Integration of Radio Frequency Identification and Wireless Sensor Networks

Shiva Mirshahi

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Electrical and Electronic Engineering

Eastern Mediterranean University
January 2013
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Prof. Dr. Aykut Hocanın
Chair, Department of Electrical and Electronic Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Prof. Dr. Şener Uysal
Supervisor

Examining Committee

1. Prof. Dr. Şener Uysal
2. Assoc. Prof. Dr. Hasan Demirel
3. Asst. Prof. Dr. Rasime Uyguroğlu

ABSTRACT

Radio frequency identification (RFID) system is used for detecting and identifying the tagged objects by electromagnetic signals. The main components of RFID are tag (transponder), reader (transceiver) and a host computer. RFID can be implemented in wide applications such as supply chain, car access, animal tracking and smart cards.

Wireless sensor network (WSN), which consists of a huge numbers of nodes, can monitor the condition of the environment including pressure, humidity, and temperature. The data are transferred via nodes to a certain location. Some applications of WSNs are in monitoring of earth, supply chain, agriculture, structural health monitoring and localization.

Integration of RFID and WSN provides a new feature and improves their functionalities. In RFID systems each tag can only communicate with a reader but integrating RFID tags with nodes, communication of the RFID tags with each other is possible and by integrating readers with nodes, readers can communicate with each other, too.

The integration of RFID and WSN in supply chain provides system intelligence. In such a case, tag is embedded in objects and reader is integrated with nodes. Therefore, identification and detection of tagged items is provided by using RFID and monitoring of environment can be obtained by using WSN.

To conclude, the present case study is simulated in Petri Net Toolbox in MATLAB environment. It represented the negotiation of smart devices spontaneously in managing variety of instructions in order to enhance system performance such as productivity and efficiency. Moreover, the impact of smart nodes has been integrated for managing different automated guided vehicle (AGVs) to load or unload products to the relevant destinations. In other words, smart nodes satisfied the utilization rates related to different devices.

Keywords: Radio frequency identification, wireless sensor network, integration of RFID and WSN, supply chain management, Petri net

ÖZ

Radyo Frekans Tanımlama (Radio Frequency Identification, RFID) Sistemi, elektromanyetik sinyaller ile etiketlenen objelerin belirlenmesi ve tanımlanması için kullanılmaktadır. RFID sisteminin ana bileşenleri, etiket (transponder), okuyucu (alıcı) ve bir host bilgisayardan oluşmaktadır. RFID sistemi, tedarik zinciri, araç erişimi, hayvan izleme ve akıllı kartlar gibi birçok uygulama alanında kullanılabilmektedir.

Çok sayıdaki düğümlerden oluşan Kablosuz Sensör Ağları (Wireless Sensor Netwroks, WSN), basınç, nem oranı ve sıcaklık olmak üzere çevre koşullarını izleme uygulamalarında kullanılabilmektedir. Elde edilen bilgiler sensör düğümleri tarafından belli bir noktaya transfer edilmektedir. Kablosuz sensör ağları, dünya izleme sistemleri, tedarik zincirleri, tarım, yapısal sağlık izleme ve lokalizasyon sistemleri gibi alanlarda kullanılmaktadır.

RFID ile kablosuz sensör ağlarının entegrasyonu yeni bir geleceğe kapı açmakta ve bu sistemlerin işlevselliklerini iyileştirmektedir. RFID sistemlerinde her bir etiket yalnızca bir okuyucu ile iletişim kurabilmekte iken, RFID etiketleri ile kablosuz sensör düğümlerinin birleştirilmesi RFID etiketlerinin birbirleri ile iletişim kurmalarına olanak sağlamakta ve okuyucular ile etiketlerin birleşimi sonucunda ise okuyucular da birbirleri ile iletişim kurma özelliğine sahip olacaklardır.

RFID ile kablosuz sensör ağlarının tedarik zincirlerinde birleşmesi ise sistemin akıllı sistem kimliğine sahip olmasını sağlamaktadır. Böyle bir durumda etiketler objelere

yerleştirilmekte ve okuyucular ise düğümlere entegre edilmektedir. Dolaysıyla etiketlenen faktörler RFID yardımı ile belirlenip tanımlanacak ve çevresel koşullar kablosuz sensör ağlarından yararlanılarak izlenecektir. Bu çalışmanın simülasyonu MATLAB, Petri Net Toolbox yardımı ile gerçekleştirilmiştir. Çalışmada sistem performansının arttırılması amacıyla akıllı cihazların çok çeşitli talimatların yönetimindeki otomatik iletişimi temsil edilmiştir.

RFID ile kablosuz sensör ağları entegre edilerek iki yapısal sağlık izleme yöntemi tanımlanmıştır. İlk yöntem olan sensör ile pasif-etiket entegrasyonu bina yapılarının izlenmesi için kullanılmıştır. İkinci yöntem olan etiket ile düğüm entegrasyonu ise köprülerde yapısal sağlık izleme uygulaması için kullanılmıştır.

Anahtar Kelimeler : Radyo Frekans Tanımlama, Kablosuz Sensör Ağları, RFID ile Kablosuz Sensör Ağlarının Entegrasyonu, Tedarik Zinciri Yönetimi, Petri Net

To My Family

My Father and Mother

My Beloved Sisters Shamim and Shadi

My Cute Nephew Artin

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the many individuals who have supported me in my studies for the Master Program in Electrical and Electronic Engineering. I wish to acknowledge first and foremost the instruction and hard work of my thesis supervisor, Prof. Dr. Sener Uysal. Without his guidance and support in giving feedback, this thesis would have been impossible.

I would like to express my deepest appreciation to Aliakbar Akbari for providing invaluable assistance and would like to thank Mohsen Jafari for his valuable support.

My especial thanks also go to my beloved family members; my kind-hearted parents, and my sisters for their strong support and encouragement during my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ABBREVIATIONS

ADC	Analog-to-Digital Converter
AGV	Automated Guided Vehicle
ASK	Amplitude Shift Keying
ASRS	Automated Storage and Retrieval
BER	Bit Error Rate
CoBIs	Collaborative Business Items
DC	Direct Current
EPC	Electronic Product Code
FSK	Frequency Shift Keying
GID	General Identifier
GPS	Global Positioning System
HEMS	Real-time Health Monitoring System
HF	High Frequency
ID	Identification
ISO	International Organization for Standardization
ISM	Industrial, Scientific and Medical
LAN	Local Area Network
LF	Low Frequency
LLC	Logic Link Control
MAC	Media Access Control
PC	Personal Computer

PDA	Personal Digital Assistant
POW	Power Optimized Waveform
PSK	Phase Shift Keying
RF	Radio Frequency
RFID	Radio Frequency Identification
ROM	Read-Only Memory
SAW	Surface Acoustic wave
SHM	Structural Health Monitoring
SMP	Sensor Management Protocol
UHF	Ultra High Frequency
Wi-Fi	Wireless Fidelity
WSN	Wireless sensor network

Chapter 1

INTRODUCTION

1.1 Introduction

Radio Frequency Identification (RFID) is a technology for identifying objects or humans automatically with the use of radio waves. The main components of RFID are the tag, reader and asset master. In this technology each product has a unique ID. The supply chain, access control and security are some of the application areas of RFID [1].

Wireless sensor network is a technology to cooperate in a network with the use of nodes and applied for monitoring environmental conditions. Processing part, memory, RF transceiver, power source, actuator and sensors are the parts of a node. Some of WSN's application areas are medical, transportation, smart spaces, and defense [2].

By using RFID and WSN four types of applications can be introduced: identifying process with the use of RFID and sensing by WSN, identifying with use of RFID and WSN, identifying with use of RFID and localization by WSN, as well as assist positioning with the use of RFID and WSN for estimating the position [3].

RFID technology is single hop and WSN is multi-hop. Therefore, new applications can be obtained by integrating them. There are four types of integration which are described as follows:

- Sensors with RFID tags,
- Cordless appliance and nodes with tags,
- Cordless appliance and nodes with readers,
- Combine of sensors and RFID [3].

An intelligent supply chain management system is presented by applying smart nodes which provides integration of RFID with WSN. In this case, RFID is used for identifying the type of products in the warehouse and WSN for monitoring the environment of the products. Therefore, the warehouse is managed without manual instruction. Moreover, a case study is going to be applied and simulated in the Petri Net Toolbox in order to display the system performance.

1.2 Outline of the Thesis

The current study consists of the following subjects:

RFID system and WSN are discussed in detail in Chapter 2. Chapter 3 investigates the methods of integration of RFID and WSN. The advantages and applications of integration of RFID and WSN are also introduced. Chapter 4 explains the methodology of the thesis. Chapter 5 discusses two scenarios with petri net simulation. Finally, Chapter 6 gives the conclusions and future work.

Chapter 2

LITERATURE REVIEW

Many applications of RFID and Wireless Sensors Networks (WSN) in diverse areas including intelligent transport vehicles, defense, environmental monitoring and forecasting such as air pollution monitoring, structural health monitoring, intelligent home, and warehouse management were offered [4].

The integration infrastructure of WSN and RFID system with a network was dedicated. Furthermore, the architecture framework of Electronic Production Code (EPC) global sensor network was proposed aiming to establish the infrastructure of global network which is able to aggregate various data [5].

However, RFID and WSN integration was developed by [3]. This research strives to elaborate accurate traceability of different objects by means of RFID which are not conveniently identifiable by applying ordinary sensors. Notwithstanding the fact that the condition of items cannot be monitored by RFID, the environmental condition as well as condition of items can be achieved by sensor nodes. To address these issue, both RFID system and WSN are applied together to overcome some difficulties in industrial environment.

The implementation of active RFID with wireless mesh sensor network was discussed in industrial automation as an automated monitoring system with the purpose of decreasing maintenance expenses, enhancing manufacturing efficiency, and reducing failures of devices. The 2.45 GHz contactless active RFID system was considered to extend rang of tags detection for real time monitoring system [6].

The importance of integration of radio frequency identification and wireless sensor network was distinguished. By RFID technology, detection and identification of objects can be obtained, but condition of them cannot be provided. Therefore, environmental condition of products could be prepared by applying WSN. Types of integration and application of each patent were discussed in [3].

Some schemes of integration of WSN and RFID were represented in detail. Three architectures of them were emphasized as follows:

In the first one, sensor node works a part from tags. A smart base station is introduced to manage nodes and tags for working better and collects information from both networks. Smart base station consists of reader, microprocessor and network connection. In the second one, the number of readers increased and integrated with a sensor node. Result device is called smart node. The information is sent via multi-hops. The final architecture is mixed of active tag and WSN node which is known as smart sensor tags. In this case message of tag can send to other tags. Therefore, the message does not correspond to reader directly and transfer between tags until receiving final object [7].

Technologies of ubiquitous computing which are technologies of connection between physical space and information space were introduced. WSN and RFID system were named as the most important ubiquitous computing technologies. The difference between RFID and WSN were considered. The architecture (sensors, applications, tags and etc.) of sensors mixed EPCglobal network is investigated. Also, different kinds of integration of RFID and WAN were elaborated to purvey an easy tool for communication. Five architectures of identification and sensor information integration were introduced. Integration of RFID and sensor were categorized as logical and hardware integration. Application of them in healthcare, logistics, and aerospace health management was considered very carefully. Sensor tags technologies were divided into fixed and variable function [8].

The RFID, which is usually used in the management system of supply chain, can be applied for application of WSN [9].

Identifying is performed by RFID and sensing is accomplished by WSN. In this case, RFID and WSN are allocated in the same item. It can be applied for PH value in dentures to determine the level of alkalinity and acidity of meal [10].

The sensor tag was introduced for sensing vibration which works in frequency of 2.4 GHz. Its range is about 100 m with battery life of 4 years [11].

The status of machines can be monitored by Smart sensor nodes and health information is aggregated in the tag's memory of RFID [12].

Sensor Embedded radio frequency identification (SE-RFID) is recommended to improve ability of RFID in sensing. In this study, two architectures for SE-RFID were presented. The use of SE-RFID in real time health monitoring system (HEMS) was highlighted. Its applications includes monitoring, recognizing the medical condition and etc. for patients with persistent and acute illness. Temperature, heart-beat rate, blood pressure are some crucial factors which can be sensed by SE-RFID [13].

Healthcare system for in-home elder was designed in order to medication intake of patients which can be monitored by means of UHF and HF RFID and sensors. Compatibility of sensor network with RFID technology was simulated and perused [14].

Techniques of indoor navigation were taken into account. Regarding several problems, GPS cannot be applied in this case. By using gyroscopes and accelerometers sensors, the responder in a building is capable to track and tags, which were located in the certain position, can indicate the correct position [15].

Technology of RFID sensing networks and Auto ID labs were pointed out. Physical objects network can attach a tag to each objects is called RFID label. Physical parameters can be monitored with integrated sensor with RFID label. Each label can be identified by the unique EPC code. Therefore, EPC Network consists of sensor, tag, reader and network infrastructure. It can be uses in patients' heart monitoring [16].

Architecture of smart wireless sensor and RFID was also demonstrated that sensor, micro controller, central control unit and RFID became parts of this system [17].

Developing application of RFID system with applying sensors was highlighted. Two challenges were mentioned. First, sensor does not provide any power until tag is not in the radio frequency field to communicate with reader. Second, when energy is used for sensor, the reading range decreases. Monitoring the temperature in the transmission of frozen chicken was discussed as well. Another significant application is monitoring the acceleration of computers, glassware and artwork to prevent from damages. Detecting harmful agent, non-invasive monitoring and tempers of products automatically was also represented [18].

CoBIs-developed tag was introduced for monitoring the environmental conditions and in critical situation alarms makes warning. Each tag integrated with accelerometer sensor. These tags have a reading range of 3 meter. Wireless transceiver is used for storing business roles. Each tag can communicate with each other. It can apply in the location which can store certain volume of chemicals for preventing to store reactive chemicals close to each other. Wider corporate network is obtained for nodes communication through the base station [19].

RFID impulse was proposed to reduce the energy consumption in wireless sensor networks. In this case, tag is embedded to the sensor node. Multicast and unicast is obtained by applying RFID impulse [20].

Multiple RFID tag shows that each node can read the RFID tag and send information to the sink which is defined as a central node. The sink transmits it to the PC for analyzing the obtained data. With use of this method tags’ data can be gathered from a point. The nodes guide the data to the correct destination [21].

A method for automated management of inventory was discussed. It decreases the cost and time. Architecture consists of a node connected to the host and a node integrated with a reader of RFID [22].

