OPTIMIZATION OF SUPPLY CHAIN MANAGEMENT BY SIMULATION BASED RFID WITH XBEE NETWORK

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A thesis submitted in
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ABSTRACT

The aim of every Supply Chain Management (SCM) is to reduce the operational cost and maximize the benefits. These necessitate the use of advance technology to optimize the operational activities. Among the widely used technology in recent years is Radio Frequency Identification (RFID). It is an advanced Auto-ID wireless network based configuration system used for identification and tracking of items movement data. Technically, basic requirements for deploying RFID network are to identify the number of readers needed, location of the readers and the efficient parameter setting for each reader. Among the problems associated with RFID technology are the multi-objective optimizations, which include tags coverage, economic efficiency, interference and load balance. In order to solve this problem, a simulation based “Multi-Colony Global Particle Swarm Optimization (MC-GPSO)” algorithm was developed. This algorithm computes the optimal results of objective functions in a scientific manner. However, RFID reader is an expensive and has limited data transmission range. It alone cannot transmit data to the main server. Thus, its communication range was enhanced by the integration of RFID with XBee (ZigBee) wireless mesh network devices. Furthermore, the identification data need to be monitored and transmitted to the business organizations, which are connected through the network. This has been achieved by the integration of RFID-XBee network with database connectivity through Internet of Things (IoT). This integrated system provides the visibility of items at real time identification and tracking activity at single control platform. This system also provides data sharing activity with business enterprises using IoT. The benefits of this system include reduction of shrinkage and data transfer time in global network. This system also increases the accuracy, productivity and improves delivery of service in supply chain to the optimum level. This would contribute towards a more sustainable and green supply chain management.
ABSTRAK

Matlamat setiap Pengurusan Rantaian Bekalan (SCM) adalah untuk mengurangkan kos operasi dan memaksimumkan keuntungan. Ia memerlukan teknologi canggih, yang memudahkan untuk melaksanakan dari segi aktiviti operasi dan mengoptimumkan manfaatnya. Radio Frequency Identification (RFID) adalah satu teknologi tanpa wayar Auto-ID digunakan untuk pengenal dan pengesanan data pergerakan barang dalam pengurusan rantaian bekalan. RFID adalah sistem konfigurasi berasaskan rangkaian yang banyak digunakan dalam SCM. Secara teknikal, keperluan asas untuk menggunakan rangkaian RFID termasuklah mengetahui bilangan pembaca yang diperlukan, lokasi pembaca dan penggunaan kuasa yang efisien oleh setiap pembaca. Antara masalah yang berkaitan dilaporkan bahawa teknologi RFID ialah pengoptimuman pelbagai objektif termasuk liputan tag, kecekapan ekonomi dan gangguan. Bagi mengatasi masalah ini, satu algoritma simulasi "Multi-Colony Global Particle Swarm Optimization (MC-GPSO)" mendapatkan keputusan optimum bagi setiap fungsi objektif secara saintifik. Walau bagaimanapun, pembaca RFID adalah mahal dan mempunyai penghantaran data yang terhad. Ia tidak boleh menghantar data kepada pelayan utama secara bersendirian. Oleh itu, komunikasi telah dipertingkatkan dengan integrasi antara RFID dengan XBee (ZigBee) peranti rangkaian mesh tanpa wayar. Tambahan pula, data pengenalan perlu dipantau dan dihantar kepada organisasi perniagaan, yang dihubungkan dengan rangkaian. Ia telah dicapai melalui integrasi rangkaian RFID-XBee dengan sambungan pangkalan data menggunakan “Internet of Things” (IoT). Sistem bersepadu menyediakan pengenalan keterlihatan item pada masa sebenar dan pengesanan aktiviti di platform kawalan tunggal. Sistem ini juga menyediakan aktiviti perkongsian data kepada perusahaan perniagaan menggunakan IoT. Antara kebaikan sistem ini termasuklah ia dapat mengurangkan ketirisan dan masa pemindahan data dalam rangkaian global. Sistem ini meningkatkan ketepatan, produktiviti dan penyampaian...
perkhidmatan dalam rantaian bekalan pada peringkat optimum. Ini mampu menyumbang kepada pengurusan rantaian bekalan yang lebih mampan dan mesra alam.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xvi</td>
</tr>
<tr>
<td>LIST OF PUBLICATIONS</td>
<td>xviii</td>
</tr>
</tbody>
</table>

## CHAPTER 1  INTRODUCTION

1.1 Research Background                       1  
1.2 Problem Statement                         3  
1.3 Aim and objectives of research            4  
1.4 Scope of the research                     5  
1.5 Summary                                  5  

## CHAPTER 2  REVIEW OF LITERATURE

2.1 Auto-ID Technology                        9  
2.2 Shrinkage                                 10  
2.3 Radio Frequency Identification (RFID) Systems 10  
   2.3.1 Physical Layer                        12  
   2.3.2 Electromagnetic Propagation (Transmission) 14  
   2.3.3 Electromagnetic Waves (Radio Waves)     16  
   2.3.4 Near-Field/Inductive Coupling          20  
   2.3.5 Far-Field/Backscatter Coupling         20  
   2.3.6 Link Budget and Read Range             22  
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3.7</td>
<td>Path loss propagation Model</td>
<td>23</td>
</tr>
<tr>
<td>2.3.8</td>
<td>Free space propagation Model</td>
<td>24</td>
</tr>
<tr>
<td>2.3.9</td>
<td>Two-ray propagation Model</td>
<td>25</td>
</tr>
<tr>
<td>2.3.10</td>
<td>Multipath propagation Model</td>
<td>26</td>
</tr>
<tr>
<td>2.3.11</td>
<td>Radar Cross Section propagation Model</td>
<td>27</td>
</tr>
<tr>
<td>2.3.12</td>
<td>Radiation Pattern of an Antenna</td>
<td>28</td>
</tr>
<tr>
<td>2.3.13</td>
<td>Antenna Gain</td>
<td>29</td>
</tr>
<tr>
<td>2.3.14</td>
<td>IT Layer</td>
<td>30</td>
</tr>
<tr>
<td>2.4</td>
<td>Application of wireless networks</td>
<td>32</td>
</tr>
<tr>
<td>2.5</td>
<td>RFID network planning (RNP)</td>
<td>32</td>
</tr>
<tr>
<td>2.5.1</td>
<td>Optimal tag coverage</td>
<td>33</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Reader collision avoidance (Interference)</td>
<td>33</td>
</tr>
<tr>
<td>2.5.3</td>
<td>Economic efficiency</td>
<td>34</td>
</tr>
<tr>
<td>2.5.4</td>
<td>Load balance</td>
<td>34</td>
</tr>
<tr>
<td>2.6</td>
<td>Optimization</td>
<td>34</td>
</tr>
<tr>
<td>2.7</td>
<td>Basic concept of Particle Swarm Optimization</td>
<td>36</td>
</tr>
<tr>
<td>2.8</td>
<td>XBee (ZigBee) (Wireless Sensor Network)</td>
<td>39</td>
</tr>
<tr>
<td>2.9</td>
<td>Summary</td>
<td>42</td>
</tr>
</tbody>
</table>

