PERFORMANCE ENHANCEMENT OF THE EPCGLOBAL NETWORK BY AGGREGATING DATA AT THE EPCIS

A Thesis by

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I have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement of the degree of Master of Science with a major in Electrical Engineering.

Ravindra Pendse, Committee Chair

We have read this thesis and recommend its acceptance:

Kamesh Namuduri, Committee Member

Krishna Krishnan, Committee Member
DEDICATION

This thesis is dedicated to my ever loving parents who offered me unconditional love support and guidance through my carrier and for the immense care and affection. Also this thesis is dedicated to all the admirable teachers for the acquired knowledge and their grateful support.
ACKNOWLEDGEMENTS

Let me utilize this opportunity to express my sincere gratefulness to all those who have facilitate me to complete this thesis successfully. I give all glory and immense to all mighty god who has strengthen me to accomplish all my work successfully.

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I take immense pleasure at this moment to acknowledge with infinite thanks to Nagaraj Thanthry, who is a PhD student at Wichita State University for his unconditional support, timely advice and kind cooperation in completing my thesis. Nagaraj has spent many of his busy days assisting me with my thesis and he was always there for me to discuss with my queries and provided valuable advice. Also I would like extend sincere regards to all my friends who work at WuTAC for their kind cooperation and sharing good times throughout my carrier at Wichita state University.
RFID is a well known acronym for Radio-Frequency Identification, which is a technology similar to the existing bar code identification. This particular technology is capable of uniquely identifying tagged objects, which can be either living or inanimate. Items such as documents, people, animal, vehicles, containers and practically everything on this planet are capable of being tagged. With the enhancement of condensing the size and the cost, RFID has become a promising technology and has created infinite opportunities for new and improved services for consumers.

In particular, RIFD technology will have an extensive variety of positive impacts in the supply chain. The main mechanism by which this will take place is the EPCglobal network, originally proposed by EPCglobal, Inc. The primary purpose of the EPCglobal network is to share product data in the supply chain.

The current architecture of the EPCglobal network presents exceptional opportunities for all- from manufacturers to retailers, to overcome challenges in the supply chain. It is designed to function as a robust, extensible, scalable, and platform independent system. Even though it does achieve the majority of its objectives, it has some limitation when it comes to address the issue of data aggregation methods.

In this thesis, the author analyses the current architecture of the EPCglobal network and provides a detailed explanation of the proposed solution in order to address the issues in the existing EPCglobal network. As the Author states, the current network does achieve the most of its duty, but there are some limitations related to data aggregation at the EPCIS of the retailer. Since every query goes out to the internet in
order to retrieve its master information from the manufacturer’s database, this introduces a significant delay as well as consumes existing bandwidth of the EPCglobal network. The proposed technique introduces a method for aggregating data based on the information in each query and will be aggregated in order to enhance the performance of the existing EPC network. In this thesis, it has been proved that the proposed data aggregation method have enhanced the performance of the EPCglobal network.
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CHAPTER ONE

INTRODUCTION

1.1 Overview of RFID

At some point in our lives, we probably have driven pass a toll road on one of those nonstop, booth-less lanes or used one of those credit-card-style security tag or badge to gain access to which allows only authorized entrance. If so, we have experienced RFID applied technology without even noticing it.

RFID is a well known acronym for radio frequency identification. It is the technique and physical communications by which a unique identifier, within a predefined set of rules, is transferred from a device to a reader via radio frequency waves. In other words, it is an uncomplicated wireless communication technology that is used to uniquely identify tagged objects, which can be either living or inanimate items. Therefore, the variety of objects that can be identified using RFID includes practically everything on this planet.

The main basic components of the RFID systems are wireless radio frequency tags, Readers, Middleware and Back-end databases. Wireless radio frequencies tags are very equivalent to bar-codes accept the fact that RFID tags do not require line-of-sight for identification. RFID tags are small devices that consist of a transponder and an antenna that release data signals. The signals consist of a simple identification number which can be linked to actual information describing the object. The tags are powered by an RFID
reader fine-tuned to the tag frequencies. Multiple frequencies have been identified for RFID that are used for different purposes. These will be discussed in depth in a different section of this thesis.