An RF-powered tag which is equipped to sense photo and temperature. It can also be used for monitoring of environment. Power of tag is obtained from external ISM (860-960 MHz) band RF signal. The tag acts in three ways: ready, interrogating as well as active states. Clock generator starts working by placing the tag in RF field. This state is called ready state. When base station demands, interrogation state of tag is started and both decoder and demodulator enable ROM block or one of the sensors. Moreover, active state is started since the selected functional block is activated and the intended information is transferred to the gateway. Then, automatically state of tag goes to ready mode [23].

A solution was offered to improve read range of passive tag for sensor networks. It also provides divided micro strip antenna and raises the DC voltage of circuit. Temperature monitoring system at 2.45 GHz band is created to indicate credibility of designed tags for improving the range longer than 9 m [24].

KSW can measure temperature alternating which measurement interval can be adjusted. It has capability to link to the objects. For instance, it can be applied for frozen chickens that can taint to salmonella in high temperature [3].

Therm-Assure-RF is a semi-passive tag with a sensor. It can monitor cold chain. It is used for products which change in temperature over time during shipping as well as long storage. It is credit card size collecting temperature information of place. It recovers threshold which is programmed by software application. It can be applied as an appropriate kind of tag in tracking inventory of whole system [3].

Dot technology, which contains three antennas and 3 radios in a chip, handles some applications such as manufacturing, government, military and education. It can be used for passive RFID product tags, real time location system and access control badges [3].

Chapter 3

RADIO FREQUENCY IDENTIFICATION AND WIRELESS SENSOR NETWORKS

3.1 Radio Frequency Identification

Radio frequency identification (RFID) uses electromagnetic field of radio frequency for automatic identification of objects with a unique ID number which is stored in the attached tag [1].

Both RFID and barcode systems have the same goal; identifying objects without human intervention. However, barcode has some disadvantages which have been solved by RFID system:

1. Barcode readers need a straight line of sight scanning.
2. Each barcode device should be read one by one.
3. Barcode reader cannot read damaged labels.
4. Only the type of objects can be identified.
5. Barcodes do not provide updating option in new process in the label.
6. In barcode system traceability should be performed by implementers. Thus, some problems may arise [25].

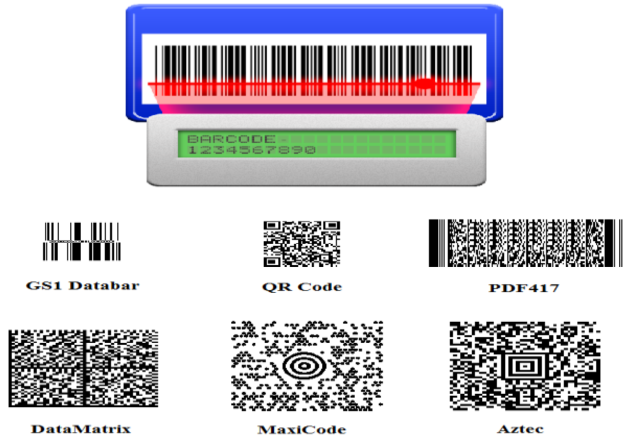


Figure 3.1: Barcode Examples [25]

3.1.1 Components of RFID System

RFID system consists of three important parts: the transponder (tag), the transceiver (reader), and the application software.

3.1.1.1 RFID Tag

RFID tags are attached to the objects and have two components: the first component refers to the antenna, which determines the reading range of RFID and transmits the data to a reader, and the second one is the microchip which stores the data.

Based on the storage, RFID tags can be categorized into *Read-write tags* where information can be stored or read from its chip, and *Read -only tag* which is written once in the manufacturing company and can be read many times [26].

Figure 3.2: Components of an RFID System

Table 3.1: Illustration of the RFID Working Principles and Comparison of RFID Chips

Types of RFID chips	Passive	Semi-Passive	Active
characteristics	No battery	Battery integrated into the chip with an active transmitter and receiver. Generally equipped with sensors	Batteries but no transmitter. Often equipped with sensors
cost	5/10 Euro cents	Afew Euros	around one Euro
Range	10 cm to few meters	Hundreds of meter	Hundreds of meter
Life	Unlimited	1-5 yrs battery life	1-5 yrs battery life

There are three main types of RFID tags which are classified based on their power sources as passive, semi-passive or battery-assisted passive, and active.

Passive tag does not provide any battery inside, so it obtains enough power from the carrier wave that is sent by the reader. The typical read- range is about one meter. Passive tag uses backscattering for communicating with the reader [26, 1].

Figure 3.3: Some Common Forms of RFID Applications [26]

Another kind of tag that applies this technique is the Semi-passive tag, but the tag circuitry is powered by the battery which results in a longer range than the passive tags.

Active tags have their own transmitters so the read range is much better (about 100 meters), but it is the most expensive.

Construction format of the tags are:

- Disk and coins
- Glass housing
- Plastic housing
- Tool and gas bottle identification
- Key and key fobs
- Clock
- Id.1 format, contactless smart card
- Coil-on-chip [26]

3.1.1.2 RFID Reader

The RFID reader is a device for reading and writing in the tag. Reader introduces two main functional blocks: HF interface and control system with transmitter and receiver.

Duties of HF interface are:

- High frequency forwarding power for activating the tag and supply its needed power.
- Transmission signal is modulated to transfer data to the tag.
- Tag sends HF signals which are received and demodulated by the HF interface.

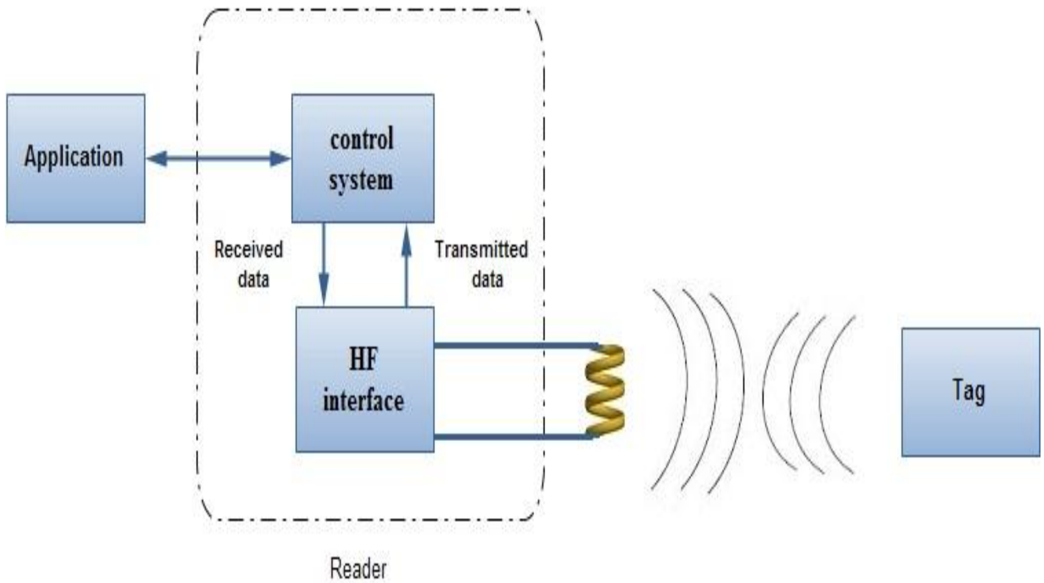


Figure 3.4: RFID Block Diagram Showing the Main Units

There are two independent ways of transmission, one of them is for sending the data to the tag and the other one is responsible for receiving the data from the tag. The data are transferred to the tag through the transmitter arm. Reversely, the data are received through the receiver arm [26].

Duties of the control unit:

- Control unit communicates with the application software and preforms its command.
- Communication between the reader and tag is controlled by this part (same principle as master and slave).
- Coding and decoding the signal are other functions of the control unit.
- In some cases, anti-collision algorithm is executed by the control system.

- The data decryption and encryption which are sent between the tag and the reader are performed by the control unit.
- Verification performance between the reader and the tag is accomplished by the system unit.

Microprocessor of the control unit fulfills its complex duty.

3.1.1.3 Application Software

The application software is used for computing and processing [26].

3.1.2 Hardware of Passive Tag

Alternating current which is induced by the carrier wave in antenna is converted to constant DC via power rectifier and regulator. DC power wakes the chip up. In clock extractor, clock pulses are separated from the carrier wave. Modulator, memory, and logic section are synchronized by clock pulses. Logic section compares the data with its interior program. If it is reliable, the certain data which are stored in the memory are made available and then the data are encoded via the logic part. The function of the modulator is to combine the data and the carrier wave. Afterwards, the tag's antenna backscatters it to the air [27].

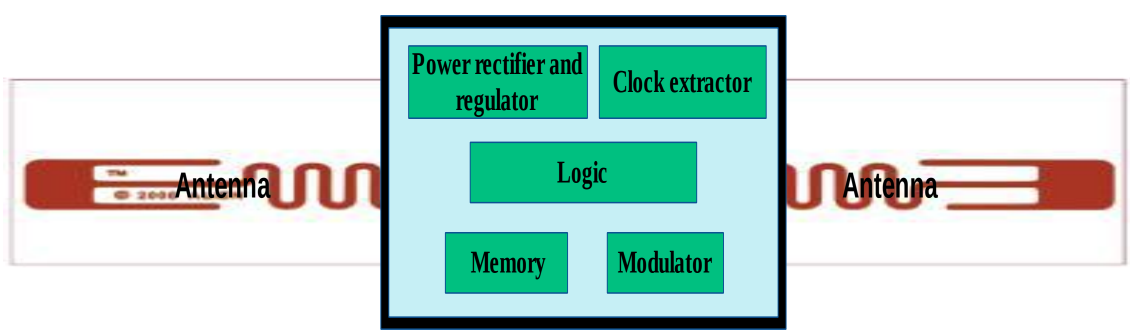


Figure 3.5: Hardware of Tag

3.1.3 Frequency of RFID System

Range and operating frequency of the reader are the scale which separate RFID systems. Frequency ranges of RFID systems are from 135 KHz to 5.8 GHz. The coupling types used in RFID are Electric, Magnetic, and Electromagnetic fields.

RFID system with a range of 1 cm is referred to as close coupling. The Reader can read this kind of tag when the tag is inserted into the reader or placed on a surface used for this purpose. Electric and magnetic fields are used in close coupling and operate in the frequency range between DC and 30 MHz. Mostly this type of tag is used in security applications like door locking and contactless smart card; otherwise it does not have significant impact in commercial markets.

RFID system with a range up to 1 meter is known as remote coupling. Inductive (magnetic) coupling between the reader and the tag is used in remote coupled systems. Some systems are based upon electric (capacitive) coupling. Recent developments mostly use inductively coupled RFID systems.

In UHF and microwave bands RFID systems have greater than 1 meter range and they employ electromagnetic wave coupling. They are also called backscatters because of the physical operating rules. They work at the 868 MHz and 915 MHz UHF frequencies and 2.5 GHz and 5.8 GHz microwave frequencies. So, by using passive backscatter tags we can obtain a range up to 3 m. However, achieving 15 m and more is possible by the active backscatter tags. Battery of the active tag only provides the power for microchip and maintenance of the stored data. Electromagnetic field of the reader supplies the required power for sending the data between the tag and the reader. UHF tags use more power and consequently have longer range [26, 1].

Table 3.2 RFID specifications in different ISM bands

Frequency band	Low frequency 125-135 KHz	High frequency 13.56 MHz	Ultra high frequency 850-960 MHz
Read range	Less than 1 m	1-2 m	Around 3 m
Power source	Passive (Inductive)	Passive (inductive)	Passive (propagation)
Affect near water	No	To some extent	Yes
Data rate	Slower	⟷	Faster
Standard	ISO 11784 ISO 11785 ISO 14224	ISO 14443 ISO 15693 ISO 18000-3	ISO 18000-3 EPC Gen2

3.1.4 Standardization

There are various standardizations used in RFID systems as Electronic product code global, International organization European article numbering /Uniform code council, American national standards Institute, and Automotive industry action group. Electronic product code (EPC) is used more frequently among these standardizations which will also be used in this thesis.

EPC global network is a global standard for identifying components automatically. Each company has a unique intellectual property that is used in EPC global. EPC in the reader is translated by the object name service to the internet address where information on the object can be found. The data are traded in the network via a standard that enabled by the physical markup language and Savant controls the traffic of the network [28].

Electronic Product Code (EPC) enables type of product to be identified in terms of its company. Each object has a unique 96 bits electronic product code. EPC is comprised of four distinct numbers known as the header, EPC manager, object class, and serial number.

3.1.4.1 Header

The Header consisting of 8 bits is used to indicate the format of the EPC code such as the length of the field partitions. It is designed to make the system flexible.

3.1.4.2 General Manager Number

General Manager Number determines an organization entity. Each company has a unique General Manager Number.

3.1.4.3 Object Class

It is used by an EPC managing entity to identify the type or class of object.

3.1.4.4 Serial Number Code:

Each object class allocates a unique serial number code [29].

3.1.5 Coding

Sending data between the tag and the reader is performed by three function blocks as same as a digital communication system comprising of transmission medium, transmitter, and receiver.

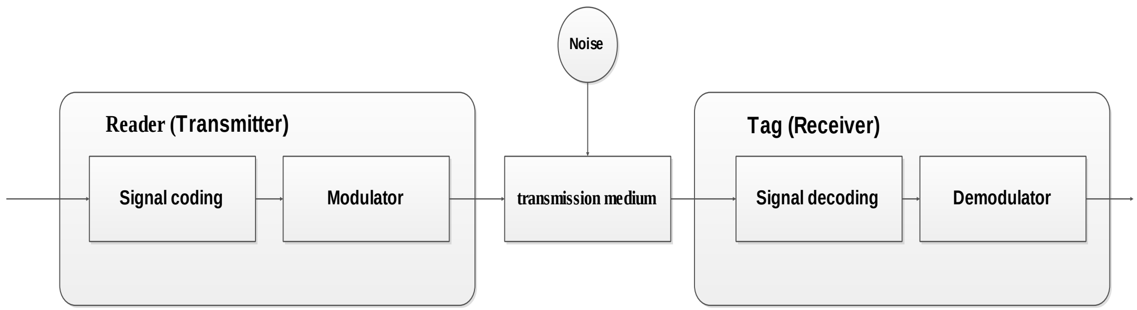


Figure 3.6: Function Blocks of Sending Data from Reader to Tag

Signal coding is different from modulation, so it is known as coding in the base band. Coding is a principle used to convert the data. On the other hand, modulation is a procedure of changing the amplitude, phase or frequency of a carrier wave by using the baseband signal.