CHAPTER 3 RESEARCH FRAMEWORK

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Research Flow</td>
<td>44</td>
</tr>
<tr>
<td>3.2</td>
<td>RFID network parameters</td>
<td>47</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Tags Coverage</td>
<td>47</td>
</tr>
<tr>
<td>3.2.2</td>
<td>Interference</td>
<td>51</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Number of readers</td>
<td>52</td>
</tr>
<tr>
<td>3.3</td>
<td>Setting parameters of search space</td>
<td>53</td>
</tr>
<tr>
<td>3.4</td>
<td>Setting topology of search space</td>
<td>55</td>
</tr>
<tr>
<td>3.5</td>
<td>Reader representation</td>
<td>56</td>
</tr>
<tr>
<td>3.6</td>
<td>Coding of tags, readers and working area</td>
<td>57</td>
</tr>
<tr>
<td>3.7</td>
<td>Coding of objective functions and all variable parameters</td>
<td>59</td>
</tr>
<tr>
<td>3.8</td>
<td>Application of MC-GPSON</td>
<td>59</td>
</tr>
<tr>
<td>3.8.1</td>
<td>Initialization</td>
<td>60</td>
</tr>
<tr>
<td>3.8.2</td>
<td>Setting Optimization criteria</td>
<td>60</td>
</tr>
</tbody>
</table>
CHAPTER 4 INTEGRATION OF RFID-XBEE NETWORK WITH DATABASE CONNECTIVITY 64
4.1 System Development 65
4.2 Hardware Configuration 67
  4.2.1 RFID Reader Connection and Testing 67
  4.2.2 XBee Module Connection and communication 71
4.3 RFID-XBee Operating Module 74
4.4 Software architecture of the system 77
  4.4.1 LabVIEW Database Connectivity Module 77
    4.4.1.1 Database connection tools of LabVIEW program 80
    4.4.1.2 Creation of UDL file for LabVIEW Database Connection 80
    4.4.1.3 The construction of LabVIEW database functional module 81
    4.4.1.4 The LabVIEW Database Connectivity Programming Model 85
    4.4.1.5 Graphical User Interface (GUI) 87
    4.4.1.6 LabVIEW developed system 91
    4.4.1.7 Validation of RFID-XBee and LabVIEW database system 94
4.5 Live video operating module 94
4.6 IoT Operating Module 96
4.7 Integrated Module 100
4.8 Summary 105

CHAPTER 5 RESULTS AND ANALYSIS 107
5.1 Implementation of MC-GPSO 107
5.2 RFID-XBee network result 120
5.3 Integrated network of RFID-XBee, database connectivity and IoT result 120

5.4 Summary 122

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS 123

6.1 Contribution 124
6.2 Recommendation 125

REFERENCES 126

APPENDIX A MATLAB CODE OF MC-GPSO 133

VITA 138
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Tangible ROI as a bottom-line positive business benefits</td>
<td>8</td>
</tr>
<tr>
<td>2.2</td>
<td>Application of operating frequencies in RFID system</td>
<td>17</td>
</tr>
<tr>
<td>2.3</td>
<td>Power comparison in dBm and mW</td>
<td>18</td>
</tr>
<tr>
<td>2.4</td>
<td>Conditions of Near-field and far-field region</td>
<td>21</td>
</tr>
<tr>
<td>2.5</td>
<td>Path loss exponent n and σ measured in different buildings</td>
<td>27</td>
</tr>
<tr>
<td>2.6</td>
<td>Previous research summary of RFID network planning</td>
<td>41</td>
</tr>
<tr>
<td>2.7</td>
<td>Previous RFID research works integrated with wireless technologies</td>
<td>42</td>
</tr>
<tr>
<td>3.1</td>
<td>The different case studies</td>
<td>53</td>
</tr>
<tr>
<td>3.2</td>
<td>Dimension of each reader for PSO solution</td>
<td>57</td>
</tr>
<tr>
<td>4.1</td>
<td>Hardware wire connections</td>
<td>71</td>
</tr>
<tr>
<td>5.1</td>
<td>Comparison results of MC-GPSO algorithm at tags 30</td>
<td>109</td>
</tr>
<tr>
<td>5.2</td>
<td>Comparison results of MC-GPSO algorithm at tags 50</td>
<td>110</td>
</tr>
<tr>
<td>5.3</td>
<td>Comparison results of MC-GPSO algorithm at tags 100</td>
<td>111</td>
</tr>
<tr>
<td>5.4</td>
<td>Comparison results of MC-GPSO algorithm at tags 30 (TE)</td>
<td>112</td>
</tr>
<tr>
<td>5.5</td>
<td>Comparison results of MC-GPSO algorithm at tags 50 (TE)</td>
<td>114</td>
</tr>
<tr>
<td>5.6</td>
<td>Comparison results of MC-GPSO algorithm at tags 100 (TD)</td>
<td>115</td>
</tr>
<tr>
<td>5.7</td>
<td>Comparison results of MC-GPSO algorithm at 50 and 100 tags (TE)</td>
<td>116</td>
</tr>
<tr>
<td>5.8</td>
<td>Comparison results of MC-GPSO algorithm at 50 and 100 tags (TD)</td>
<td>118</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