RFID readers are placed at selected points in the supply chain in order to acquire data from the RFID tags. Upon the RFID reader’s requests, readers send RF signal to power and activate the appropriate tags. Then the reader can process the signals and obtain data from tags.

Collected data may be filtered at the reader and propagated or passed on to the product information databases (connected server) where the middleware is. Then, this particular information can be used by the system as desired according to the requirements of vendors or integrators in order to identify the read objects.

RFID is one of the most promising technologies in today’s world. Its application has the potential to influence an exceptionally wide variety of the population such as adaptors, vendors, integrators and finally the end users. Even though this technology has been around since late 1930s, it had not become a widely recognized technology until the early 1990s. Since then, RFID technology is changing at a rapid pace due to potential users and others curious about this emerging technology. A spike in this technology has mainly occurred due to the efforts of Wal-Mart and the department of defense (DoD) to integrate RFID technology in to their supply chains. In 2003, with the intention of facilitating pallet-level tracking of inventory, Wal-Mart issued an RFID mandate demanding its top suppliers embark on tagging pallets and cases, with the Electronic Product Code (EPC) labels. Shortly thereafter, the Department of Defense (DoD) promptly followed suit and issued a similar mandate to its top 100 suppliers to have EPC
labels in their products as well [2]. This in turn drove others to integrate RFID technology into their supply chains. Preliminarily, these companies were motivated by the increased shipping, receiving and stocking effectiveness, minimized costs of labor and storage and of course, reduction of product loss at the pallet level. By implementing this technology into this field, which is capable of being easily observed and monitored, inventory has become a much easier task.

Wal-Mart and the DoD are the world’s largest supply chain operators. As a result, RFID mandates have gained unexpected growth in the RFID industry as well as carrying this promising technology into the mainstream.

1.2 History of RFID

It is quite a complicated process to trace the history of RFID technology, since it does not have a well defined starting point. However, several reliable sources revealed that the RFID technology was invented by a Russian inventor known as Leon Theremin in 1946. His invention was an espionage tool, in other words it was a spying tool for the Soviet Union [1].

In addition to that, the RFID can even be traced back to World War II, in that era the Americans, Germans, British as well as Japanese were all using radar which had been invented in 1935 by well known Scottish Physicist Sir Robert Alexander [2]. His mechanism was to inform the users of approaching planes while they were miles away from the base. The main issue was the base could not recognize whether the plane
belonged to them or to the enemy [2]. This was the main drawback of this particular invention.

Then the Germans discovered a much better mechanism compared to the previous one. When the pilots returned to their appropriate base, a signal from the plane would get reflected back to the base so that this method would help the radar crew at the base to recognize the planes belonging to them [2]. This was the first passive RFID system discovered, which will be precisely discussed in a later section.

On the other hand, Watson-Watt who worked as head of the British secret project discovered the first active RFID system called Identify Friend or Foe (IFF). It was much more advanced than the above mechanisms. In this particular mechanism, they inserted a transmitter on each British plane, when it receives signal from its base station, the plane begins broadcasting signals back to the station. In this situation, the base station would recognize the signal that was sent from the plane and identify it as a friendly plane [1]. As a matter of fact, the current RFID technology works on the same basic concept.

In 1973, Mario W. Cardullo claimed the first U.S. patent to invent the active RFID tag with rewritable memory in it. In that same year, a Californian entrepreneur named Charles Walton claimed the patent for the passive transponder that was discovered to open doors without using a typical key [1]. In this innovation, an RFID tag was used instead of the key. In other words, a passive transponder was embedded into a card, which can communicate via a signal to a reader that was inserted in the door. The reader in the door releases the lock, every time it detects the legitimate or the unique identity
number that was stored in the RFID tag.