Several line codes exist because of the arrangements of binary ones and zeros. In RFID systems the coding usually used are NRZ, Manchester, uni-polar RZ, differential bi-phase, differential coding PP and miller coding methods [26].

3.1.6 Modulation

The process of changing the signal properties (frequency, phase and amplitude) of an electromagnetic wave (carrier) by the baseband data are known as modulation. The methods of digital modulation which are often applied in RFID are amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK) [26].

3.1.7 Method of Checksum

Transmission errors which occur in wireless technology can be recognized by checksum. Checksum imports corrective measures. Parity check, CRC, and XOR sum are the popular methods of checksum [26].

3.1.7.1 Parity Checking

In this method, each byte is combined with a bit of parity. It means that each byte sent has 9 bits. There are two parity types as odd and even. The sender and receiver should check odd or even parity with the same procedure. The number of 1s in 9 bits must be odd by using odd parity and the number of 1s in 9 bits must be even by using even parity.

3.1.7.2 XOR Sum (LRC)

The XOR checksum is produced as a data block which contains the recessive XOR gating of bytes of data. Then, the obtained LRC added to the data block which is sent. If the sum of the data block and LRC in the receiver is not zero, it implies sending errors.

3.1.7.3 CRC Method

This method is reliable in large data which is suitable for RFID systems. Remainder of the division of the polynomial is the CRC. The data byte is shifted to the left in 4 positions and 4 bit CRC can be calculated [26].

3.1.8 Anti-Collision Procedures

Generally anti-collision procedures are categorized into three groups:

1. Spatial domain: the reader searches the space near itself and only reads small numbers of tag and performs to find the transponder.

2. Frequency domain: the data transfer from the tag to the reader by extension of the spectrum signal.
3. Time domain: there are two cases regarding this issue. Regarding the first case, if the tags control the anti-collision, their response signals are sent causally with a delay. Therefore, collisions between the tags will never happen. In this case, however, process is slow without any flexibility. In another case, the reader controls the anti-collision and applies the binary search method [30].

3.1.9 Increasing the Read Range of Passive Tag

Previously, the read range of the passive tag considered is only a few inches. As the application areas of the passive tag is more than the others, solutions for improving the passive tag range are needed.

Some parameters which affect the passive RFID range are:

- Power of transmission
- Sensitivity and efficiency in receiving
- Antenna
- Frequency
- Direction of tag
- Surrounding [31]

Using 2.44 GHZ surface acoustic wave (SAW) has a 30 times read range more than the usual. It applies lower reader power. However, data capacity of SAW tag is low. Nowadays, by using EPC global standard, it increased higher than 128 bits. SAW is used in traffic control, automobile manufacturing, distance in real time, and it is suitable for applying in temperature measurement because of good tolerance to gamma radiation, high temperature, and low temperature [32].

Passive UHF tag producer Omni-ID uses a platform to improve performance of EPC Gen 2 tags. Thus, the new platform and tags which are called Tom Pavela, CEO and Omni-ID's president can obtain read range of 115 feet (35 meters). Omni-ID uses structure of coupling called Margie Kriebel is comprised of Plasmonic layer, near-field loop antenna which is attached to the chip [33].

Another method is to use power optimized waveform (POW) in RFID systems. It boosts the charge pump power efficiency to improve reliability and allows longer distance between the tag and the reader [34].

When the power output of the reader antenna is improved, the read distance of the passive tag increases, too. However, high amounts of RF energy have health hazards and may interfere with the operation of other devices [35].

The tag with dual dipole antennas which collects higher power from the RF field is introduced by Motorola to improve the read range [36].

Using an extended-range RFID skimmer can read ISO-14443 tag. Therefore, the read range of 25cm is achieved. It contains a light weight-diameter copper- tube antenna which needs a 12 V battery and obtains read range 3-5 times longer than the usual range [37].

3.1.10 RFID Applications

RFID is usually used for detecting the presence of objects or humans equipped with tags. The other major RFID application is to find the place of the objects. In the early applications, RFID tags were embedded in the train cars, shipping containers, and automobiles for automatic tracking. Later, RFID tags were used for automated tool collections. With the reduced production costs of the tags they were made available in larger quantities for reduced cost applications. Some other well-known RFID technology applications are contactless payment, access control, and stored value system.

Healthcare: The efficiency is improved by using RFID in healthcare applications. In addition, safety of the patients is greatly increased. This allows the limited resources can be utilized more efficiently as in the case of tracking inventory, staff and patients [38].

Supply chain: RFID can be applied for product movement, tracking, handling and shipment. It eliminates errors in tracking products and increases the efficiency in the usage. The tags can be inserted to each pallet to be recognized, counted and tracked [39].

Smart cards: primarily, this was used in the banking sector. In the passive smart cards, the card should be close to the reader for reading. Some advantages of smart cards in transportation includes no requirement to have cash, validation of smart node, calculation of the exact fare, elimination of the delays and printed tickets [26].

Airport: RFID systems are used in the luggage delivery system in an effective way. Also using RFID in the management of airport logistics provides tracking for tagged objects [40].

Animal tracking: Each animal is tagged with an RFID tag which is used in estimating the location of the animal. Rewritable tags can be used for saving the data of animals. Also, basic data about the animal is identified [41].

Figure 3.7: Applications of RFID System [41]

3.2 Wireless Sensor Networks

Wireless sensor networks (WSNs) consist of sensing, computing, and communication elements and are used for monitoring environment's temperature, humidity, pressure, etc. In other words, WSN is a network which is made up by nodes that sense and control the environment cooperatively. Nowadays, WSN is used in many areas such as traffic control, health care monitoring, healthcare applications, and supply chain.

The main WSN characteristics:

- limited power

- tolerate harsh situation
- capable of managing the node errors
- mobility of nodes
- changeable topology of network
- failures of communication
- nodes dissimilarity
- spreading in huge scale criterion
- proceeds without assist (using easily) [42]

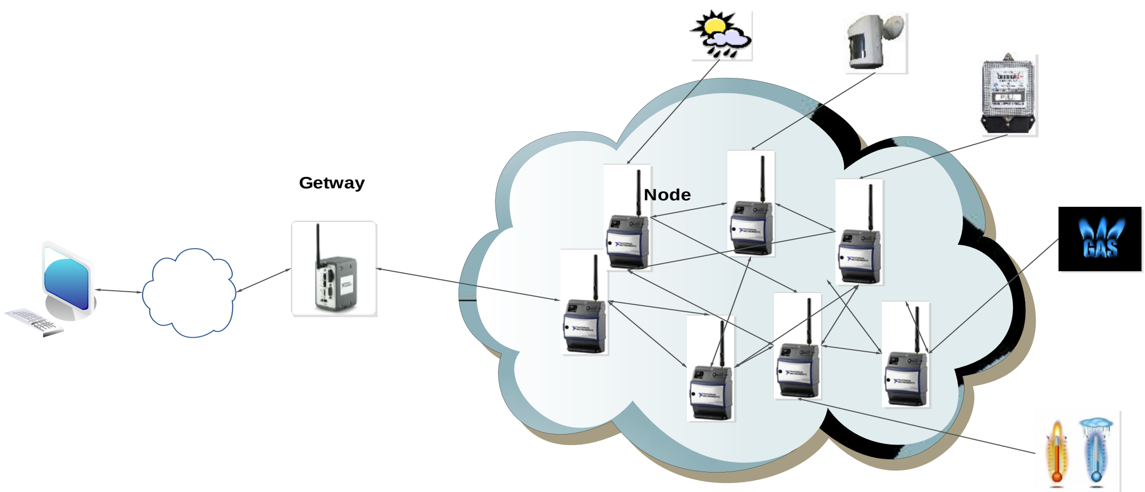


Figure 3.8: Components of Wireless Sensor Network

3.2.1 Sensor Nodes

A sensor node, also called mote, has the ability to collect sensed environmental conditions, accomplish processing, and communicate with other nodes. A sensor node consists of sensors, communication devices, memories, processing units, and a power supplies.

The phenomenon is observed (sensed) by the sensor and analog signals are produced. An Analog to Digital Convertor converts analog signals into digital signals. The processing unit corresponds to memory section and manages the collaboration between the nodes. Nodes with communication devices connect to the network. Power supplies of sensor nodes are very important and maybe obtained by solar cells [43].

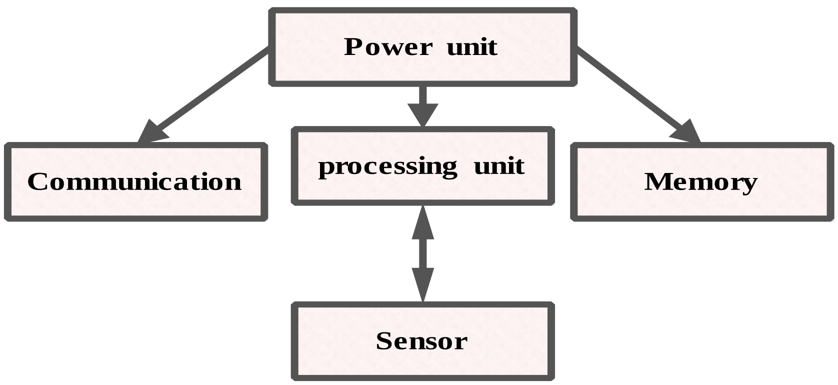


Figure 3.9: Parts of a Node

3.2.2 Network Topologies

Quantity and quality services are very important in communication networks. Delay in message, BER, message due dates, losing of packet, power and cost of transmission are all represented as quality of service. Topology of the network is defined according to some conditions like environment of installation, application, and quality of service Nodes constitute the entire communication network. The main network topologies are referred to as star, ring, bus, tree, fully connected, and mesh [44].

3.2.2.1 Fully Connected Networks

A fully connected network is a topology in which every node is connected to one other. It cannot be used in large networks because of the large number of connections.

3.2.2.2 Mesh Network

In this topology, transmission is usually between the nodes that are in nearest neighborhood. It is also called peer to peer nets. In large scale networks, it is a significant topology. In case there is a failure in leader of a group another node can do its job.

3.2.2.3 Star Topology

All the nodes are linked to a single hub. If a node and hub are disconnected, it does not affect any other nodes. However, if the hub is not working, the network fails.

3.2.2.4 Ring Topology

There isn't any leader node, each node has a duty. The data moves in a circle from one node to another. Therefore, a cut in one connection disrupts the whole system.

3.2.2.5 Bus Topology

Nodes are connected by a shared communication line which is called the bus. When message is put on the bus, header is checked in the destination address via each node.

3.2.3 Base Station

Base station is usually used as a central part to collect information from the nodes. This is a useful approach which makes an easy way for users to control their products. Based on the base station, routing and data processing the information can be shared globally and in the WSN network. Base station provides an interface between the user and internet. It basically acts as a gateway. Data are transmitted to the internet by the gateway. Asset master can connect to the internet directly [45,46].

3.2.4 Protocol Stack

Protocol stack of WSN provides five levels: Physical, data link, network, transport, and application [43].

Physical layer: frequency selection, generation of carrier frequency, signal detection, modulation, and encryption are supported by the physical layer and the output power requirement is minimized.

Data link layer: sharing the data stream, detection of data frame, medium access and controlling of error are all supported by the data link layer. The data link consists of two sub-layers: media access control (MAC) and logic link control (LLC). Addressing as well as control mechanisms of channel access occurred in the MAC. It provides the base of network which means that making communication links between the nodes and self-organizing in the network are the duties of the MAC sub-layer. Sharing communicator resources (frequency) in an efficient way amongst the nodes is another role of the MAC. Therefore, the link layer handles how the nodes can communicate with each other.

Network layer: Inter networking is provided by the network layer for external networks. Determining which node should talk is the duty of the network layer.

Transport layer: Transport layer determines when the system requires to link with outside.

Application layer: There is a sensor management protocol (SMP) in the application layer by which the hardware and software in the lower layers for managing applications of the sensor network is made. Applications and sensor networks can act and react by the rules provided by the SMP [46].

3.2.5 Applications of wireless Sensor Networks

Wireless sensor networks have a wide range of applications in different areas. Usually, they are used for emergency services. Nowadays, WSNs are applied for national security as well by employing chemical and biological sensors. Defense, air traffic control, industrial and manufacturing automation, environment monitoring, and structures and building monitoring are some of the important applications of WSNs.

Environmental data collection: The large number of nodes collects the data from the environment continuously and transfers them to the base station.

Supply chain management: The process efficiency is improved by the WSN in the supply chain. Sensors can monitor the temperature of the products which should be maintained all the time. Each product's node can communicate with other nodes. It is noteworthy that smart nodes detect products types in order to store them in particular places when they negatively affect one another.

Security monitoring: Nodes are fixed in a certain location and continuously check the status of the sensors. In this case, the nodes send a data report only in the case of security violation which is the difference between the environmental monitoring and security monitoring.

Node tracking scenarios: A sensor node is attached to the object for tracking when it enters in a field of sensor nodes placed in the environment at a particular location.

Health applications: physical conditions of patients in the hospital can be monitored by using wireless sensor networks.

Home applications: wireless sensor networks are helpful to work intelligently at home. People do not need nurse and body guard anymore [46].

Chapter 4

INTEGRATION OF RFID AND WSN

4.1 Difference between RFID and WSN

The most important applications of WSNs are in monitoring objects and sensing the environment. Otherwise, RFID can be used in detecting the presence and location of objects. Sensing data from the nodes and transferring to the sink nodes are performed within relay nodes. It means that WSNs are multiple hop networks, while RFID system follows a single hop. Firmware of the nodes is reprogrammed easily, but most of the RFID readers are not user programmed [3].

4.2 Combining of RFID and WSNs

Usually sensing and monitoring the environment are performed by the wireless sensor networks. RFID commonly is used to track objects where a tag is attached. However, RFID has some disadvantages such as disability to read closely placed metals or liquids in some cases.

Four new applications can be defined by combining the properties of RFID and WSN:

a. WSN is used for sensing and RFID for identifying in three ways. RFID and WSN can be embedded in the same item. Objects presence is detected by RFID and sensing the condition of objects is performed by WSN; Just RFID is embedded to the item and provides the data. Presence of the item is identified by

WSN; RFID is fixed to the item and sensing the environment is fulfilled by WSN.

b. Identifying item is performed by both RFID and WSN in order to enhance security. For example, fingerprint is checked and, then tag's information can be read.

c. Location is provided by WSN and identifying the objects is obtained by RFID.

d. Finding the exact location of objects by using of RFID and WSN [3].