2.1: Important Auto-ID technologies 9
2.2: Typical RFID System 11
2.3: RFID system layers 12
2.4: Various RFID Tags 13
2.5: Electromagnetic wave propagation 15
2.6: Electromagnetic wave path loss in free space 16
2.7: Electromagnetic wave 16
2.8: Summary of worldwide UHF band allocations 17
2.9: Radiated field regions of an antenna having maximum dimension D 22
2.10: Path Loss Propagation Models 24
2.11: Two-ray Path Loss 25
2.12: The graphical representation of the radar system 28
2.13: The 3D radiation pattern of an electrically short current element 29
2.14: The E-plane and H-plane patterns of an electrically short current element 29
2.15: RNP basic problems 33
2.16: Types of computational Intelligence 35
2.17: Particle Swarm Optimization flow diagram 38
3.1: Research flow chart 46
3.2: Randomly plotting of tags 48
3.3: Randomly deploy number of readers 49
3.4: Best location of readers in the network 49
3.5: Multiple readers interference 52
3.6: Topology diagram 55
3.7: Randomly plotting of 100 number of tags in 50m x 50m working area
3.8: Optimization criteria flow strategy
4.1: Sustainable Supply Chain Management Optimization Model
4.2: Optimal Green Supply Chain Management Model
4.3: System Development
4.4: Circuit diagram of RFID reader connection with Xbee Router/End device
4.5: Snaps of physical devices network connection
4.6: Protocol of the RFID Reader
4.7: Tag ID
4.8: XBee configuration procedure
4.9: Configurations of set of XBees
4.10: RFID-XBee Operating Module
4.11: LabVIEW Database Connectivity Module
4.12: Database connectivity model
4.13: Simple LabVIEW Database Construction Model
4.14: Microsoft Access database tables
4.15: LabVIEW database functional module
4.16: Data execution in sequential order
4.17: Data displayed by index array
4.18: Verification of data in the database
4.19: VISA Close operation
4.20: LabVIEW Database Connectivity Programming Model
4.21: Vehicle and Item information
4.22: Live Cam Tab
4.23: Parameter setting Tab
4.24: Address source file Tab
4.25: LabVIEW Algorithm
4.26: Monitoring by LabVIEW Control panel
4.27: Microsoft Access Database Report (a) & (b)
4.28: Live video process diagram
4.29: Live video block diagram 95
4.30: Wireless connection between two computers via IoT 97
4.31: Data server.vi and Data client.vi 98
4.32: Optimal solution of supply chain management 101
4.33: Optimal position of RFID readers 102
4.34: Integrate module 103
4.35: Live monitoring 104
5.1: Simulation results of case study 1 with 30 tags 110
5.2: Simulation results of case study 1 with 50 tags 111
5.3: Simulation results of case study 1 with 100 tags 112
5.4: Simulation results of case study 2 with 30 tags (a), (b) and (c) 113
5.5: Simulation results of case study 2 with 50 tags (a), (b) and (c) 115
5.6: Simulation results of case study 2 with 100 tags (a), (b) and (c) 116
5.7: Simulation results of case study 3 with 50 and 100 tags (a) and (b) 117
5.8: Simulation results of case study 3 with 50 and 100 tags (a) and (b) 119
5.9: Physical model of RFID-XBee network 120
5.10: Live Cam monitoring by LabVIEW application 121
5.11: Communication between two computers by IoT 122
6.1: Monitoring of items by RFID-XBee network 125
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABC</td>
<td>Ant Bee Colony</td>
</tr>
<tr>
<td>ACO</td>
<td>Ant Colony Optimization</td>
</tr>
<tr>
<td>ADO</td>
<td>Active X Data Object</td>
</tr>
<tr>
<td>AIDC</td>
<td>Auto Identification and Data Capture</td>
</tr>
<tr>
<td>BFO</td>
<td>Bacterial Foraging Optimization</td>
</tr>
<tr>
<td>COM</td>
<td>Component Object Model</td>
</tr>
<tr>
<td>DBMS</td>
<td>Data Base Management System</td>
</tr>
<tr>
<td>DSN</td>
<td>Data Source Name</td>
</tr>
<tr>
<td>EA</td>
<td>Evolutionary Algorithm</td>
</tr>
<tr>
<td>EPC</td>
<td>Electronic Product Code</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSCM</td>
<td>Green Supply Chain Management</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HF</td>
<td>High Frequency</td>
</tr>
<tr>
<td>IZ</td>
<td>Interrogation Zone</td>
</tr>
<tr>
<td>JIT</td>
<td>Just-In-Time</td>
</tr>
<tr>
<td>LabVIEW</td>
<td>Laboratory Virtual Instruments Engineering Workbench</td>
</tr>
<tr>
<td>LF</td>
<td>Low Frequency</td>
</tr>
<tr>
<td>MAC</td>
<td>Medium Access Control</td>
</tr>
<tr>
<td>MATLAB</td>
<td>Matrix Laboratory</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>OCR</td>
<td>Optical Character Recognition</td>
</tr>
<tr>
<td>ODBC</td>
<td>Open Data Base Connectivity</td>
</tr>
<tr>
<td>OLEDB</td>
<td>Object Linking and Embedded Data Base</td>
</tr>
<tr>
<td>ONS</td>
<td>Object Naming Service</td>
</tr>
<tr>
<td>PAN</td>
<td>Personal Area Network</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>POS</td>
<td>Point Of Sale</td>
</tr>
<tr>
<td>PSO</td>
<td>Particle Swarm Optimization</td>
</tr>
<tr>
<td>RCS</td>
<td>Radar Cross Section</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio Frequency Identifications</td>
</tr>
<tr>
<td>RNP</td>
<td>Radio Frequency Identifications Network Planning</td>
</tr>
<tr>
<td>ROI</td>
<td>Return On Investment</td>
</tr>
<tr>
<td>RTLS</td>
<td>Real Time Locating System</td>
</tr>
<tr>
<td>SCM</td>
<td>Supply Chain Management</td>
</tr>
<tr>
<td>SI</td>
<td>Swarm Intelligence</td>
</tr>
<tr>
<td>SMI</td>
<td>Small and Medium Scale Industry</td>
</tr>
<tr>
<td>UART</td>
<td>Universal Asynchronous Receiver Transmitter</td>
</tr>
<tr>
<td>UDL</td>
<td>Universal Data Link</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
</tr>
<tr>
<td>UPC</td>
<td>Universal Product Code</td>
</tr>
<tr>
<td>WPAN</td>
<td>Wireless Personal Area Network</td>
</tr>
<tr>
<td>WSN</td>
<td>Wireless Sensor Network</td>
</tr>
</tbody>
</table>
LIST OF PUBLICATIONS

Journal Articles

1. **Integration of Value Stream Mapping with RFID, WSN and ZigBee Network**
   
   *Aftab Ahmed, Khalid Hasnan, Badrul Aisham, Qadir Bakhsh*
   
   
   *(SCOPUS, EI and ISI Proceedings)*

2. **Optimization of RFID Real-time Locating System**
   
   *Khalid Hasnan, Aftab Ahmed, Winardi Sani, Qadir Bakhsh*
   
   
   *(ISI Indexed)*

3. **Optimization of RFID network planning using ZigBee and WSN (In Press)**
   
   *Khalid Hasnan, Aftab Ahmed, Badrul Aisham, Qadir Bakhsh*
   
   
   *(SCOPUS, EI and ISI Proceedings)*

4. **Impact of RFID and XBee Communication Network on Supply Chain Management**
   
   *Aftab Ahmed, Khalid Hasnan, Badrul-aisham, Qadir Bakhsh*
   
   
   *(SCOPUS and ISI Indexed)*

5. **A novel optimal RFID network planning by MC-GPSO**
   
   *Khalid Hasnan, Aftab Ahmed, Badrul-aishama, Qadir Bakhsh, Kashif Hussain*
   
   
   *(SCOPUS Indexed)*

6. **RFID with XBee communication network enhance the visibility of supply chain management (Accepted)**
   