However, not only individuals but also the U.S. government was involved in the RFID Field in that time period. In the mid 1970s, Los Alamos National Laboratory was developing a RFID system to track nuclear materials for the Energy Department [2]. A group of scientists came up with a proposal to insert a transponder into the trucks of the Energy department and readers at the entrance of secured services. When a truck enters at the gate, the gate antennas would power up the transponder in the truck and get the response signal back from the truck which would consist of information about the particular truck. This could include a truck identification number, the driver's ID and other potential data that would be important data for the Energy Department to evaluate in order to keep track of their stocks as well as their supply chain.

After implementing this project at the Energy Department, this proposal was commercialized in the mid 80s and the Los Alamos scientists who worked on the project had decided to leave in order to form a new company to develop automated toll payment systems. These particular automated systems have developed into one the most extensively used system around the world.

At the same period, Los Alamos scientists also developed a passive RFID tag for cows, at the demand of the Agricultural Department [2]. This developed in the Agricultural Department due to the lack of tracking of cows while they were on medication. When cows were ill, they were being treated with special hormones and medicines. However, it was very complicated to ensure that each cow got the precise dosage and not one was given two doses accidentally. For this particular issue, this group
of scientists invented the passive RFID system that was used with UHF radio waves.

In the early 1990s, the ultra high frequency (UHF) RFID system was discovered and copyrighted by a group of engineers from IBM. This UHF RFID system allows reading the tag from a longer range up to 20 feet along with much faster data transfer as compared to other systems [2].

In the late 1990s, UHF RFID had a sudden boost in the market when a group of gigantic companies such as EAN International, Proctor & Gamble, Uniform Code Council and Gillette started funding to launch the Auto-ID Center at the University Of Massachusetts Institute Of Technology. In this project, a couple of professors were involved in researching low cost RFID tags for products which are to be tracked throughout their whole supply chain. Their main idea was to insert only a serial number on to the tag to keep the price low. This idea revolutionized the way that people thought about RFID in the supply chain.

Eventually, the Auto-ID center accomplished an excellent foundation by gaining the support of hundreds of huge companies including the U.S. department of defense and numerous major RFID vendors in order to keep this brilliant technology going further into the future.
1.3 Current Implementations of RFID

RFID technology has been experimented with in many ways, such as wristband, payment cards, Soccer balls, casino chips, power tools and many more. Further, it has been proven that this technology has its potential to not only to revolutionize the supply chain, but also to have an unpredictable positive effect on a person's lifestyle. The following instances point out how efficiently RFID technology is being implemented in real-world environments.

In minor-league ball games at Jacksonville and Nashville, RFID technology is used by inserting RFID chips into wristbands for spectators to purchase cashless payments for foods, drinks and other items at the concession stands [5]. This made the concession line move much faster during the intermission of the game. A test indicated a 10% increase in per-person spending compared to a regular game which attracted this particular technology into the sports organizations.

Similarly, Jacoby Medical Center in the Bronx, New York, invented a way to apply RIFD technology into their system. They inserted a RFID chip into the wristbands of their patients, each tag holds information such as the patient's name and medical record number, so that nurses can easily scan it by using a hand held PC which included a RFID reader to pull previous records of the patient’s from the hospital database [5]. This particular method has led to drop in drug-administration errors as well as improvement of productivity in the hospital.
On the other hand, Robert Bosch, a company which sells very expensive tools, has found a way to implement RFID technology into their system in order to protect its customers as well as their sales [5]. It has been reported that every year, stolen tools cost its customers such as construction industries an estimated one billion dollars in replacement costs associated with stolen merchandise. They embedded a RFID chip into their every expensive tool along with the RFID reader and software in order to track the stolen tools.

In casinos, they have introduced the RFID technology to their gambling chips in order to prevent the use of counterfeits. The Gaming Partner International Corporation has produced a gambling chip with a RFID placed inside [5]. Also they have sold more than 3 million RFID gaming chips along with readers. These chips have made a revolution in the gambling field and more casinos have shown interest in using these RFID chips in future.