In this chapter, types of integration are introduced: Mixing sensors with tags, merging cordless appliance and nodes with tags, assimilating cordless appliance and nodes with readers, combine of sensors and RFID.

4.2.1 Combining Tags with Sensors

In this case, tags are equipped with specific sensors and are called sensor-tag. In addition, sensors collect sensed information and RFID identify the objects. Sensor tags apply the protocols and method to the reading tags and for gathering the sensed information that is used for RFID.

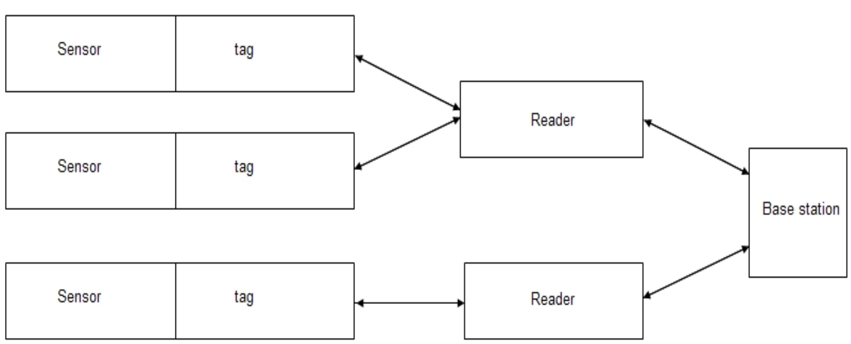


Figure 4.1: An Overview of system

Sensed data are converted by the ADC and readers send the outcome to the base station. Corresponding operation is then provided by the application system. As an illustration, monitoring physical parameters, finding product tampers automatically, finding damaging factors, as well as monitoring of noninvasive can be categorized as sensor tags applications.

Three main classes of sensor tags can be defined: active tags, semi-passive tag, and passive tags based on the powering of the tags.

4.2.1.1 Integrated Passive Tags with Sensors

The sensor tags which powered up with the reader's Radio Frequency signal are known as sensor passive tags and usually are used for identification of a photo, detection of PH value, and sensing and monitoring of the temperature.

4.2.1.2 Integrated Semi-Passive Tags with Sensors

In this situation, sensor tags operate with a battery. Applications of sensor semi-passive tags are in recording the location, asset tracking of vehicle, access control, and temperature monitoring by sensing the object environment.

4.2.1.3 Integrated Active Tags with Sensors

Sensor active tags have various uses including detection of vibration, blood pressure and heart beat rate monitoring, and sensing and monitoring of temperature [3].

Two cases of integrating sensors with RFID are introduced. In the programmable system, timer controls the sensor which collects the information autonomously in specific times and independently from the reader. At the first microprocessor, information is gathered and, then it is sent to the data warehouse part for more processing and management by means of the reader. There are two schemes of SE-RFID tags [13].

- SE-RFID type 1:

  The primary processing into the sensor information is performed by fusion processor. The controller merges the information simultaneously. Information on the external sources is mixed with the reader information in the data warehouse section. This part also transfers ordinances to the SE-RFID. Since the sensor information should be read sporadically, the tag is equipped with a battery [13].

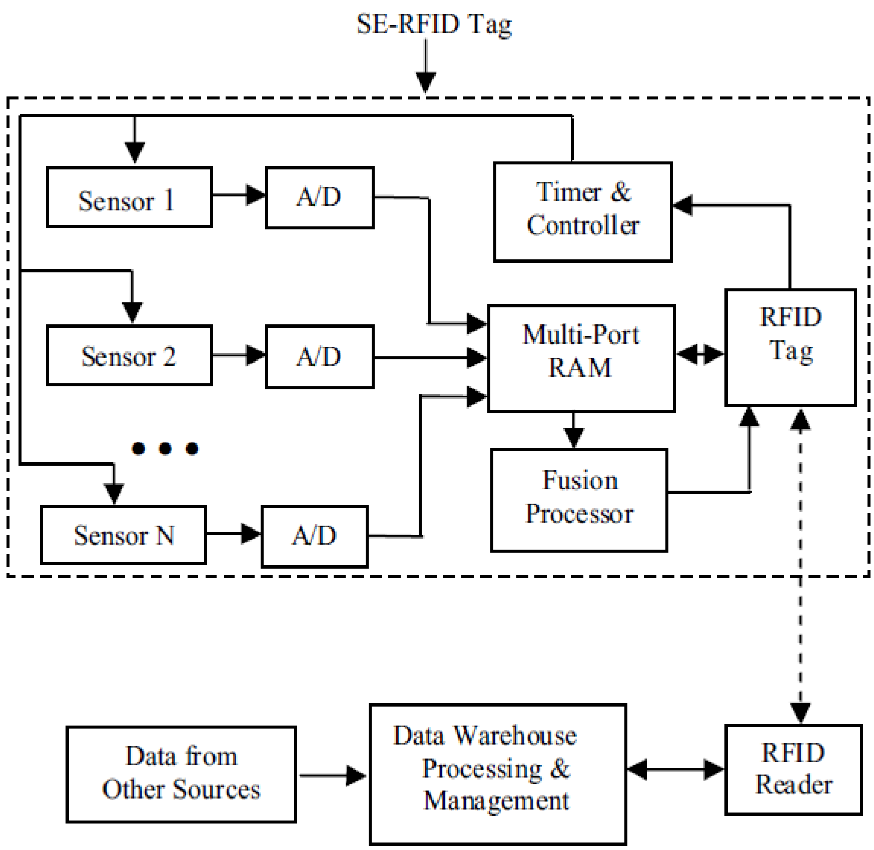


Figure 4.2: Sensor-Embedded RFID Type 1 [13]

- SE-RFID type 2:

In SE-RFID type 2, for each sensor a tag can be inserted. According to the dual port memory, the sensor's information is transmitted to the tag. The fusion processing part can be allocated inside or outside the reader. Using this type of SE-RFID, each sensor can be placed in separate geographical locations. The power source used in this type is less than the previous type due to separate timing and control sections [13].

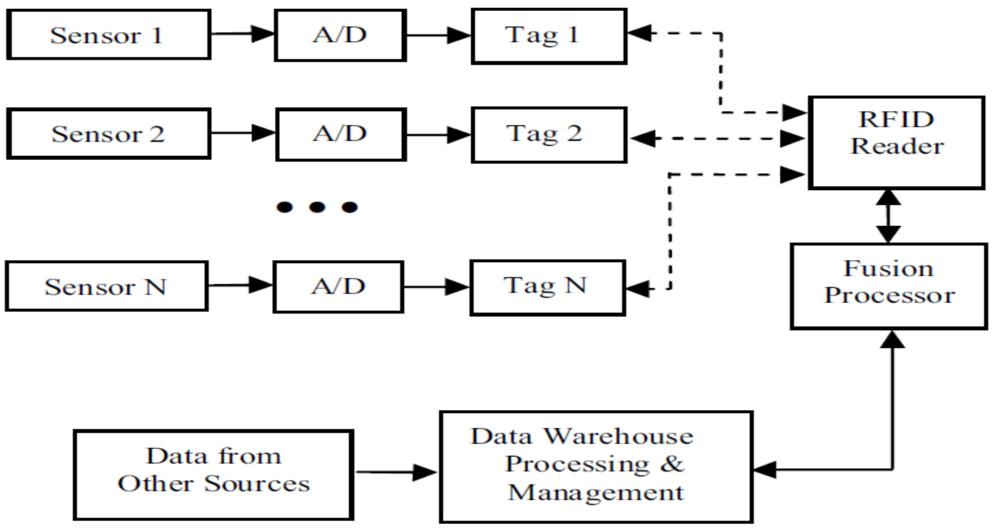


Figure 4.3: Sensor-Embedded RFID Type 2 [13]

4.2.2 Merging Cordless Appliance and Nodes with Tags

Communication ability of sensor tags is very limited. As a solution, mixing of cordless appliance and nodes with tags are used. In this case, tags can communicate with wireless devices and other tags and mimic a multiple hop network. However, in previous types of integration, the sensor tags are only able to communicate with the readers. This integration type may be compatible with standards of RFID, but they can have separate protocols as well. Each tag can communicate with other tags with separate peer to peer protocols. Nodes' information can be delivered to other nodes by a unique ID. It is designed for monitoring the conditions of ambient and one interesting place that can be used is the chemical containers. In a critical situation, the alarm is switched on. It helps to separate reactive chemicals away from each other [3].

4.2.3 Integrating Cordless Appliance and Nodes with Readers

This kind of integration is more functional and allows it to be used in novel applications. By integrating the reader with Cordless appliance and nodes, the reader can sense the condition of the environmental variables. In wireless method, the readers communicate with each other among the network. Furthermore, they read tag’s ID number and efficiently send the information to the host. Current integration can be divided into three classes. In the first class, wireless devices and RFID reader are integrated with each other. Wireless devices can be used in Wi-Fi standard to provide contactless communications.

In the second class, sensor nodes are integrated with RFID reader. Sensor nodes are used for sensing and have the ability to communicate.

In the third class, sensors and reader are incorporated with devices which are multi-functional like cell phones and PDAs [3].

4.2.4 Combination of RFID and Sensors

In this case, RFID and WSN work apart, but integration between them exists in the software layer. Information of RFID and WSN are sent to the same control system. With the cooperation of both of them, operation is carried out effectively. For instance, WSN can detect the particular items by using the identification provided by RFID. Extra knowledge for RFID is supplied by WSN. Scheme of integrated node is not required in case of using combination of RFID and sensors. Processing of WSN and RFID is done in the software layer. Although RFID system and WSN are distinct physically, however, they are acting in the same system. In order to prevent interposition, a decision in programming of the communication is needed [3].

For example, a framework is designed by RFID and WSN for guiding services of group tours. The current case is comprised of a sensing field with different group of tourists that per group possess separate members and leader. Per member should pursue the leader's moving way. However, some members may want to visit the places that they like most. Therefore, leader's location must be tracked by nodes by sending signals. Each member of the group conveys a tagged ticket with a passive tag. Every node contains a "direction board" that shows essential information. Some nodes are used for "Help center" and are connected to the readers and a computer in order to prepare more information services.

The aims of the scenario are:

a) For each leader preserve the guiding path.
b) Location of leaders is tracked.
c) The guiding path is displayed for lost members.
d) Tourist data are published from leaders to members.
e) Support leaders to muster members.

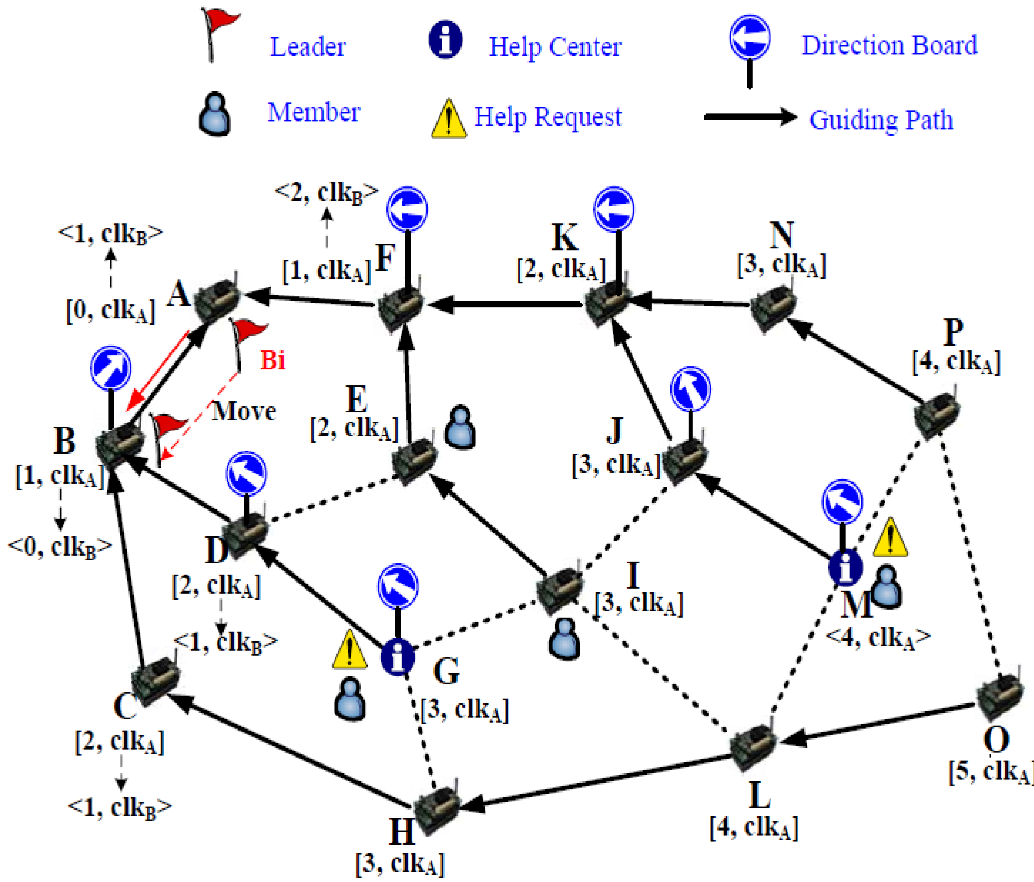


Figure 4.4: System architecture [47]

Four service scenarios are available:

i) Trace of leader: Every badge sends signals periodically and the location of the leaders is traced by the sensors and specifies the guiding path from each node to the leaders.

ii) Help service: If one of the group members misses the other group members, he/she can go to the help center then, with the use of a ticket and a reader finds the right direction.

iii) Member muster: by a button that is on the badge, leaders can evoke members. The message is sent and direction boards of sensors indicate the guiding path.

iv) Push-message: when the leader is going to present significant information, by pushing a push-MSG button, it is displayed on the screen of all sensors [47].

Another example is the integration of RFID tag and sensor nodes' architecture. Combining sensor nodes and tags are used for detecting the area. Information of tags and nodes are collected by smart station and sent to the local host PC or remote LAN. Data of RFID and WSN can be mixed in the base station for more intelligence. For instance, the data of WSN triggers the reader to act in certain uncommon occurrence. Three classes of devices are defined for the system. The first one is smart stations which consist of wireless devices without significant power limitations. RFID reader, microprocessor and network connection are organized in the device. Two other classes are the ordinary tags and nodes.

Traditional protocol architecture can be used because of non-limitation on the power. In every smart station, a multi-layer networking stack is performed. Thus, some processing routing of data and dependable protocols of transport are allowed [7].