   *Khalid Hasnan, Aftab Ahmed, Badrul-aishama and Qadir Bakhsh*
   
   Procedia CIRP ELSEVIER

7. **A Novel Integration of RFID Network Planning With XBee Network (Accepted)**
   
   *Khalid Hasnan, Aftab Ahmed, Badrul-aishama, Qadir Bakhsh, Kashif Hussain*
Conference Presentations


2. 2nd International Conference on Engineering and Technology ICET-2013
Organized by: TATIUC at Bali Indonesia on 12-13 December, 2013

3. 2nd International Conference on Robotics, Automation Systems ICoRAS-2013
Organized by: TATIUC at Bali Indonesia on 12-13 December, 2013

4. 4th International Conference on Mechanical and Manufacturing Engineering (ICME 2013)
Organised by: Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, at Bangi, Putrajaya, Malaysia on 17-19 December 2013

5. International Conference on Mathematics, Engineering & Industrial Applications 2014 (ICoMEIA 2014)
Organised by: Institute of Engineering Mathematics, Universiti Malaysia Perlis Universiti Malaysia Perlis (UniMap) at The Gurney Resort Hotel & Residences, Penang, Malaysia on 28th ~ 30th May, 2014

6. 12th Global Conference on Sustainable Manufacturing
Organized by: Universiti Technology Malaysia (UTM), Malaysia at The Puteri Pacific Hotel Johor Bahru on 22-24 September 2014

7. 5th International Conference on Mechanical and Manufacturing Engineering (ICME 2014)
Organised by: Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, at Grand Preanger Hotel, Bandung, Indonesia on 29-30 October 2014

8. International conference on Green Computing and Engineering Technology 2015 (ICGCET'15)
Organized by: Gyancity Laboratory at Radisson Royal Hotel Dubai, UAE on 25-26 July 2015

9. 13th Global Conference on Sustainable Manufacturing (Accepted)
Organized by: Technische Universität Berlin (TU Berlin) Vietnamese-German University (VGU), at Ho Chi Minh City / Binh Duong, Vietnam on 16th - 18th September 2015

10 Malaysian Technical Universities Conference on Engineering and Technology (MUCET) 2015 (Accepted)
Organised by: Malaysian Technical Universities Network (MTUN), at Johor Bahru on 11-13 October 2015
CHAPTER 1

INTRODUCTION

Radio Frequency Identification (RFID) is an Automatic Identification and Data Capture (AIDC) wireless technology used for real time identification and data collection of entities. It has been used since more than half century. Currently the RFID technology is most commonly used in toll collection, logistics, asset tracking and supply chain management. It has great potential to use in various applications.

Currently the enterprises are going towards advance RFID technology in place of barcode system. However, RFID is an enabling and promising technology, even though it has challenging issues of the optimal deployment of RFID network are tags coverage, interference, economic efficiency and load balance (Chen et al., 2011b). RFID network has multi-objective optimization functions, which can be solved by optimization algorithm. However, the RFID reader has limited communication range and high cost. It has been found that the RFID reader can easily integrate with XBee (ZigBee) wireless mesh network to increase communication range. RNP-XBee network can integrate with database connectivity and Internet of Things (IoT) to enhance business benefits by data sharing among enterprises.

1.1 Research Background

Radio frequency identification (RFID) wireless technology has been used for automatic identification and data capture of entities at real time locating system through electromagnetic waves (Turcu, 2010). It has also been used in a library management system and various other applications. This technology has been used by thousands of
companies for a decade or more. It quickly gained attention because of its ability to track moving objects. As technology is refined, RFID tags are used in different works tends to spreading throughout.

RFID and barcode technologies are used for the same purpose, but the principle of operation is different and has various advantages. The advantages of RFID over barcode are that it can track through human body and non-metallic materials. It does not require direct orientation to scan. Moreover it can detect large number of items at the same time and is able to read in harsh and dirty environment. RFID tags have longer read range and large storage data as compared to the barcode tag and it can be writable to update the data at any time (Lehpamer, 2008).

The implementation of RFID system based upon network configuration. The RFID network planning (RNP) has some challenging issues that includes coverage, interference, economic efficiency and load balance. Before deploying RFID readers consider the basic requirement for achieving the optimized network such as minimum number of readers deployed at strategic placement and best suitable parameter setting for each reader (Chen et al., 2011b, Gong et al., 2012).

In this research particle swarm optimization algorithm was used innovatively for solving RNP issues by using multi-colony global particle swarm optimization (MC-GPSO) algorithm.

However, RFID reader has limited communication range and high cost. It has been found that the RFID can easily be integrated with XBee (ZigBee) wireless mesh network devices for increasing the node placement and wider the range of communication (Bolic et al., 2008). XBee (ZigBee) is low cost and low power consumption network device in RFID system. RFID-XBee integrated system can increase the overall function and efficiency to get real time information of supply chain effectively resulting to cut the product loss (shrinkage) and bullwhip effect (Sumi et al., 2009, Elshayeb et al., 2009). RFID has been widely used in supply chain cycle (Soon & Gutiérrez, 2008, Kok et al., 2008). Aim of every supply chain is to maximize the overall benefits which depend on several decisions relating to the real time flow of information, product, and funds for successful supply chain management (Darla et al., 2012).
This research focuses on novel approach to solve RFID network planning (RNP) and to integrate with XBee (ZigBee) wireless network devices, database connectivity and IoT. It enhances the efficiency of supply chain management.

The benefit of integrated system is to increase the range of communication of RFID system by low cost XBee (ZigBee) network. It can provide accurate real time visible picture of items flow status at single platform and update the database during running operation. This information can share among networked organizations and it is useful to forecast the business benefits at each level of supply chain. It could control product loss or shrinkage. The system also has ability to significantly reduce the wastage in terms cost, expenditure, time and services which makes the organizations in supply chain green and sustainable.

1.2 Problem Statement

Mostly organizations use optical barcode technology for items scanning process, because barcode system can easy to implement, less expensive/economic and it takes few minutes to train the operator for scanning items. However, the barcode scanning system has some drawbacks e.g. It needs proper orientation for scanning by human intervention. Each item scan individually takes longer time and might be human error happened by missing of an item during scanning activity. Currently business enterprises are going towards advance RFID auto-ID technology for collecting the object movement data, which can cut labor cost significantly (Kao & Lee, 2011). There are various advantages of RFID over barcode technology in terms of accuracy, speed, quality and flexibility of operational strategy and it can scan multiple items at longer distance (Ferrer et al., 2010).

The implementation of RFID system based upon network configuration. It is difficult to implementation in any specific area. The basic issues of RNP include coverage, economic efficiency, interference and load balance (Irfan et al., 2012, Tsai & Lin, 2013, Nawawi et al., 2014). Before deploying the optimal reader network following queries are raised.

i. How many minimum readers are required to cover all tags?

ii. Where to deploy these minimum readers?
iii. What parameters are to be set for each reader?

