Antennas can be classified into two groups: directional and omnidirectional. The directional antennas have a high gain, but a narrow field view (i.e., patch). The omnidirectional antennas have a low gain, but a wide field view (Botero & Hakima 2011).

2.6.1.2 Signal Propagation

Currently, RFID systems can be separated into two main categories: near-field systems and far-field systems. Near-field systems utilize the inductive (magnetic) coupling with the transponder tag because of the reactive energy circulating around the reader antenna, while the far-field systems couple to the real power contained in free space propagating electromagnetic plane waves (Lehpamer 2012). RFID systems based on UHF and higher frequencies use far-field communication in RNP applications. Designing RFID-RNP system model needs to give careful consideration of the signal propagation because the uplink signals (i.e., tag-to-reader) and downlink signals (i.e., reader-to-tag) in an RFID
system are not equal. Also, the signals propagated from the readers' antenna overlap in coverage areas, which impedes the accurate decoding of backscattered signals and cause serious reduction in the RFID system performance (Hatano et al., 2000) (Kim & Yook 2008). Signal propagation follows the well-known Friis transmission formula. The received power from the formula is the theoretical value that can only be obtained in an anechoic chamber. Friis equation is used for estimating the powering region in a portal, reflection, scattering, diffraction, and shadowing may occur in signal propagation (Lehpamer, 2012) (Botero & Hakima, 2011). The read range of a UHF-based RFID propagation system can be calculated by the Friis free-space equation as follows:

$$P_{\text{reader}} = P_{\text{tag}} \times \left(\frac{\lambda}{4\pi r}\right)^2 \times G_{\text{reader}} \times G_{\text{tag}}$$  \hspace{1cm} (2.1)$$

where $P_{\text{tag}}$: Power received at receiver (tag), $P_t$: Transmitted (reader) power, $G_t$: Transmitter (reader) antenna gain, $G_r$: Receiver (tag) antenna gain, $r$: Distance between transmitter and receiver, $\lambda$: Radio wavelength

This formula can be used to estimate the minimum power required at the RFID tag's antenna based on the tag distance $r$ in outdoor free space environment. The indoor environments contain many different types of physical obstacles, thus the path loss is considered as a function of distance between transmitting antenna and receiving antenna (Debus & Axonn 2006) which can be calculated by the equation as follows:

$$L_p(d) = L_p(d_o) + 10n\log\left(\frac{d}{d_o}\right) + X, \text{dB}$$  \hspace{1cm} (2.2)$$

where; $d_o$ represents the reference distance which is normally 1 meter, $n$ represents the path loss exponent term based on the operating frequency and the surrounding environment, and $X$ represents the normal random variable referred to as the multipath fading term. To formulate the
\[ P_{\text{read,Tag}} = P_{\text{reader}} - L[\text{dB}] \] (2.3)

power received at tag based on path loss, equation 2.3 included the propagation loss effect (Nawawi et al., 2011) (Botero & Hakima, 2011) (Mehrjerdi, 2014).

### 2.6.1.3 Interference

The RF fields of two or more readers may overlap and interfere. UHF RFID system, which operates in the 860–960 MHz band, can operate within close range to each other, which may cause serious interference problems. There are two main types of RFID system interference, interference from physical obstacles and interference from RFID readers and/or tags (Lehpamer, 2012). The RFID readers and/or tags also classified into three types of UHF RFID interference as shown below: tag interference, multiple reader-to-tag interference and reader-to-reader interference (Kim & Yook, 2008). Tag interference: this problem arises when multiple tags are simultaneously energized by the reader and reflect their respective signals back to the reader. Due to a mixture of scattered waves, the reader cannot differentiate individual IDs from the tags; therefore, anti-collision mechanisms such as those known as binary-tree and ALOHA are needed (Islam et al., 2014) (Kim & Yook, 2008).

Multiple reader-to-tag interference: this problem occurs when a tag is located at the intersection of two or more reader interrogation ranges and the readers attempt to communicate with the tag simultaneously as shown in Figure 2.11. The active signal interference can be characterized by the coverage ratio of the multiple readers in order to specify the amount of allowed overlapping on each reader. The total coverage area of a particular RFID reader deployment indicates the reader capability. The threshold of allowed overlapping represents the interference which reduced the RFID reader’s maximum read distance.
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