In the last illustration an infrastructure of global standard for RFID and WSN according to EPC global standard is perused. Standard for integrating RFID and WSN in the same network does not exist. Therefore, the present study offers the EPC sensor network to create a global network infrastructure. Association and processing data of the WSN with RFID internet based architecture are integrated by the EPC sensor network. A large number of nodes with different sensors, which are used for careful monitoring of property assets, exist in the built cultural property management system. Meanwhile, tourists tracking and limitation in their movement are performed by RFID [5].

Chapter 5

METHODOLOGY

5.1 Smart Node

The smart node consists of sensors which are called the sensing part, reader which is called the reading part, the radio transceiver part which sends the sensed information, the power unit and a microprocessor.

Major functions of smart nodes are classified as follows:

- Monitoring the environmental conditions
- Identifying the items
- Transferring the processed information via the network to the base station

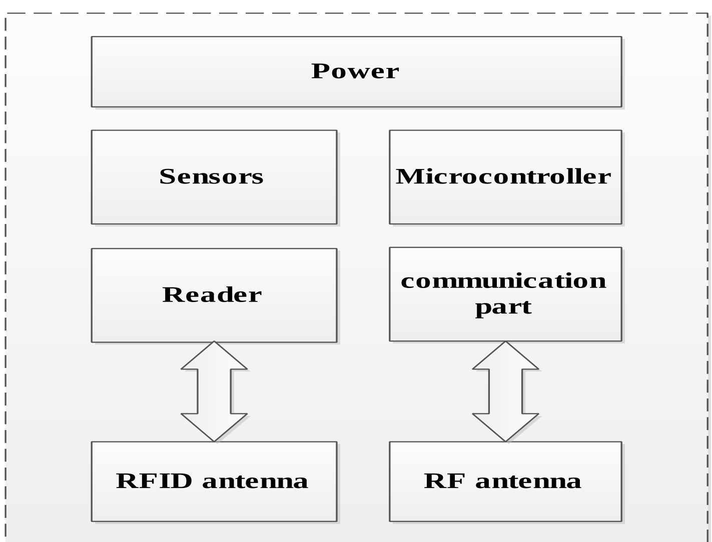


Figure 5.1: Components of Smart Node

Fewer numbers of tags can be read by smart nodes; it runs independently and translates information to the sink node. Collected data are sent by multi-hop connections. Tags' data are homological in the same place, therefore in smart nodes data can be compacted with methods of compacting and pliable communication protocol is needed. Nowadays, ZigBee is the best nomination for this architecture. In the physical layer and MAC layer, ZigBee uses a lot of methods for decreasing the power. Limitation in energy and changing battery is a huge problem when using smart nodes in the industry.

5.2 Integration of RFID and WSN for supply Chain Intelligence System

This chapter illustrates the method for the intelligent supply chain system through applying smart nodes. Moreover, the significant role of the smart nodes will be elaborated in such a system in order to improve the system performance. In a warehouse, there are some important parameters such as inventory accuracy, real-time inventory, smart instrument, communication between systems, improvement in cost and time efficiency, preventing from errors etc.

For the purpose of establishing an intelligent system, a strategy and framework are proposed to investigate the parameters which were mentioned above. In the previous chapter, the types of integration of RFID and WSN were introduced. For this method, a combination of RFID and sensors is applied. RFID is applied to identify the tagged items and WSN is used to sense the environment such as humidity, temperature and air. Some products should be protected against humidity and some have to be kept at a certain temperature.

The integration of RFID and WSN are illustrated both at the supply chain and WSN in this section. A reference model for automated warehouse intelligence is explained. First of all, each unique tag is embedded into a product. Some smart nodes, which consist of sensor nodes and a reader, are placed in each room and are fixed in automated guided vehicle (AGV). Each tag can be recognized by a unique identification (ID) number. The Reader of smart nodes transmits radio waves and the tag which is placed in the field wakes up and modulates its information by the carrier wave and then sends the result (modulated data) back. The sensor nodes are capable of monitoring the environmental conditions (temperature, humidity, air, pressure, sound etc.).Then, the reader and the sensor node's data are transmitted to the base station. Finally, the data are sent to asset master.

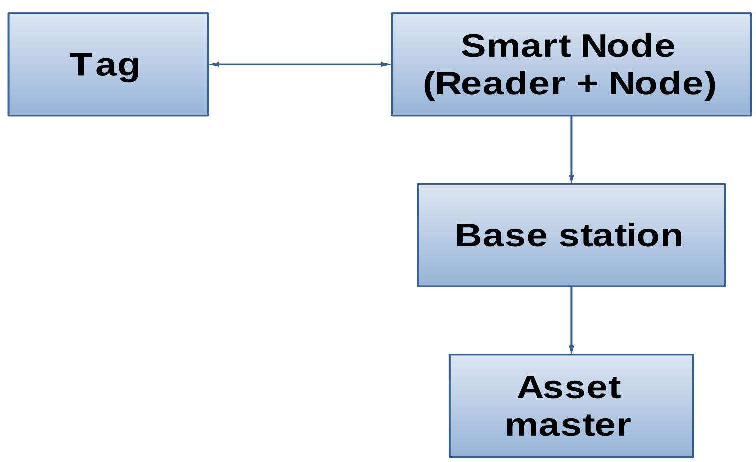


Figure 5.2: The Main Parts of the Proposed Method

5.2.1 Supply Chain and Warehouse Equipment

In the supply chain, basic equipment should be used in order to perform different jobs. The conveyor is a kind of automated transportation line that moves target products to the destination. Label printer applicator is a device for encoding RFID chips and prints it in the barcode shape and alphanumeric characters which can be read by humans.

RFID gate has an RFID antenna which is connected to the reader. Reader identifies the products and is able to set the certain level for products which are going to be loaded on the AGV. AGV is used for carrying the products from the departure (supply chain) to a target position (different warehouse rooms). The number of AGV depends on the application.

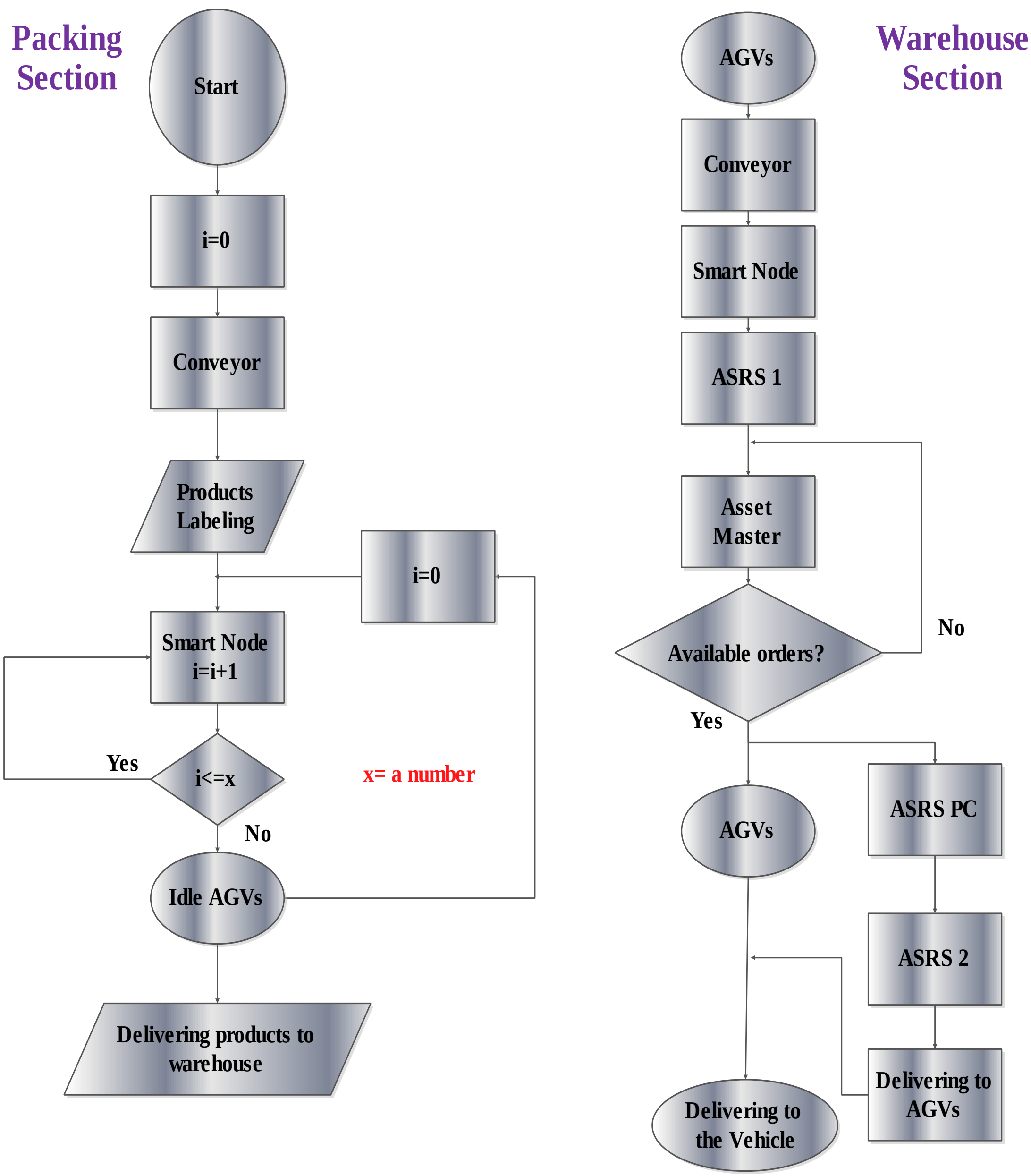


Figure 5.3: The Method of intelligence Supply Chain Management

5.2.2 Warehouse Management System Consists of Following Tools

Automated storage and retrieval system (ASRS) used for storing various products types in storage rooms' shelves and retrieve them in time by own robots. The number of robots can be determined according to the requirement.

Then, AGV is used for loading goods through storage rooms to vehicles. When companies' orders are made, products can be transferred to the vehicles in the WMS. Smart nodes are fixed in each room and AGVs. Some alarms can be installed for critical situations in each area.

5.3 Structural Health Monitoring

The strategy for finding damage in substructure of mechanical, civil, and aerospace engineering is called structural health monitoring (SHM). Damage is described by variation in material, exclusivities of geometric of systems such as changes in the connectivity of the system and boundary conditions. This factor conflicts in the performance of the system. A lot of instruments are used for monitoring without any destruction in the system. Recently, using SHM is spread because of its advantages such as life-safety. State of the system is compared with the initial and undamaged state for finding the damage.

When damage occurred in material, it is called defect or flaw. While the damage attain a point that operation of the system is not acceptable, it is called failure. Using SHM, structure of the system is observed and measured in certain intervals over time. When an extreme event like earthquake happens, SHM can help to screen for rapid defect identification. Screening is used for obtaining a reliable data about the performance of the system in real time.

Most of the industries desire to discover damaged products and manufacturing infrastructure as early as possible which affect life-safety and economic impact. There are some problems in the traditional systems of SHM. They are using wired connections with high-cost equipment, thus disturbance in the operation of the system is unavoidable. Because of the wiring, the cost of installation is high and maintenance in the wired system is expensive, too. According to these mentioned problems, the use wireless communication in these systems is more reliable and the cost is significantly lower.

Figure 5.4: Some Areas Which Use Structural Health Monitoring [42, 46]

In this chapter, two methods are introduced for structural health monitoring using the integration of RFID and WSN.

5.3.1 Method 1: Using Integration of Passive-Tag with Sensor

Energy storage is one of the important factors in SHM. Using passive RFID tags, which are placed in the objects, is the best solution for low power because of the fact that a battery is not needed. Each tag characteristics including the exact location of the object and information concerning the relevant sensor can be sent to the reader.

Although the disadvantage of passive tag refers to its reading range, carrier wave of the reader is used for waking up as well as communicating with the tag's chip. It is used for the power supply of the sensor as well. Consequently, the reading range of the passive tag is decreased by adding a sensor. In Chapter 3, increasing the read range of the passive tag was considered. Therefore, those methods can be implied in the architecture of the tags for the current case.

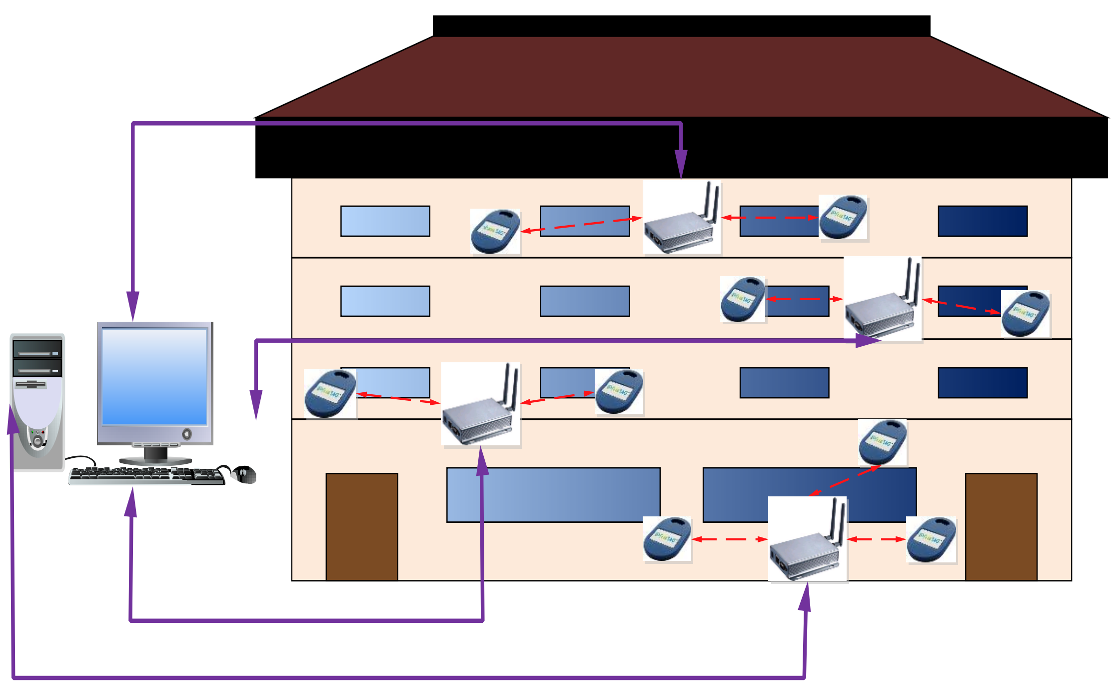


Figure 5.5: Structure of Method 1

Sensor tags can be installed at particular places of a building to monitor the structural health. Damage in the building can be detected by the sensor tags, and then the problems can be recognized in order to find the related solution. As a result, it prevents any critical situation that may potentially develop in the future.