The RFID network planning (RNP) is a multi-objective optimization problem (Lee, 2010), need to solve innovatively using optimization techniques to achieve the goal of optimum RFID network planning for sustainable competitive business benefits of enterprise operations focus on green supply chain management.

Due the limited communication range and high cost of RFID reader, it has been found that the RFID reader can easily integrate with XBee (ZigBee) wireless mesh network devices. This can increase the number of node placement and enhance the communication range of RFID reader (Sumi et al., 2009, Bolic et al., 2008).

The RNP-XBee integrated system is used to identify and data collection of items at longer distance. The collected data can be monitored and updated on real time basis at single control platform of LabVIEW database connectivity program (Elshayeb et al., 2009). This data can be shared among other organizations, which are connected in to the global network by using IoT to enhance the optimal business benefits.

1.3 Aim and objectives of research

The aim of this research was to develop an optimal RFID network and to integrate with XBee (ZigBee) wireless network devices, database connectivity and IoT module, to achieve the competitive business benefits of green supply chain management by real time data exchange into the network organization. The specific objectives of this research are included:

i. To develop and implement multi-colony global particle swarm optimization algorithm for RNP issues.

ii. To integrate RNP with XBee wireless network devices.

iii. To integrate RFID-XBee network with database connectivity and Internet of Things (IoT) module for data exchange into the network connected organizations.
1.4 Scope of the research

The scope of this research is wide aimed at enhancing business profits by improved supply chain cycle through updated data on commodities on trade and in transit. However solution of integrated RFID and XBee network will help:

i. Developing and implementing multi-colony global particle swarm optimization (MC-GPSO) algorithm for the solution of RNP issues.

ii. Developing the physical RFID-XBee wireless communication module for data collection of items and to communicate at longer distance.

iii. Developing a database connectivity module for RFID-XBee applications to monitor the data collection of items at single control platform.

iv. Develop an Internet of Things (IoT) module, which is used for data exchange to the business related organizations connected into the network to enhance business benefits.

1.5 Summary

The outline of this research begins with the introduction of RFID and its application. The background study is focused on supply chain management. On the basis of background study the problem statement has to be identified and establish the aims and objectives of research. Finally followed by scope of research is outlined to achieve the target of research outcomes.

The literature review is explained in Chapter 2, which describe the Auto-ID technology, shrinkage, the basics of RFID wireless communication system and its type (near field & far field), link budget and read range, path loss propagation model, optimization of RFID network planning by PSO, XBee (ZigBee) wireless mesh network and its application are introduced. At the end the research gap is defined.

On the basis of research gap the research framework is explained in Chapter 3, which describes the RFID network parameter and their objective functions (coverage, interference and number of readers). The parameters and topology of search space was set, and then represent coding of tags, reader and objective function. Followed by the
application of MC-GPSO its operating procedure and their simulation results are explained.

The modules of RFID-XBee network, database connectivity, live video, IoT and integrated module were developed and their implementation is explained in Chapter 4. After development of integrated module, the results and their analysis are explained in Chapter 5. Finally conclusion and recommendations are explained in Chapter 6.
CHAPTER 2

REVIEW OF LITERATURE

The real time information is the back bone of every supply chain; this can be achieved by Radio Frequency Identification (RFID) auto-ID wireless technology to meet the target of real time information exchange of enterprise operations. The numbers of organizations produce, distribute, handle or sell various goods. These organizations are exploring what RFID can do to improve operating efficiency, product quality, reduce inventory, shrinkage and bullwhip effect also drive additional revenue opportunities in supply chain (Bottani et al., 2010). Decreasing of tag cost has been widely recognized as the important factor influencing the widespread usage of RFID technology (Lin & Ho, 2009). The wide adoption of RFID across the supply chain will bring significant benefits leading to reduce operational costs and increase profits (Mueller & Tinnefeld, 2008). Many experts in financial matters suggested that, this will happen in following basic areas.

i. Reduced inventory and shrinkage
ii. Reduce labor expenses in store, warehouse and on shop floor to get benefit.
iii. Minimize out-of-stock items
iv. Bullwhip effect

Various scientists are believed that the application of RFID technology would not be failed; if following issues are to be resolved.

i. Tag prices and efficiencies
ii. RFID standards must be harmonize,
iii. Interoperability throughout the supply chain
iv. Large volumes of data handle by IT infrastructure
v. Modification or change of work and labor practices
vi. cost of deployment properly shared
vii. Privacy issues

According to Alinean research, the new RFID projects could cut supply chain costs by 3-5% and achieve 2-7% increase in revenue. RFID provides accurate and real time visibility of entities in the supply chain. This can make every project as sustainable to get benefits on long term basis. On average basis, over 90% of projects need a formal business case justification in order to get approval of projects. RFID wireless technology gives promise of bottom-line positive business benefits and a tangible ROI (Pisello, 2006, de Souza et al., 2011) as shown in Table 2.1.

Table 2.1: Tangible ROI as a bottom-line positive business benefits (Pisello, 2006)

<table>
<thead>
<tr>
<th>Goal</th>
<th>Typical Savings</th>
<th>Tangible Benefits with Manufacturing Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity improved through automation</td>
<td>18% productivity improvement</td>
<td>$3.5M annual recurring labor cost savings</td>
</tr>
<tr>
<td>Reduce production-related expectations</td>
<td>21% reduce in expectations</td>
<td>$8.4M annual recurring labor and cost avoidance</td>
</tr>
<tr>
<td>Reduce purchase order processing costs</td>
<td>30% productivity improvement</td>
<td>$860,000 annual recurring productivity improvements/potential labor cost savings</td>
</tr>
<tr>
<td>Inventory savings</td>
<td>10% inventory reduction (safety stock)</td>
<td>$500,000 one-time working capital savings $55,000 annual recurring carry-cost reduction</td>
</tr>
<tr>
<td>Reduce scrap</td>
<td>45% write-off avoidance</td>
<td>$40,000 in annual savings</td>
</tr>
<tr>
<td>Reduce days sales outstanding</td>
<td>8% days sales outstanding (DSO) improvement</td>
<td>$5.7M one-time accounts receivable working capital improvement</td>
</tr>
<tr>
<td>Reduce accounts receivable disputes</td>
<td>40% dispute avoidance</td>
<td>$2.3M annual write-down cost avoidance</td>
</tr>
<tr>
<td>Improve net fixed asset utilization</td>
<td>2-3% NFA utilization improvement</td>
<td>$2M one-time working capital improvement</td>
</tr>
<tr>
<td>Lost asset recovery</td>
<td>40% reduction in loss assets</td>
<td>$25,000 annual recurring savings</td>
</tr>
<tr>
<td>Improve plant asset maintenance</td>
<td>48% cost avoidance</td>
<td>$75,000 annual recurring savings</td>
</tr>
<tr>
<td>Improve customer satisfaction*</td>
<td>1.5% improvement in customer retention</td>
<td>$1.5M annual recurring customer attrition and replacement cost avoidance</td>
</tr>
</tbody>
</table>

**Over all project summary**

| Total investment: | $17M |
| Net Present Value (NPV) of benefits: | $26M |
| Project time span: | 3 years |
| Return On Investment (ROI): | 188% |
| Payback period: | 11 months |

*Indirect (soft) benefits are risk adjusted to 10% of original value before calculating ROI.
2.1 Auto-ID Technology

Klaus, (2010), presented the Automatic Identification and Data Capture (AIDC) technologies are used for automatically identifying objects, data collection, and to transmit that data directly in to computer systems without human intervention. AIDC include the following technologies such as bar codes, biometrics, Optical Character Recognition (OCR), smart cards, and Radio Frequency Identification (RFID), (Su et al., 2007) as shown in Figure 2.1.