American Express Corporation started issuing their payment cards containing a RFID chip in it. This will require the store to have a RFID reader installed at the store in order to scan the payment card instead of ordinary fashion of swiping it. Shortly, this method was followed by many companies such as Master cards, Visa card and etc to make the customer’s life much simpler and faster in this rapidly growing world.

As RFID chips and readers get more affordable and available, many applications tend to develop in this field. For example, a doctoral student from the University of Florida has created an RFID grid in the carpet of the dorm hallway and along the outdoor walk way up to the university, in order to help visually handicapped students to navigate
the campus using a hand-held RFID reader. Another Graduate student from the University of Washington has used RFID tags in the research of genetically modified trees. By inserting a RFID chip into a tree that can be interpreted by a reader inserted into a hand-held computer, monitoring throughout the trees life can help to develop conservation techniques [5].

Considering the above facts, RFID technology has a rapid rate of development and the ranges of applications are constantly expanding. Some applications are already being commercialized and other capable applications are still being developed in order to adapt to the real-world necessities and policies.

1.4 Current Issues.

RFID has become a promising technology and has created infinite opportunities for new and improved services for consumers. However, RFID has its own complexities such as implementation issues, compatibility issues and mainly privacy and security concerns to overcome in order to safely lead this technology into the current market. Overall, most of the issues were eclipsed by the security and privacy concerns, due to the public attention. This has significantly affected the pace of the RFID development process. The following section highlights some issues that contribute to slowness of the process.
1.4.1 Privacy and security issues

If the RFID is not killed at the point of sale, the RFID would get carried out to the customer’s personal world, which could represent vulnerability in the privacy of the consumer. The unique ID attached to the purchased item can be read and tracked by any organization without the notification of the consumer. This information can be used in order to benefit the organization for their future sale or this private information could be sold to a third party. Organizations carrying out surveillance do not have to be the manufacturer or reseller. Since the RFID readers are extremely low-priced, even a hobbyist snooper or private investigator could take advantage of this technology to acquire the private information of consumers.

A perfect example for personal privacy vulnerability pertaining to RFID is insurance companies, which would be able to read the RFID tags of medicine purchases and track their customers, so that they can accept or deny insurance policies based on their customer’s records. This could lead one party take the advantage of another party which causes an enormous threat to the privacy of individuals. Another aspect would be the malicious use of readers which could read RFIDS from several yards away and gather useful information from individuals and use that gathered private information against them.

When considering the invention of human implantable RFIDs, VeriChip personal identification system is a tiny RFID about twice the length of a grain of a rice, which is
implanted into human bodies in order to verify criteria such as identity verification, medical records access and other uses [1].

After development of the Verichip, there were issues raised related to privacy, security as well as health. Initially, most of the issues were related to privacy and security, which there is a much higher potential of stored information in the chip being easily stolen by malicious readers, due to the fact that the data stored in the chip is unencrypted and does not have a special functionality to only authorize certain people to read the data. Also, the chip could lead to cause such issues as identity theft, allow access to protected private database, etc. Finally, not only privacy and security issues, but also there were health issues related to this technology. There have been research articles which clearly stated that implanting RFIDs into human bodies could cause cancer. However, after all the above obstacles, RFID field is still proving to be a promising technology in the current market.

1.4.2 Implementation Issues

In the start, RFID was mandated by a number of companies such as Wal-Mart, DoD and etc, and it was successfully implemented at a certain level, where it seems to be operating without any issues. But the question is; will RFID be able to be implemented and adopted throughout the whole supply chain?