Reader sends the carrier wave to the tags. Sensors and tag's chip are powered by the carrier wave. Sensor tags sense the building status and send this information to the reader in real time. Then, sensed data, including the exact location, are transferred and processed on the host computer. Afterwards, users have the ability to control the structure.

5.3.2 Case2: Using Integration of Tag with Node

In the previous case, tags could not communicate with each other. They can contact only with the readers. This may not cause any problems in the building, but it can be a substantially critical factor in outdoor applications.

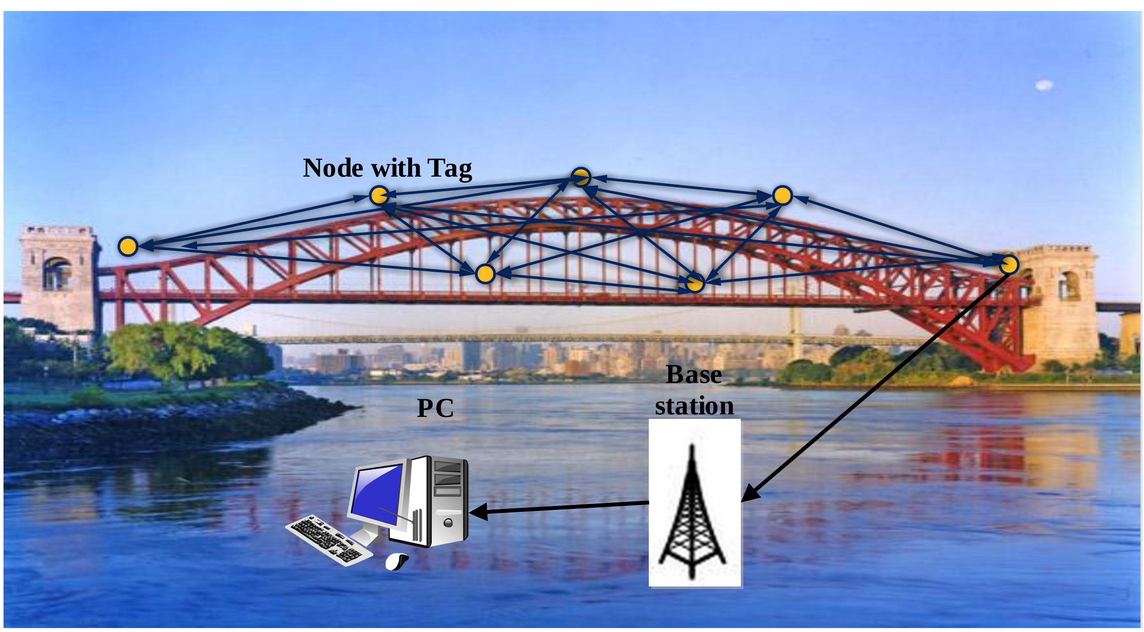


Figure 5.6: Structure of Method 2

If the cost of the structure is not very important, a new case can be introduced for structural health monitoring in the bridges. By installing an integrated node and a tag in the required place of a bridge, not only its condition can be monitored, but also the location and information are recognized.

Nodes can communicate with each other and send their information to an individual base station. Then, the base station transmits this data to the asset master. Power of each node can be stored by the method which is mentioned in [48]. Solar and wind energies can be offered as a useful source to power up the required nodes.

Chapter 6

CASE STUDY

6.1 Description of Case Study

Several ways for integration of RFID with WSN and their applications were discussed in Chapter 3. The methodology in terms of integrating devices algorithm was emphasized in Chapter 4.

In this chapter, applying integration of RFID with WSN is discussed in terms of a scenario. The scenario is concerned with the intelligent warehouse system and is simulated by petri net. Petri Net as a MATLAB Toolbox is considered. The aim is to show how the system works. Each part can communicate with another one by the smart nodes and each product can be detected by a unique RFID tag.

6.2 Petri Net

Petri Net is a Toolbox which depicts graphical scenes to analyze the system based on mathematical modeling for discrete circumstances. In the modern industrial system, a model of the system is needed for designing an optimal model considering saving cost, time, and performance. Petri Net may be applied to perform various processes in manufacturing, supply chain, and production control. It can be applied to provide safety of critical systems in real time; another functionality of Petri Net is to perform communication protocol successfully.

Place, transition and arc are components of Petri Net. Arc is used for connecting places and transition to each other. Circle represents a place and box or bar displays a transition. Places demonstrate the states and transitions illustrate the activities.

Usually a Petri Net is indicated by five tuples:

PN= (P, T, I, O,M_0)

P is a set of places and T is a set of transitions. The union of places and transition are not empty; however, their intersection is empty. When the token flows from the transition to the places, this act can be called as output function $\left(O\colon (P \times T)\right)$, otherwise it is known as input function $\left(I\colon (T \times P)\right)$. Each place which is marked by a natural number is called initial marking (M_0).

6.3 Intelligent Supply Chain Management System

In this scenario two separate rooms exist. One is for preparing parts and the other one is warehouse.

When the products are brought to the first room, they are packaged and, then a unique tag is attached on them. Afterwards, they are loaded on the conveyor in order to be labeled by the RFID printer. Some characteristics can be printed in the box such as serial number of box, date of manufacturing, expiry date, type of boxes, and other properties of the product. At the end of the conveyor, there is a gate equipped with a smart node to sense the parts. Once each product type reaches to the certain level defined by the user, it detects the idle AGV and communicates with AGV smart node to take the products and bring them to the warehouse room.

Entering AGV into the warehouse, it unloads the boxes. If in the warehouse there are more than one room, AGV of each room carries the boxes. However, it is assumed that only a room can belong to the warehouse management .Thus, AGV carries them to the room’s conveyor. Conveyor is installed with a smart node gate aiming to read the required product types in order to locate them at the defined positions.

ASRS environment has to be integrated with several smart nodes to determine the entrance as well as status of the different product outputs. It provides the facility to convey the input parts to the specific locations and remove output parts from the required places.

Two robots are available for ASRS in this scenario. The first one allocates the products to the defined positions, and the other one delivers products through the ASRS for the last AGV.

Once orders are made, vehicle gets ready to transport the related products from the warehouse to the market. The implementer sends the information to the ASRS through the base station. Products are stored and can be recalled according to the type and expiry date. Therefore, asset master can decide which products should be departed based on the priority. ASRS robot delivers the determined products to the out site space. An AGV is ready to load boxes and then put them in the vehicle.

It is needed to maintain products in certain conditions sensed by the smart nodes which are strongly related to temperature and gas. In case of any unpredictable situations such as gas release, the alarm must be alerted. The temperature of the environment can be monitored continuously and be set if required. It is noteworthy that smart nodes detect products types in order to store them in the particular places when they negatively affect one another. WSN and RFID can work in the same ISM frequency without any collision. It also can be used in separate frequencies because they have different modulation techniques.

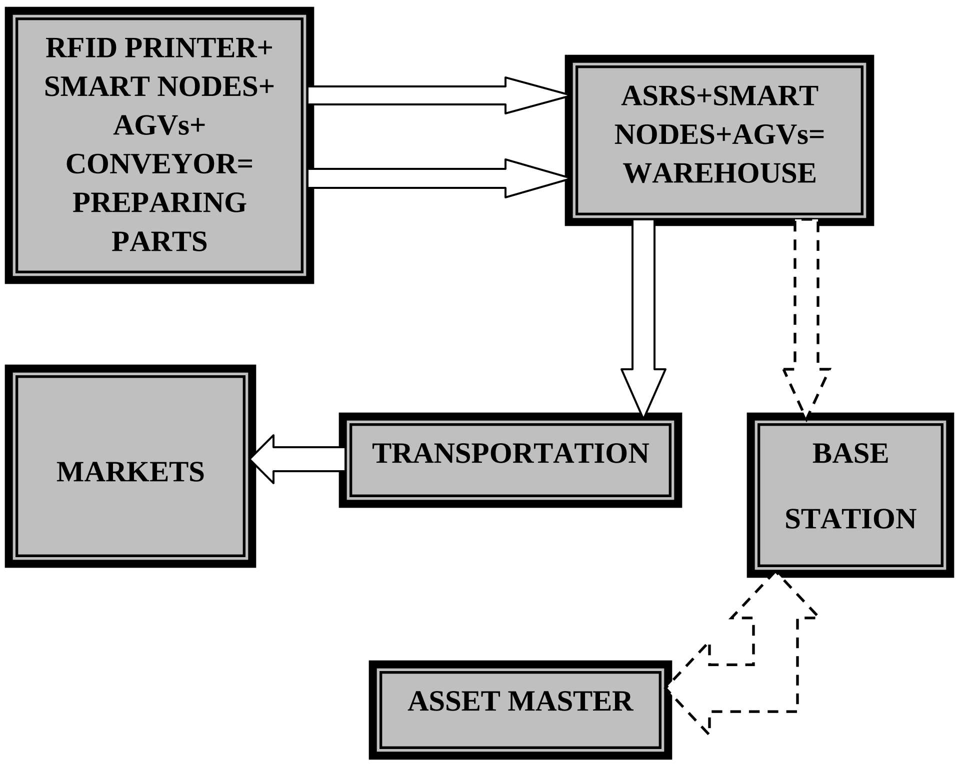


Figure 6.1: Structure of Introduced Intelligent Supply Chain

6.3.1 Performance Measurement

The present case study is simulated in the Petri Net Toolbox (see Figure 6.2) in order to display the system performance. Table 6.1 and 6.2 explains all sources and transitions in the Petri Net model.

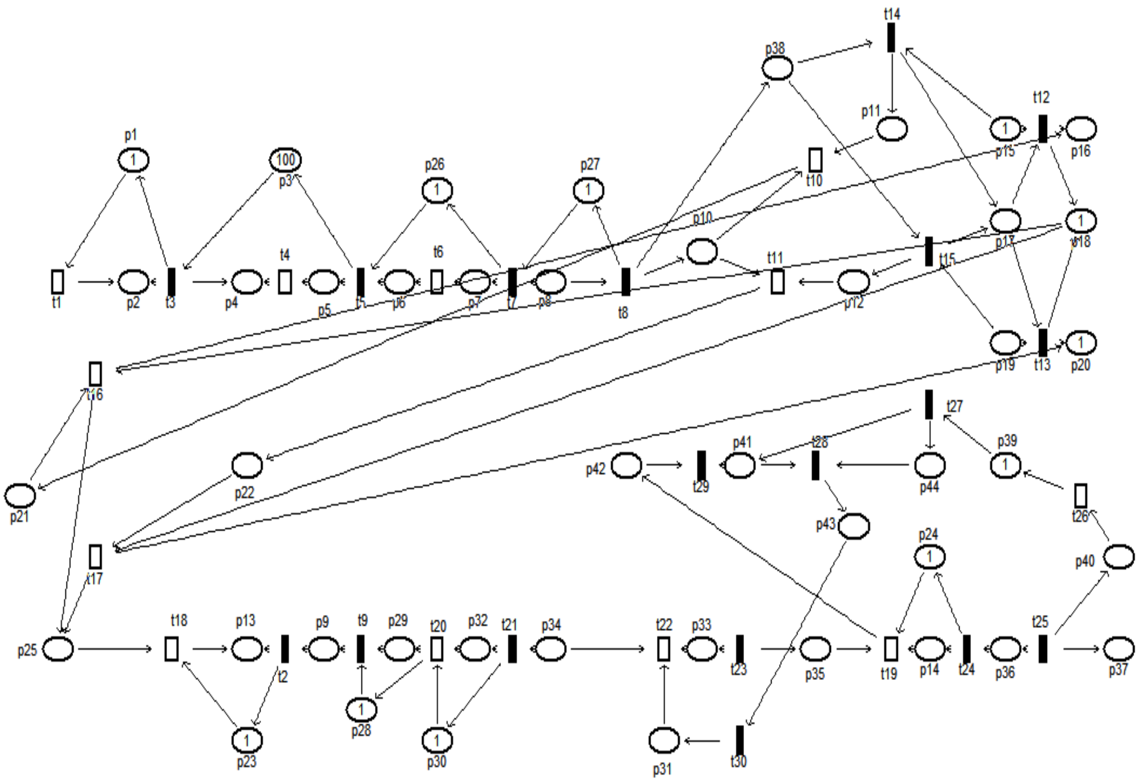


Figure 6.2: Simulation of the Case Study

Table 6.1 Description of places

P1	Number of parts put on the conveyor periodically
P2	Starter
P3	Capacity of first conveyor
P2 through 9	Available parts on the conveyors
P10	Available parts for AGV in room 1
P11 through 12	AGVs 1 and 2 pick the products
P13 through 14	Parts on AGVs 3, and 4 respectively
P15 through 16	Place of AGV 1 in room 1
P17 through 18	Managing AGVs in the queue
P19 through 20	Place of AGV 2 in room 1
P21 through 22	Place of AGVs 1 and 2 in room 2 respectively
P23 through 24	Place of AGVs 3 and 4
P25	Available parts for AGV 2
P26	RFID printer
P27 through 28	Smart node 1 and 2 respectively
P29	Determining storage parts
P30 through 31	ASRS robots
P32 through 33	ASRS robots with parts
P34	Parts in the ASRS

P35	Available parts for AGV 3
P36	Vehicle
P37	Output parts
P38 through 39	Orders are made
P40	Order is performed
P41	Asset master
P42	Base station
P43	ASRS application software
P44	Transferring orders to ASRS software

Table 6.2 Description of transitions

T1 through 2	Transitions of parts to the conveyors
T3 through 9	Transitions of parts on the conveyors
T10 through 11	Transitions of AGV 1 and 2 to load parts respectively
T12 through 15	Transitions of AGVs to own locations in room 1
T16 through 17	Transitions of AGVs 1 and 2 in room 2
T18 through 19	Transitions of AGVs 3 and 4 in room 2
T20 through 23	Transitions of ASRS robots
T24	Transition of parts to the vehicle
T25	Transition of vehicle
T26 through 30	Transferring orders to related applications software

Figure 6.3 represents the number of selecting appropriate AGVs in order to enhance the productivity in the second room. In other words, it shows the overall products can be taken to the room 2. Regarding to the figure, if two AGVs and one AGV, which put products on the conveyor, are provided at room 1 and 2 respectively, the arrival sum can satisfy maximum 183 products for the second room.