![Figure 2.1: Important Auto-ID technologies (Klaus, 2010)](image)

Automatic identification (Auto-ID) technologies are very popular at present; it provides information about, people, animals and items in transit. Among these identification technologies, barcode is the most widely used technology, because it has very low cost but it has some deficiencies i.e. (low storage capacity and cannot be reprogrammed and it need to be very close to optical reader for scanning).

However the RFID technology is superior to barcode technology because its user does not need to know where an object is and does not need to get close to scan it (Konsynski & Smith, 2003). Since RFID tags can be read at a distance and do not require line-of-sight, it can provide more applications across a supply chain; which holds a promise of significantly improving business operational efficiencies and increasing the visibility of business objects. It also reduces inventory and shrinkage.
Stanton, (2005) presented that the tags are just high-tech barcodes, attached to items to allow them to be tracked through the supply chain and make life easier at supermarket checkouts. The other technologies are either lack of automation capability or lack of ability to attach to business object.

A unified EPC and ISO, globally interoperable RFID standard is an ideal to earn the full benefits of RFID applications (Baars et al., 2008). But due to the lack of a complete security, privacy and unified RFID standard issues, it has caused many people and companies to hesitate in adopting the RFID system (Stanton, 2005, Jungbae et al., 2009).

2.2 Shrinkage

The one of the major issues in the supply chain management is product loss or shrinkage. Radio-Frequency Identification (RFID) as an emerging technology has generated tremendous amount of interest in the supply chain domain to reduce the shrinkage. The shrinkage is the difference between recorded and actual inventory (Elshayeb et al., 2010). The loss of inventory is caused by some factors, including employee theft, shoplifting, administrative error, vendor fraud and damage in transit or in store and cashier errors that benefit the customer. According to the National Retail Security Survey, conducted by the University of Florida, shrinkage in the United States during 2009 represented 1.44% of retail sales (A. Kok et al., 2008). This percentage amounts to billions of dollars in lost inventory each year for U.S. retailers. Thus, security guards, security tags and cameras are used by retailers as an effort to reduce shrinkage.

2.3 Radio Frequency Identification (RFID) Systems

The RFID has become an integral part of our life. It increases productivity and convenience. It has been used in many applications such as preventing theft of automobiles and other commodities; tolls collection without stopping; managing traffic; control entrance into buildings; automating parking; controlling access of vehicles, corporate campuses and airports; distributing goods; providing ski lift access;
tracking library books; to track assets in supply chain management (Landt, 2005, Sabbaghi & Vaidyanathan, 2008) describing the modality of this system. Dressen, (2004) mentioned that this system works on different radio frequencies such as LF, HF, UHF and Microwave based on its nature of utility. RFID has five basic components such as tag, reader, antenna, middleware and application software (Chuang & Shaw, 2007, Ahsan et al., 2010). The working principle of an RFID system as an electronic data carrier device “tag” is physically attached to the object having unique ID that is to be identified. In a remotely application, RFID reader transmit radio wave signals through antenna. Tags in the range of radio wave at a distance attached to the objects will transmit response back through an attached antenna to identify the object instantaneously (Asif, 2005). Then the collected data transmit to communication infrastructure (middleware) which update the information, finally sends information to the enterprise application according to the business requirements (Ahmed et al., 2014) as shown in Figure 2.2.

![Typical RFID System](Hasnan, et al., 2013)

RFID helped millions of people around the world to protect their property and make their workplaces secure. Its need for privacy issues that technology solves through this viable system has also been realized (Stanton, 2005).

Ilie-zudor et al., (2006), has explained the overview of principles of the RFID technology, tags and readers, commonly used frequencies and identifier systems,
current and predicted fields of application, as well as advantages, concerns and limitations of use explained. It is further advised that the RFID needs to be standardized in order to large-scale usage in the retail supply chain; this process is currently in progress. On the global front, two international bodies are involved: EPCglobal™ (www.epcglobalinc.org) and the International Organization for Standardization (ISO) (www.iso.org) (Loebbecke, 2005).

Due to the numerous advantages of RFID systems as compared to other identification systems, RFID systems have super seated the mass markets.

The RFID system is divided into two layers as shown in Figure 2.3.

i. Physical layer

ii. IT layer

Figure 2.3: RFID system layers (Karmakar, 2010)

2.3.1 Physical Layer

The physical layer comprises tag (transponder), reader (interrogator), and questioning zone or interrogation zone (IZ).

1. Tag (transponder)
Tag is a microprocessor chip, consists of an integrated circuit with memory and antenna. It is similar to the optical barcodes, which are attached to the items or case having unique identification. It can be grouped in to basic categories are Power source, memory type, operating frequencies, functionality, protocol, energy transfer and communication. It may be active (battery powered and proactively radio frequency signal) or passive (unpowered and reactively emitting a radio frequency signal). Bhattacharya et al., (2011), proposed that the information about object could be serial No; Model No. or other characteristics of object for identification purpose and distinguish from others or to track the movement of object e.g TAG = [Type of product | Subtype | Product-ID | Position | Date]. Various tags according to different application requirements are shown in Figure 2.4.

![Figure 2.4: Various RFID Tags (Ahmed et al., 2013)](image)

**II. Reader (interrogator/transceiver)**

RFID reader is a device which talks to tags. A reader may support one or more antennas; it can read and /or write data to an RFID tag (Su et al., 2007, Ngai et al., 2008, Grillmayer, 2013). Its types are hand held, vehicle mounted, post mounted and hybrid. The interfaces that connect the reader with the host computer are one or more
of the following: USB, Ethernet, Wi-Fi, RS232, RS485, PCMCIA, and Compact Flash etc Su et al., (2007). Readers basically contain two components: the antenna and the interrogator circuitry. The antenna is used for communication with the tag using electromagnetic waves. Whereas the interrogator circuitry is a channel or negotiator between the reader antenna and the IT layer. Interrogator circuitry performs the task of sending data through the reader antenna and also receiving data and then sending it to the back end for processing. Interrogator circuitry also carries out an action of coordination between different reader antennas for the efficient and successful reading of tags.