There are quite a few issues that have already been noticed when implementing RFID throughout the supply chain. The goal of the RFID is to develop and implement the
network called EPC global network which is a set of standards and architecture designed to construct the idea of the “internet of things”. As the field of RFID develops, the volume of data generated by each implementer goes much higher, despite the fact that each item is tagged with a unique identification, and the information related to that item is located in the remote place in a data center that belongs to that respective manufacture. According to RFID architecture, every item purchased by the consumer must query its manufacturer’s database via the internet in order to retrieve the data of that particular item. Therefore, a large amount of data can be generated by all RFID implemented stores which could definitely overwhelm all existing infrastructure components. Also, it has been clearly documented that current databases will not be able to support this large volume of data. As an example, if the RFID is completely implemented, it is estimated that 7 million terabytes would be generated by only Wal-Mart stores on a single business day[6]. It is possible that every item in this world could be tagged with a RFID including human being to animals to practically every thing on this planet. Therefore, the amount of data generated would be unimaginable and not only the EPC global network, but also the Internet and network infrastructure might collapse under such a heavy data load.

Other implementation issues would be implementing guidelines for the sharing of RFID transactional data between other corporations, maintaining a global standard for RFIDs and the replacement of existing bar-code technologies with RFIDs.
1.5 Organization of Thesis

In this research, the Author presents a special data aggregation technique at the local EPCIS, in order to enhance the performance of the existing EPCglobal network. The thesis is organized as follows. Chapter one presents an introduction to RFID technology, the history of the RFID, its development throughout the years, current applications, privacy as well as security issues and finally the implementation issue of this technology. Chapter two provides a literature survey including detailed survey of the components of RFID system along with its basic physics. In addition to that, this chapter also explains and compares the RFID technology with the existing bar code technology. Third chapter presents a detailed analysis of the EPCglobal network architecture and its operation in the supply chain. In this chapter, the author indicates the current issues as well as what factors leads it to degrade the performance of the EPCglobal network. The fourth chapter provides in detailed analysis of the problem description and proposed the solution to the problem. In this chapter, the Author proves the capability of proposed technique which leads to enhance the performance of EPCglobal network by using calculations and simulations. In final chapter, the Author concludes this research and offers few guidelines for future research on this technology.
CHAPTER TWO

LITERATURE SURVEY

In this chapter the author presents a detailed survey of the radio frequency identification (RFID) technology, including its physics, components, standards and comparisons with adjacent technologies that are similar to RFID technology.

2.1 Physics of RFID

RFID technology makes use of electromagnetic waves in order to exchange information between RFID tag and the reader. Electromagnetic waves are broadcast or formed in space by utilizing electric and magnetic components. These waves are formed by coupling an electric field and magnetic field. In the electromagnetic field, the electric field and magnetic field are perpendicular to each other and to the direction of the wave. Electromagnetic waves are categorized according to their frequency. For example, in order of increasing frequency: radio waves, microwaves, terahertz radiation, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays. Radio waves are low-frequency electromagnetic waves which fluctuate more slowly with a longer wavelength than other types of electromagnetic waves. Radio waves share many common characteristics with other types of electromagnetic waves; however, they vary from light waves and microwaves in several respects.
Radio waves and light waves pass through air; however, radio waves have a superior ability to penetrate other materials, such as wood, cloth, cardboard, plastic, etc. than light waves. Radio waves have difficulty passing through graphite, metal, sodium and liquids; therefore, these substances are called opaque materials. The level of restriction radio waves experience when penetrating these substances depends on the frequency of the radio wave. Low-frequency and high-frequency waves can more efficiently go around (in the former case) or penetrate (in the latter case) the opaque materials than ultra-frequency waves. However, low-frequency or high-frequency RFID tags are too large and they are financially prohibitive compared with ultra-frequency RFID tags. Therefore, ultra-frequency RFID tags have become the standard for the RFID supply chain.

2.1.1 Frequency and Wavelength

The frequency of a wave refers to how often the particles of a medium vibrate when a wave passes through the medium. Frequency is measured in units of Hertz (Hz), where one hertz is equivalent to one complete wave cycle per second.