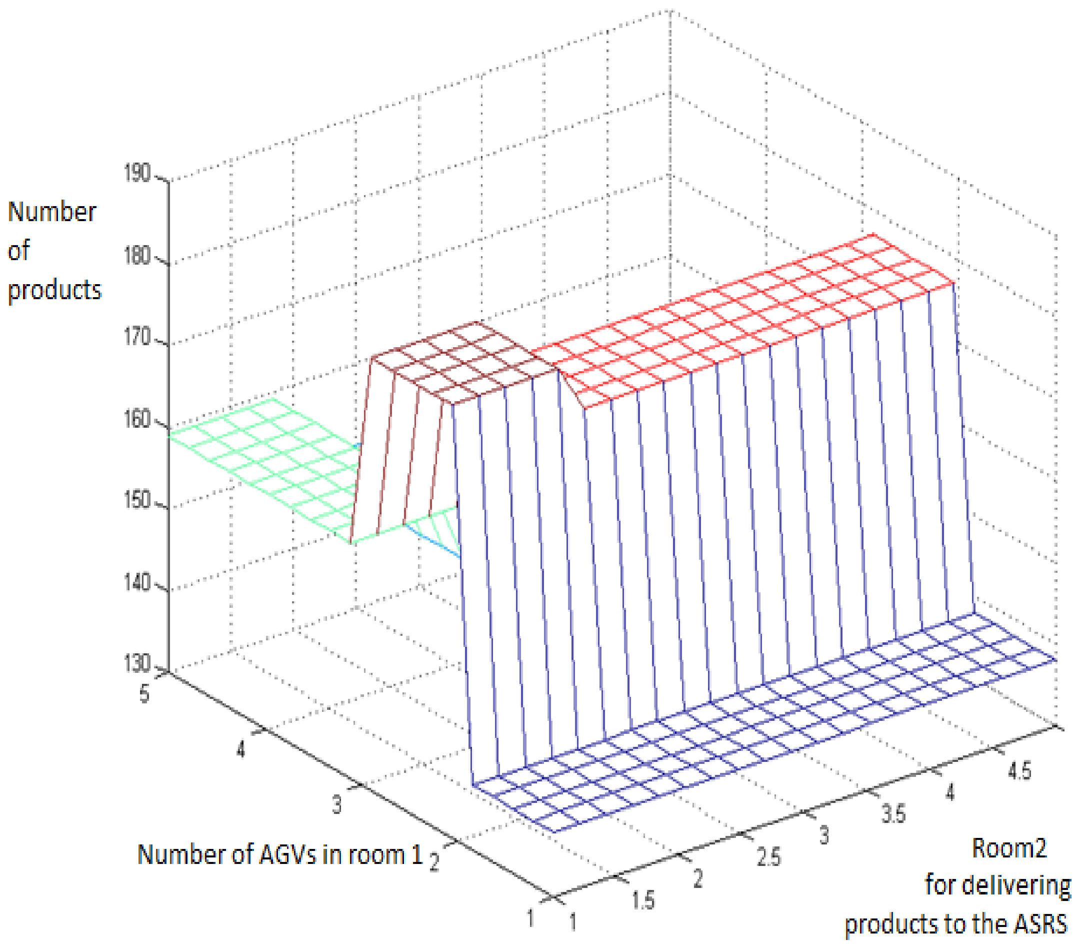
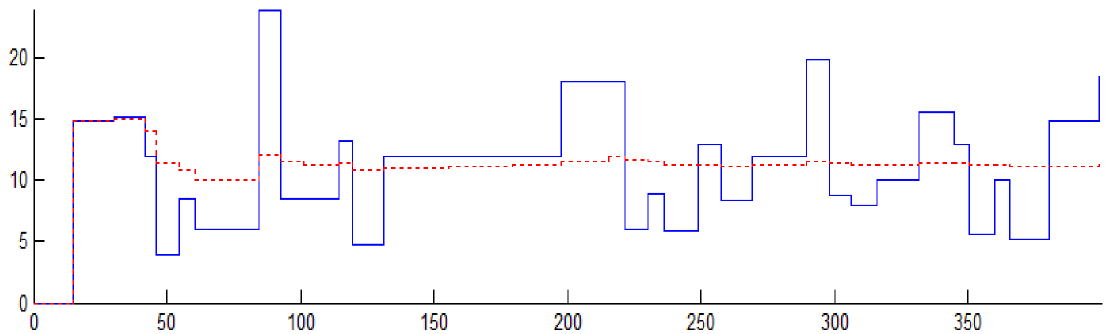


Figure 6.3: Optimization Model for Determining AGVs

Figure 6.4 (a-d) demonstrate the fluctuation of dynamic arrival distance commands for AGVs 1 through 4 in 395 time units. In addition, it depicts time period used for each smart node which is going to send the signal to the related AGV in order to be started for performing the job. The red color shows the arrival distance mean for all the intelligent devices.

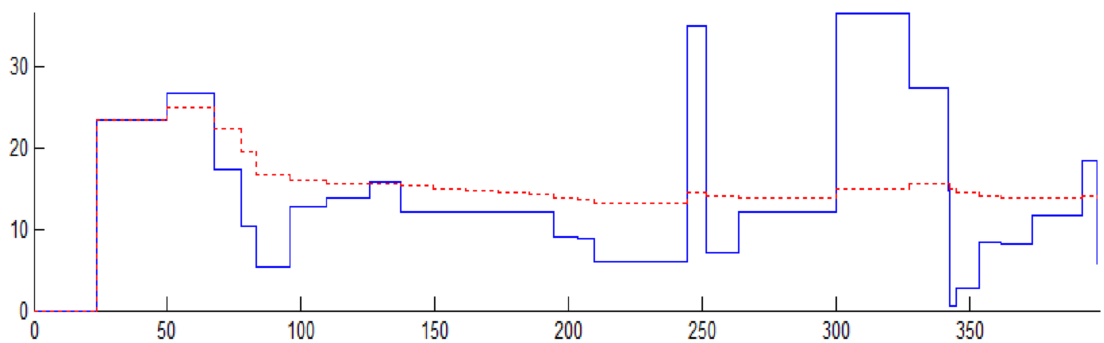
Arival distance



(a)

Time units

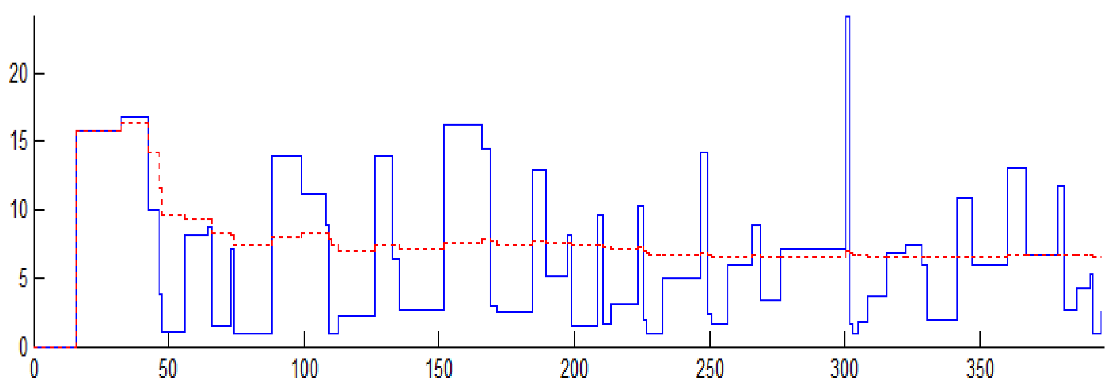
Arival distance



(b)

Time units

Arival distance



(c)

Time units

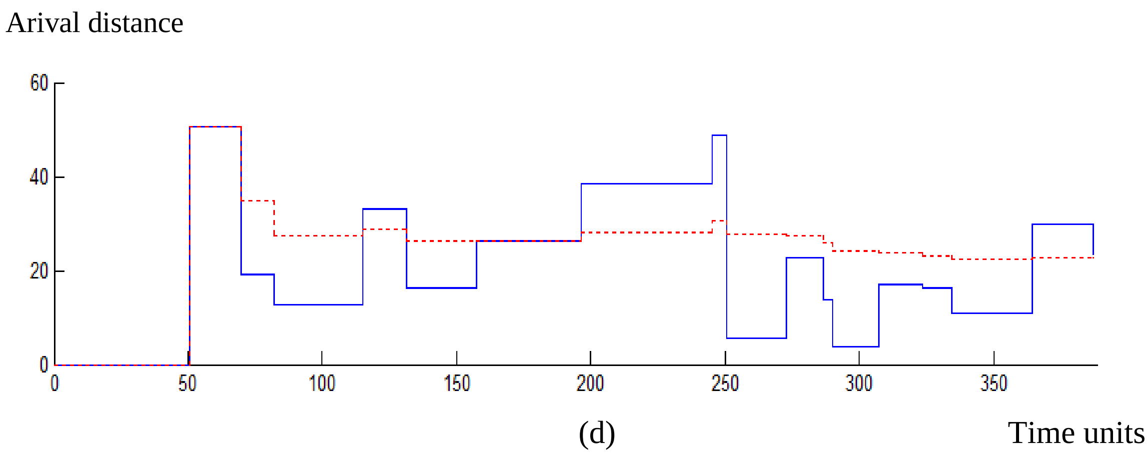


Figure 6.4: Arrival distance commands

Figure 6.5 depicts the total number of products which have been entered and delivered during 395 time units in the supply chain system. As can be seen, two rooms are provided that totally 194 products come to the first room and 186 products exited and rest of them stayed in the room. Therefore, 183 products were brought to the next room by related AGVs and also 170 products delivered to the retail. In this case, there are two types of the products which the first type is shown by blue color and the second type is shown by pink color.

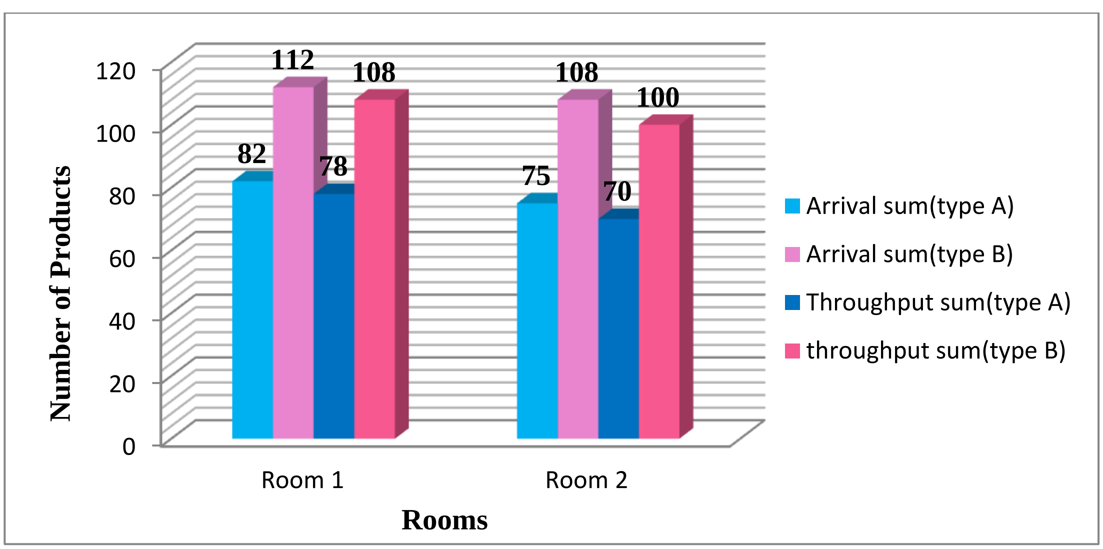


Figure 6.5: Number of products in rooms

Table 6.3 represents the whole indices concluded during the same time units for both intelligent rooms. Throughput sum demonstrates the quantity of products output which are delivered for the further job although the number of times per AGV is given in this index for carrying products. On the other hand, AGVs 1, 2, and 3 can transport just three products and the last AGV take only ten products per time. According to the performance, the fourth AGV makes the highest throughput distance and the lowest utilization rate depending on the different orders. Based on the proposed algorithm, all devices are equipped with specific smart nodes in order to negotiate one another in managing variety of instructions. Thus, the smart node, installed on the conveyor in room 1, can communicate with the first and second AGVs with regard to detecting the idle AGV. Consequently, similar utilization values are adapted to both robots approximately for loading and unloading products.

Table 6.3 Performance evaluation of the system

	Throughput Sum	Throughput Rate	Throughput Dist.	Utilization
Input parts	194	0.49181	2.0333	-
AGV 1	29	0.073518	13.6022	0.78572
AGV 2	33	0.083658	11.9534	0.8209
AGV 3	61	0.15464	6.4666	0.1552
AGV 4	17	0.043097	23.2037	0.096318
ASRS	170	0.43097	2.3204	0.70127
Output parts	180	0.45798	2.1835	-

Chapter 7

CONCLUSION

7.1 Conclusion

This thesis has demonstrated the integration of RFID and WSN for the supply chain management system by establishing an intelligent management system. The whole system can be integrated as smart devices in order to communicate with others.

An algorithm is then proposed for the supply chain, including a number of rooms, to satisfy a variety of instructions. Base on the proposed model, the main object of smart node is to identify the exact location of the products. Moreover, it has the capability of sorting different products in terms of various parameters such as expiry date, type, color, and size.

Sensors of smart nodes are allocated to identify objects which may be a concern to the environment. However, the reader of the smart nodes detects tagged products in order to recall them in a convenient time.

This study has also investigated the Structural Health Monitoring (SHM) by applying integration of WSN and RFID. Two methods, comprising of the use of integration of the passive tag with the sensor and also the integration of the tag with the node, were represented to illustrate the benefits derived by the proposed integration in the buildings and bridges, respectively.

Finally, a case study is simulated in the Petri Net Toolbox for the supply chain intelligent system. It demonstrates how the system provides different functions automatically and spontaneously. In addition, the system performance depicted the role of smart nodes in managing several AGVs to load or unload products. On the other hand, it enabled the similar utilization values of the first and second AGVs.