III. Interrogation Zone (IZ)

According to Karmakar, (2010), the interrogation zone is the Euclidean space (three-dimensional physical space) between reader and tag where the electromagnetic (EM) wave is used for communication activity of reader reads/writes data from/to a tag. The basic characteristics of interrogation zone are defined in detail as follows.

2.3.2 Electromagnetic Propagation (Transmission)

According to Hunt et al., 2007, Brown et al., 2007, Thornton & Sanghera, 2011, an electromagnetic wave propagates in the direction to the right angles with the vibrating electric and magnetic field vectors. It carries energy from its base station radiation source “RFID reader” to the tag. Figure 2.5 shows that the electric and magnetic fields are perpendicular to each other.

All electromagnetic waves travel at the same speed in vacuum, at the speed of light, 299,792,458 meters per second (m/sec). The speed of light is denoted by the lowercase letter \( c \) and is usually approximated to \( 3 \times 10^8 \) m/sec is used for all calculations.
The relationship of speed of electromagnetic waves \((c)\), with frequency \((f)\) and wavelength \((\lambda)\) is as follows:

\[
c = \lambda \times f
\]

As electromagnetic waves travel in 3D space, the same power is dispersed in all radial directions of the surface of sphere. The power density reduces as the wave travels away from the source. This phenomenon is called \textit{path loss}. Figure 2.6 shows a transmitter antenna \(T_X\) at the center of a sphere and a receiver antenna \(R_X\) at the surface of the sphere. The distance between the two antennas is \(\text{“}d\text{”}\) and the effective area of the receiver antenna is \(A\).

\[
Path\ Loss = \frac{R_X\ effective\ area}{total\ area\ of\ sphere} = \frac{A}{4.\pi.d^2}
\]

The power density \((PD)\) of a radio wave at a distance \((d)\) from its source is inversely proportional to the square of the distance, or power attenuates with the square of the distance.

Mathematically \(PD \propto 1/d^2\).
2.3.3 Electromagnetic Waves (Radio Waves)

According to Dobkin, (2008) Radio waves are part of the electromagnetic spectrum. It has longest wavelength in the entire electromagnetic spectrum. The range of radio waves available at different frequencies bands include \{LF (30kHz-300 kHz), HF (3MHz - 30MHz), UHF (300MHz - 1000MHz) and Microwave (1GHz - 6GHz)\}.

RFID technology uses the radio waves among the available frequencies from LF (125 kHz -134 kHz), HF (13.56 MHz), UHF (433 MHz & 860 MHz -960 MHz) and Microwave (2.4 GHz to 5.8 GHz) as shown in Figure 2.7.

Figure 2.6: Electromagnetic wave path loss in free space (Dobkin, 2008)

Figure 2.7: Electromagnetic wave (Dobkin, 2008)
An RFID system is working on different operating frequencies according to the region of the world located, as shown in Figure 2.8.

The selection of operating frequency of RFID readers and tags for specific application depends upon various parameters to be considered. These parameters are maximum read range (especially for passive tags), reading speed, sensitivity to water and humidity etc. Application of different operating frequency bands are illustrated in Table 2.2.

When the radio waves travels in the medium, their signals are attenuated in different ways according to the objects properties in their path. The attenuation of signal strength is called path loss. The propagation of original signals will vary in their strength due to the objects in their path than the resultant (signal strength) received is reduced.

Figure 2.8: Summary of worldwide UHF band allocations (Dobkin, 2008)

Table 2.2: Application of operating frequencies in RFID system (Curtin, 2007)
<table>
<thead>
<tr>
<th>Frequency band</th>
<th>Description</th>
<th>Operating Range</th>
<th>Applications</th>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>(125-134) KHz</td>
<td>LF</td>
<td>&lt;0.5m or 3 ft</td>
<td>Access Control, Animal Tracking, Vehicle immobilizers, Product authentication, POS applications</td>
<td>Work well around water and metal products</td>
<td>Short read range and slower read rates</td>
</tr>
<tr>
<td>13.56 MHz</td>
<td>HF</td>
<td>&lt;1 m or 3 ft</td>
<td>Smart card, Smart shelf tags for item level tracking, Library books, Airline baggage, Maintenance data logging</td>
<td>Low cost of tags</td>
<td>Lower read range than UHF</td>
</tr>
<tr>
<td>433 MHz</td>
<td>UHF</td>
<td>(1–100) m or 300 ft</td>
<td>Defense applications, with active tags</td>
<td>Larger read range</td>
<td>Higher tag cost</td>
</tr>
<tr>
<td>(860-930) MHz</td>
<td>UHF</td>
<td>3m or 9.5 ft</td>
<td>Pallet tracking, Cartoon tracking, Electronic toll collection, Parking lot access</td>
<td>EPC standard built around this frequency</td>
<td>Does not work well around items of high water or metal contents</td>
</tr>
<tr>
<td>2.4 GHz</td>
<td>Microwave</td>
<td>1m or 3 ft</td>
<td>Airline baggage, Electronic toll collection</td>
<td>Fast read rates</td>
<td>Most expensive</td>
</tr>
</tbody>
</table>

The signal strength quality and level is very important in the RFID system designing and application. It is measured in dBm or mW. It depends upon the distance between the transmitter (Tx) and receiver (Rx) (Dobkin, 2008). The power in dBm is the 10 times the logarithm of the ratio of actual Power/1 milliWatt.

The formulas are used to measure power in dBm and power in watt as follows.

\[
P_{(\text{dBm})} = 10 \cdot \log_{10}(\text{P(W)} / 1\text{mW})
\]

\[
P_{(\text{W})} = 1\text{W} \cdot 10(P_{(\text{dBm})} / 10) / 1000
\]

Where

- \( P_{(\text{dBm})} \) = Power expressed in dBm (decibel milliatts)
- \( P_{(\text{W})} \) = the absolute power measured in Watts
- mW = milliWatts
- \( \log_{10} = \log \) to base 10

The power calculated in dBm and milli-watt is shown in Table 2.3

Table 2.3: Power comparison in dBm and mW
The negative number is representing small value but it shows positive number on a logarithmic scale. In logarithms, the value indicated represents an exponent. for example, under a log 10 scale, a value of -1 represents 10 to the -1 power, which equals to 0.1. Similarly a value of -2 represents 10 to the -2 power, which equals to 0.01. In similar manner, a negative dBm means that a negative exponent in power calculations; 0 dBm equals 1 mW of power, so -10 dBm equals to 0.1 mW, -20 dBm equates to 0.01 mW, and so forth. a weak signal as -100 dBm equal to 0.000000001 mW.