Wavelength is defined as the distance between two successive peaks of a propagating wave of a known frequency and it is measured in meters. The frequency and wavelength of a particular wave are proportional; higher frequencies are associated with shorter wavelengths and vice versa. Figure 2-1 describes the relationship. Table 2-1 describes allocated frequency bands and their related wavelengths for RFID systems.
Allocated frequency bands and their related wavelengths for RFID systems

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<th>Wavelength (approx.)</th>
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<td>23000 meters</td>
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<tr>
<td>High Frequency</td>
<td>13.55 -15.56 MHz</td>
<td>22 meters</td>
</tr>
<tr>
<td>Amateur Radio Band</td>
<td>430 – 440 MHz</td>
<td>69 centimeters</td>
</tr>
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</table>
Ultra-high Frequency | 860 – 930 MHz | 33 centimeters
---|---|---
Microwave Frequency | 2.4 – 2.4835 and 5.8 GHz | 12 centimeters

Table 2-1 [8]

2.1.2 Low Frequency RFID systems

As Table 2-1 describes, low-frequency RFID systems fall in the range of 9 to 135 KHz. This particular range is distinguished by its long wavelength and use by long range radio communications. In the field of RFID, typical low-frequency RFID systems generally use the 125 KHz to 134 KHz frequency range and this low frequency is usually used by passive RFID tags, which will be discussed in a later section. These passive tags have a low data transfer rate while communicating with a reader. Also, low frequency tags operate well under environments containing liquids, metals, dirt, snow, or mud. Low frequency RFID systems are frequently used for tagging animals, vehicle immobilizers and access controls and considered the oldest RFID systems in existence and its low frequency range is accepted worldwide [8].

2.1.3 High Frequency RFID systems

High frequency ranges from 3 MHz to 30 MHz however, typical RFID high frequency system ranges 13.55 to 15.56 MHz and the wavelength of 22 meters. Similar to the low frequency RFID system, high frequency system uses passive tags which have the
same characteristics as low frequency RFID systems, such as slow data rate between the reader and the tag. However there is better performance with respect to liquids and metals.

High frequency RFID systems are generally used for access control, smart cards, biometric identification systems, luggage controls, libraries and apparel management systems. High frequency RFID systems have been successful in item level tagging. As a fine example, one of the leading shipping companies named DHL has already announced their plans for item level tagging for all their deliveries they ship, and they have successfully implemented item level tagging by using the 13.56 MHZ Identec tags. Also it has already been authorized in the United States to broadcast up to 30 micro volts effective radiate power (ERP) which is measured at 30 meter in range using high frequency RFID systems [8][1].

2.1.4 Amateur Radio Band RFID systems

In amateur radio band RFID, the system operates at the range of 430 to 440 MHz and has a wavelength of nearly a meter. This radio band has come forward as an RFID channel in number of applications. Due to the fact of its nature, this signal system can propagate around barriers such as vehicles, containers and other large obstacles. The other advantage of this band is the power requirements. The amateur band active system requires only 1 milliwatt for 100 meter communication, where other band such as UHF system would need more than 100 milliwatts in order to accomplish the same task. This amateur radio band system has been used by the Department of Defense for equipment tagging over the last ten years [9].
2.1.5 Ultra-high Frequency (UHF) RFID system

UHF falls in the range of 860 – 930 MHz, however, the RFID system operates at the frequency of 915 MHz in the United States, but it operates at different frequencies in other countries. In Europe, it operates at 868 MHz, and in Japan it operates at 954 MHz, therefore the operating frequency of UHF depends on the country that it is used in [7]. Tags and readers are manufactured in terms of old EPCglobal specifications for the class 0, class 1, and class 2. In this particular UHF RFID system, both passive as well as active tags are available and they are capable of storing up to 8000 characters and have a read range of 4 to 5 meters. Unlike LF and HF RFID systems, UHF has a faster data transfer rate between the reader and the tag and it has tag read rate of 1600 tags per second [8]. So far these tags are the least expensive to produce and they are commonly used in supply chain applications for pallet and box tagging. In addition to that, they are also used for electronic toll collections and some companies use these tags as asset management. The only issue that arises in the UHF tags is the inconsistent frequency applications that have been deployed around the world.