7.2 Future Work

Major future work includes integration of RFID and WSN in traffic control and its influence on structural health monitoring of bridges to be investigated with the use of Time NET. Time NET enables a graphical computer program to model a case with Stochastic Colored Petri Net and Stochastic Petri Net. The system can be modeled in time intervals. Token in Colored Petri Net can be chosen arbitrarily. Colored Petri Net is a suitable tool for simulating the sensor networks.

REFERENCES

[1] K. Domdouzis, B. Kumar & C. Anumba, Radio-frequency identification (RFID) applications: A brief introduction, *Advanced Engineering Informatics* (ELSEVIER), vol 21, no. 4, pp. 350–355, 2007.

[2] M. Ilyas and I. Mahgoub, *Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems*, CRC Press, 2004.

[3] H. Liu, M. Bolic, A. Nayak and I. Stojmenovic, "Taxonomy and Challenges of the Integration of RFID and Wireless Sensor Networks," *IEEE Network*, vol. 22, no. 6, pp. 26 - 35 , 2008.

[4] P. C. Jain and K. P. Vijaygopalan, "RFID and wireless sensor networks," in *Proceedings of ASCNT–2010, CDAC*, Noida, 2010.

[5] J. Sung, T. S. Lopez and D. Kim, "The EPC sensor network for RFID and WSN integration infrastructure," in *proceedings of the fifth annual IEEE International Conference on Pervasive Computing and Communications Workshops*, White Plains, pp 618-621. 2007.

[6] C. Z. Zulkifli, W. Ismail and M.G. Rahman, "Implementation of embeded active rfid," *Electronics World*, vol. 117, no. 1908, pp. 28-36, 2011.

[7] L. Zhang and Z. Wang, "Integration of RFID into wireless sensor networks: architectures, opportunities and challenging problems," in *Proceedings of the Fifth International Conference on Grid and Cooperative Computing Workshops(IEEE)*, pp.483-486, 2006.

[8] J. Mitsugi, T. Inaba, B. Pátkai, L. Theodorou, J. Sung, T. S. López, D. Kim, D. McFarlane, H. Hada, Y. Kawakita, K. Osaka and O. Nakamura, "Architecture development for sensor integration in the EPCglobal network," *White paper WPSWNET-018, Auto-ID Labs*, pp 1-35, 2007.

[9] S. Cheekiralla and D. W. Engels, "A functional taxonomy of wireless sensor network devices," in *2nd International Conference on Broadband Networks*, Boston, pp. 949-956, 2005.

[10] J. Collins , "RFID Journal," Instrumentel Ltd, 20 4 2005. [Online]. Available: http://www.rfidjournal.com/article/articleview/1520/1/1/. [Accessed 7 2012].

[11] "BISA technologies," [Online]. Available: http://www.bisatech.com/product.asp?pid=2&zid=3&do=view&id=50.. [Accessed

7 2012].

[12] H. Ramamurthy and A. . M. Madni, "Wireless Industrial Monitoring and Control Using a Smart Sensor Platform," *Sensors Journal, IEEE,* vol. 7, no. 5, pp. 611 - 618, 2007.

[13] H. Deng, M. Varanasi, K. Swigger, O. Garcia, R. Ogan and E. Kougianos, "Design of sensor-embedded radio frequency identification (SE-RFID) systems," *International Conference on Mechatronics and Automation(IEEE),* pp. 792 - 796, 2006.

[14] L. Ho, M. Moh, Z. Walker, T. Hamada and C. F. Su, "A prototype on RFID and sensor networks for elder healthcare: progress report," *proceedings of the 2005 ACM SIGCOMM workshop on experimental approaches to wireless network design and analysis* , New York,pp.70-74, 2005.

[15] L. E. Miller, "Indoor navigation for first responders: A feasibility study," *national institute of standards and technology,* pp.1-46, 2006.

[16] D. C. Ranasinghe, K. S. Leong, M. L. Ng, D. W. Engels and P. H. Cole, "A distributed architecture for a ubiquitous RFID sensing network," in *International Conference on Intelligent Sensors, Sensor Networks and Information Processing*

Conference, pp.7-12, 2005.

[17] B. S. Prabhu, X. Su and R. Gadh, "RFID based general wireless sensor interface," wireless internet for the mobile enterprise consortium, [Online]. Available: www.wireless.ucla.edu, 2003.

[18] R. Want, "Enabling ubiquitous sensing with RFID," *Computer(IEEE)*, vol. 37, no. 4, pp. 84 - 86 , 2004.

[19] J. Collins , "RFID Journal," BP, [Online]. Available: http://www.rfidjournal.com/article/articleview/2443/1/1/.2006 [Accessed 8 2012].

[20] A. G. Ruzzelli, R. Jurdak and G. . M. O'Hare, "On the RFID wake-up impulse for multi-hop sensor networks," in *In proceedings of (SenseID) Workshop,* 2007,[Online]. Available: http://ruzzelli.org/~aruzzelli/pubs/SenseID07.pdf.

[21] C. Englund and H. Wallin, "RFID in wireless sensor network," communication systems group, 2004, [Online].Available: http://citeseerx.ist.psu.edu.

[22] M. L. McKelvin, M. L. Williams and N. M. Berry, "Integrated radio frequency identification and wireless sensor network architecture for automated inventory management and tracking applications," in *Proceedings of the 2005 conference on*

Diversity in computing , New York, pp.511-536, 2005.

[23] N. Cho, S. J. Song, S. Kim, S. Kim and H. J. Yoo, "A 5.1-µW UHF RFID Tag Chip integrated with Sensors for Wireless Environmental Monitoring," in *Solid-State Circuits Conference*, pp.279-282, 2005 , [Online]. Available: http://ieeexplore.ieee.org.

[24] H. Kitayoshi and K. Sawaya , "Long range passive RFID-tag for sensor networks ," in *IEEE Vehicular Technology Conference* , Vol. 62, No. 4, p. 2696, Dallas, 2005.

[25] G. White, G. Gardiner, G. Prabhakar and A. Abd Razak, "A comparison of barcoding and RFID technologies in practice," *Journal of Information, Information Technology and Organizations*, vol. 2, pp. 119-132, 2007.

[26] K. Finkenzeller, *RFID Handbook: Fundamentals and applications in contactless smart cards and identification*,second edition, England: John Wiley & Sons, Ltd., 2003.

[27] R. Moscatiello, "A Reflection of the future: RFID today," *SGIA Journal*, pp. 25-29, 2005, [Online]. Available: http://www.tagonline.org.

[28] E. Mousavidin, "RFID Technology: An update," *ISRC technology briefing ser ies*,

2004, [Online]. Available: *www.bauer.uh.edu.*

[29] "GS1 EPC eag data standard 1.6," GS1 AISBL, Brussels, 2005- 2011, [Online]. Available: *www.gs1.org.*

[30] D. H. Shih, P. L. Sun, D. C. Yen and S. M. Huang, "Taxonomy and survey of RFID anti-collision protocols," *Computer Communications(ELSEVIER)*, vol. 29, no. 11, p. 2150–2166, 2006.

[31] "Wireless technology advisor," [Online]. Available: http://www.wireless-technology-advisor.com/rfid-range.html. [Accessed 5 2012].

[32] C. .S. Hartmann and L. T. Claiborne, "Fundamental limitations on reading range of passive IC-based RFID and SAW-based RFID,"*IEEE International Conference,* pp.41-48, Grapevine, 2007.

[33] "The Technology of On-Metal RFID," Omni-ID, 2009. [Online]. Available: http://www.omni-id.com.

[34] M. S. Trotter, J. D. Griffin and G. D. Durgin, "Power-optimized waveforms for

improving the range and reliability of RFID systems," in *IEEE International Conference*, pp.80-87, Orlando, 2009.

[35] P. Sorrells, "Optimizing read range in RFID systems," *EDN network*, Vol. 45, no. 25, pp. 173-184, 2000.

[36] Motorola, "Two RF inputs make a better RFID tag," *Motorola*,2007, [Online]. Available: www.motorola.com/web.

[37] I. Kirschenbaum and A. Wool, "How to build a low-cost, extended-range RFID skimmer," *15th Usenix Security Symposium*,2006, [Online]. Available: http://eprint.iacr.org/2006/054.

[38] P. Booth, P. H. Frisch and S. Miodownik, "Application of RFID in an integrated healthcare environment," in *Proceedings of the 28th IEEE EMBS Annual International Conference*, New York City, pp.117-119, 2006.

[39] R. Angeles, "Rfid Technologies: Supply-Chain applications and implementation issues," *Information Systems Management*, vol. 22, no. 1, pp. 51-65, 2005.

[40] T. Datta, D. Sheet, A. K. Si, S. D. Biswas and D. Ghosh, "RFID based airport

logistics management," in *3rd Innovative Conference on Embedded Systems, Mobile Communication & Computing*, Infosys, pp 228-232, 2008.

[41] T. Balch, A. Feldman and W. Wilson, "Assessment of an RFID system for animal tracking," *Georgia Institute of Technology*, Atlanta, 2004, [Online]. Available: http://smartech.gatech.edu/handle/1853/6495.

[42] J. Norman, J. P. Joseph and P. P. Roja, "A Faster Routing Scheme for Stationary Wireless Sensor Networks - A Hybrid Approach," *Secretary Aircc Journal,* vol. 1, no. 1, pp. 1-10, 2010.

[43] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A survey on sensor networks," *Communications Magazine, IEEE,* vol. 40, no. 8, pp. 102-114, 2002.

[44] F. L. LEWIS, "Wireless sensor networks," in *Smart Environments: Technologies, Protocols, and Applications*, New Jersey, John Wiley & Sons, 2004, pp. 11-46.

[45] D. Kohanbash, A. Valada and G. Kantor, "Base Station Design and Architecture for Wireless Sensor Networks," in *International Conference of Agricultural Engineering (CIGR)*,pp.162-175, 2012, [Online]. Available: www.ri.cmu.edu.

[46] K. Maraiya, K. Kant and N. Gupta, "Application based Study on wireless sensor

network," *International Journal of Computer Applications*, vol. 21, no. 8, pp. 9-15, 2011.

[47] P. Y. Chen, W. T. Chen, Y. C. Tseng and C. F. Huang, "Providing group tour guide by RFIDs and wireless sensor networks," *Wireless Communications, IEEE*, vol. 8, no. 6, pp. 3059 - 3067, 2009.

[48] G. Park, T. Rosing, M. D. Todd, C. . R. Farrar and W. Hodgkiss, "Energy harvesting for structural health monitoring sensor networks," *Journal of Infrastructure Systems*, vol. 14, no. 1, p. 64–79, 2012.

APPENDIX

Appendix A: An example of Electronic Product Code

GID stands for General Identifier. In this case EPC code is written in hex.

GID-96	
EPC Binary Encoding (hex)	350007AB70425D4000000586

Header Value (binary)	Header Value (hexadecimal)	Encoding Length (bits)	Coding Scheme
0011 0001	31	96	SSCC-96
0011 0010	32	96	SGLN-96
0011 0011	33	96	GRAI-96
0011 0100	34	96	GIAI-96
0011 0101	35	96	GID-96
0011 0110	36	198	SGTIN-198
0011 0111	37	170	GRAI-170
0011 1000	38	202	GIAI-202
0011 1001	39	195	SGLN-195
0011 1010	3A	113	GDTI-113
0011 1011	3B	Variable	ADI-var

Figure A.1: Header in Electronic Product Code [29]

EPC Scheme	EPC Binary Coding Scheme	EPC Bit Count	Serial Number Limitation
	gdti-113	113	All values permitted by GS1 General Specifications (up to 17 decimal digits, with or without leading zeros)
gid	gid-96	96	Numeric-only, no leading zeros, decimal value must be less than 2^{36} (i.e., decimal value must be less than or equal to 68,719,476,735).
usdod	usdod-96	96	See "United States Department of Defense Supplier's Passive RFID Information Guide" that can be obtained at the United States Department of Defense's web site (http://www.dodrfid.org/supplierguide.htm).

Figure A.2: EPC Scheme and EPC Binary Coding Scheme [29]

EPC Scheme	Tag Encodings	Typical Use
gdti	gdti-96 gdti-113	Document
gsrn	gsrn-96	Service relation (e.g., loyalty card)
gid	gid-96	Unspecified
usdod	usdod-96	US Dept of Defense supply chain
adi	adi-var	Aerospace and defense – aircraft and other parts and items

Figure A.3: EPC Schemes and Their Applications [29]

GID-96				
EPC Binary Encoding (hex)	350007AB70425D4000000586			
Scheme	GID-96			
Total Bits	96			
Coding Segment	EPC Header	General Manager Number	Object Class	Serial Number
Coding Segment Bit Count	8	28	24	36
Bit Position	$b_{95}b_{94}\ldots b_{88}$	$b_{87}b_{86}\ldots b_{60}$	$b_{59}b_{58}\ldots b_{36}$	$b_{35}b_{34}\ldots b_{0}$

Figure A.4: General Manager Number in EPC [29]

GID-96	
EPC Binary Encoding (hex)	350007AB70425D4000000586

Scheme	GID-96			
Total Bits	96			
Coding Segment	EPC Header	General Manager Number	Object Class	Serial Number
Coding Segment Bit Count	8	28	24	36
Bit Position	$b_{95}b_{94}\ldots b_{88}$	$b_{87}b_{86}\ldots b_{60}$	$b_{59}b_{58}\ldots b_{36}$	$b_{35}b_{34}\ldots b_{0}$

Figure A.5: Object Class in EPC [29]

GID-96	
EPC Binary Encoding (hex)	350007AB70425D4000000586

EPC Scheme	EPC Binary Coding Scheme	EPC Bit Count	Serial Number Limitation
	gdti-113	113	All values permitted by GS1 General Specifications (up to 17 decimal digits, with or without leading zeros)
gid	gid-96	96	Numeric-only, no leading zeros, decimal value must be less than 2^{36} (i.e., decimal value must be less than or equal to 68,719,476,735).
usdod	usdod-96	96	See "United States Department of Defense Supplier's Passive RFID Information Guide" that can be obtained at the United States Department of Defense's web site (http://www.dodrfid.org/supplierguide.htm).

Figure A.6: Serial Number Limitation in EPC and its Limitation [29]

Scheme	GID-96			
Total Bits	96			
Coding Segment	EPC Header	General Manager Number	Object Class	Serial Number
Coding Segment Bit Count	8	28	24	36
Bit Position	$b_{95}b_{94}\ldots b_{88}$	$b_{87}b_{86}\ldots b_{60}$	$b_{59}b_{58}\ldots b_{36}$	$b_{35}b_{34}\ldots b_{0}$

Figure A.7: Serial Number Coding Segment Bit Count [29]