Radio signal propagates in the RFID system and is used as free space propagation. It is the short range communication system (Brown et al., 2007). For economic and technical reasons, the standard of spectrum is harmonized worldwide for regulating various aspects of radio spectrum use. There are two types of communication methods in RFID system relative to the frequency of operation and distance between reader and tag are near field or inductive coupling and far field or backscatter coupling (Karmakar, 2010).
2.3.4 Near-Field/Inductive Coupling

Coupling is the full duplex communication or transfer of EM energy between reader and tag (Want, 2004). Near field is the three-dimensional space surrounded by an antenna, where the plane wave has not yet fully developed it is separated from the antenna. The magnetic field strength attenuates as inverse cube of the distance ($\propto 1/d^3$). The distribution of waves in near field is fairly omni-directional, and the magnetic field strength is translated in to power available to the tag, the power attenuates is inversely proportional to the sixth power of the distance ($d$) from the antenna ($\propto 1/ d^6$). The energy transfer through shared magnetic field and frequencies of operation used are LF and HF of RFID tags (Brown et al., 2007). The boundary limit of near field communication or the range of outer edge depends upon frequency of operation and size of antenna. The transmission of energy fluctuates by change of current flow through “inductive coil.” in one device that induces current flow in the other device in a “push–pull” manner, and the antenna used as a transformer (Karmakar, 2010). The applications of RFID near field are item tagging, animal tagging, and library database management system etc.

2.3.5 Far-Field/Backscatter Coupling

The area in the three-dimensional space beyond the near field is called “far field”. The communication between tag and reader takes place by EM radiation backscatter coupling (Want, 2006). EM energy is continuously transmitted “away” from the antenna in a radial manner and the power drops, obeying the inverse square law of distance ($d$) from the antenna ($\propto 1/d^2$). The EM energy transmits from the reader’s antenna and encounters the tag’s antenna, where it is reflected or absorbed depending on the tag antenna’s radar cross section (RCS) or reflection cross section. If the tag is terminated with a matched load, almost no energy is reflected back, whereas if the tag has an open/short-circuit termination, most of the energy is transmitted back (Karmakar, 2010). The tag IC, depending on the data to be transmitted to the reader, switches between a load and an open/short circuit and thus controls the reflected EM wave. This technique of changing RCS of the tag antenna is called the “antenna load modulation.”
This reflected EM wave, which is much smaller in magnitude compared to the incident wave, is detected at the reader antenna by means of a directional coupler/circulator and then amplified, decoded to extract the data sent by the tag. This kind of communication is prevalent in the UHF and microwave frequency ranges of passive RFID tags (Brown et al., 2007). The communication efficiency depends on the size of antenna. If the largest physical linear dimension of antenna is greater than the wavelength, it will be the much higher efficient as compared to inductive coupling. It is found that if increase the power level consequently the communication read range increases between reader and tag.

The region between the reactive near field and the far field is a transition region and is known as the “radiating near field (or Fresnel region)” where the reactive field becomes smaller than the radiating field. All three field regions are summarized in Table 2.4 and shown in Figure 2.9 (Huang & Boyle, 2008).

Table 2.4: Conditions of Near-field and far-field region (Huang & Boyle, 2008)

<table>
<thead>
<tr>
<th>Antenna size $D$</th>
<th>$D &lt;&lt; \lambda$</th>
<th>$D \approx \lambda$</th>
<th>$D &gt;&gt; \lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive near field</td>
<td>$d &lt; \lambda / 2\pi$</td>
<td>$d &lt; \lambda / 2\pi$</td>
<td>$d &lt; \lambda / 2\pi$</td>
</tr>
<tr>
<td>Radiating near field</td>
<td>$\lambda / 2\pi &lt; d &lt; 3\lambda$</td>
<td>$\lambda / 2\pi &lt; d &lt; 3\lambda \text{ and } 2D^2/\lambda$</td>
<td>$\lambda / 2\pi &lt; d &lt; 2D^2/\lambda$</td>
</tr>
<tr>
<td>Far field</td>
<td>$d &gt; 3\lambda$</td>
<td>$d &gt; 3\lambda \text{ and } 2D^2/\lambda$</td>
<td>$d &gt; 2D^2/\lambda$</td>
</tr>
</tbody>
</table>

Where

$D =$ Maximum linear dimension of antenna in (m)

d = Radial distance from (reader to tag) antenna in (m)

$\lambda =$ Wavelength of radiated signal in (m)
2.3.6 Link Budget and Read Range

Link budget calculation in wireless communications specifies the power budgeting for the transmitter and receiver, the antenna gain, and effective isotropic radiated power (EIRP) of the reader antenna to obtain a certain link distance (reading range). The link budget helps to calculate the required antenna gain and related specification to obtain a robust and viable communication in the specific conditions of wireless communications. The communication from the reader to the tag is called the “downlink” and the communication from the tag to the reader is called the “uplink”.

Therefore, the link budget is a calculation used to specify the read range in any RFID system. It encounters all the losses and gains taking part in the communication.
and thereby, depending on the sensitivity of the components, determines the distance at which reliable communication can take place between the tag and the reader in any RFID system. Factors like noise floor, cable losses and free space losses are taken into account in calculating the link budget (Brown et al., 2007, Karmakar, 2010).

2.3.7 Path loss propagation Model

In every RFID system it is important decision to select path loss propagation model. It is defined as the difference between the transmitted power form source antenna and the received power at receiver antenna. The propagation model can calculate the estimation of coverage area of RFID reader accurately.

The signals are attenuated by the distance between the reader and tag, interference from adjacent readers and obstacles in the system. The most common path loss propagation models and their parameters are shown in Figure 2.10.

These models are grouped on the basis of downlink or the uplink communication channels. For the downlink channel the free space, two-ray and multipath models are used. These same path loss propagation models can be used for uplink channel and in an addition of the radar cross section (RCS) model used for more precise calculations. The each type of path loss propagation model is described as follows.
2.3.8 Free space propagation Model

The communication between Tx antenna and Rx antenna in Free Space (FS) propagation model takes direct Line of Sight (LoS). The FS propagation model is desirable for outdoor RF communications without obstacles in the environment. It also can be used in an indoor environment in the far-field region. The signal power at the receiving antenna is calculated by *Fris's transmission equation* as shown in equation.

\[ P_r = P_t \times G_t \times G_r \times \left(\frac{\lambda}{4\pi d}\right)^2 \]

\[ d = \frac{c/f}{4\pi\sqrt{P_r/P_t \times G_t \times G_r}} \]

Where

- \( \lambda \) = signal wavelength (m)
- \( c \) = Speed of light (m/s)
- \( f \) = operating frequency (Hz)
- \( P_r \) = received signal strength (W)
REFERENCES


Dominikus, S., & Schmidt, J. (2011). Connecting passive RFID tags to the Internet of Things. *Interconnecting Smart Objects with the Internet*, 1–3