2.1.6 Microwave Frequency RFID system

Finally, the microwave frequency utilizes upwards from 1 GHz, but typically the microwave frequency RFID system functions either at 2.45 GHz or 5.8 GHz at a wavelength of nearly 15 centimeters. Microwave RFID systems commonly use active tags as well as passive tags. The active tags are capable of storing up 16000 characters
and tag read range up to 10 meters, while passive tags have a read range of up to 100 meters [8]. The only downside of these types of tags are the frequency that they use is also used by different technologies such as cordless telephones, medical equipments and microwave ovens. Therefore, there is a higher potential for interference between those devices and the RFID systems. However, cautiously managing these RFID systems can eliminate the above malfunctions. This particular RFID system is often used in electronic toll collection applications and for real time locations of assets and etc.

2.2 Components of an RFID system

An RFID system consists of many components that work together in order to accomplish its task, which is to capture, integrate and exploit data and information. This section illustrates in detail all the components of the RFID system. In addition, the responsibilities and interactions with other components of the current RFID system will be presented. The main components of RFID system are as follows:

- Tags
- Readers
- RFID middleware

2.2.1 Tags

An RFID tag is a small object that can be attached to a product, animal or person in order to identify and track it by using a radio wave. These particular tags are also called transponders that are consisted of a microchip and an antenna. These elements are connected to a fabric called substrate and are fixed into the
surface of the substrate at some level. The inlay usually is enclosed in a material that provides protection to it. This shield can be a ceramic, plastic, epoxy or glass. Because of this protection, the tags can be expected to operate even in the harshest environments such as wet, cold, heat and even exposure to strong chemicals. These tags can be mainly categorized into three types as follows:

- Passive tags
- Active tags
- Semi passive tags

**Passive tags**

Power to tags usually comes from a battery which is located in the tag, but passive tags do not have an internal power source; therefore, they derive power from the reader’s radio wave and broadcast their encoded data in the backscatter transmitted back to the reader. Due to the nature of these types of tags, they require a strong signal from the reader in order to function in a proper manner. Due to this fact, everything depends on the reader's signal. If the signal strength of the reader is poor, the passive tags produce weak signals back to the reader. This could lead to improper data transfer between the reader and the tag and create confusion in the RFID system [7].

Passive tags only transmit data when they are in the field of a reader’s boundary. If not, they remain silent. Compared to active tags, passive tags are much less expensive than active tags, and they much more ideal to implement in the supply chain as well as item level tagging. Passive tags are most ideal in environments where the movement of tags is extremely reliable as well as dependable and controlled with minimum security.
Active Tags

On the other hand, unlike passive tags, active tags have their own internal power source in the tag. This enables it to power the integrated circuit which is contained in the tag and broadcast the signal to the interrogator in order to exchange information between the tag and the reader. The power usually comes from an onboard battery, but it could also be come from another source. Active tags are capable of broadcasting data with greater ranges on the order of hundreds of meters. Also they have greater capacity to store data and better processing power, with a battery life of up to 10 years [8]. They also have a better ability to work with highly weak reader signal. On top of that, they are capable of integrating sensors that record and time-stamp such telemetry data as location via GPS, temperature radiation and any data tampering events [9].

These tags also can be referred as a micro computer, because of the potentials such as operating sensors, accomplishing calculations and logic operations, encryption and decryption and most modern two-way wireless communication over extensive distances.

The only downfall of this technology over the passive tag is the cost of the active tag. It could cost as much as 20 dollars [8][1], which lead the active tags to the back seat.

Semi passive tags

Semi passive tags are comparable to the active tag, in that it does have its own internal power source. The only difference is that the battery supplies power only to the
microchip and does not broadcast the signal. The signal of the semi passive tag works exactly like the passive tag, in that it is modulating the backscatter. The benefits of the semi passive tags are, primarily they are capable of being read at higher speeds than passive tags. Secondly, it has the ability to continuously monitor and record external conditions such as temperature, data tampering and etc. Finally, the semi passive tags will transmit data, even in the presence of opaque materials that would restrain the data transmission of the passive tags. Overall, the semi-passive tags proved to be a more superior technology than passive tags, except for the fact that the cost of the semi passive tag was only the draw back comparing to the passive tag.

2.2.2 Readers

RFID readers can also be referred as interrogators that are capable of reading data from RFID compatible tags. A reader is the central nervous system of an entire RFID system. The term reader should be “reader/writer” according to the task that is being offered by the reader, because it does not only read, but also it has the capability to write data into writable RFID tags.

The reader utilizes its antenna to reproduce tags and read their data and transmit those data via a network to the middleware, where the data is processed. The process is done by a reader transmitting a simple query and a tag within range of the reader’s field would respond with the necessary contents of the tag, which would complete the data transaction between the reader and the tag. In today’s world, there are readers that are capable of performing sophisticated additional tasks such as transmitting/receiving
authentication information, activating/deactivating tags and enabling/disabling functionalities within the RFID tags.

A typical RFID reader would consist of a transmitter, receiver, microprocessor, memory, input/output channels for external sensors, controller, communication interface and power. These components located in the reader would work together in order to accomplish its task.

Readers can be mainly classified into stationary readers, handheld readers and mounted readers depending on the configuration and the system of operation. Readers are also categorized according read performances such as identification range, identification rate, read range, read rate, writer range and finally write rate.

In the RFID system, readers and tags follow some set of rules such as protocols in order to communicate between each other. These particular protocols are called singulation and Anti-Collision protocols and they are defined to prevent read collisions of different tags responding to the same reader. Slotted Aloha, Adaptive Binary Tree and Slotted Terminal Adaptive are some of the examples of anti-collision protocols. On the other hand, readers are also responsible for communicating with the rest of the network with a set of reader protocols in order to achieve its task in the RFID system [7] [10].

2.2.3 RFID Middleware

The main task of the middleware is to process a raw tag database from the readers and convert it into useful, meaningful information. Middleware works with in the restrictions of a company's corporate standards and security policies and it must interface with the corporate management systems such as enterprise resource planning systems and
along with the supply chain partner’s systems. Even though companies have their own unique requirements and set of circumstances, middleware must provide the following functionalities to accomplish its role in the RFID system [4][7].

- Management of devices for both readers as well as other devices
- Integration and collection of data
- Data acquisition and structuring
- filtering and routing of data
- Line management and control
- EPC allocation. (global as well as local)
- Track and trace applications
- Graphics formation

### 2.3 Bar codes and RFID tags

Bar code and RFID are two different technologies, but functionalities of RFID tags can be viewed as a very dominant upgrade to the barcode. However, there are many similarities as well as differences in these two technologies. Unlike RFID, Bar code technology is an automatic identification in which a combination of numbers and characters are encoded in patterns such as vertical bars, squares and dots. These particular patterns can be read by a scanner that translates these patterns into real data and transmits them to a computer, where the transferred data are processed and identified. Barcodes can be used to identify products, shipments, documents, tools, equipments and etc, but it has its limitations when compared to the RFID tags which will be described in the following section.
2.4 RFID comparison with Bar codes

Bar codes offer major advantages when compared to the physical processes they usually replace. Compared to manual data entry, bar codes speed up data collection in with very high accuracy. The overall accuracy of the bar code reading is one error per three million. When compared to RFID, bar codes have the following advantages over RFID.

- Price of the tag
- Universal presence and approval
- Human readable and world wide acceptance
- Privacy
- Establishment of the technology

On the other hand, RFID claims numerous advantages over older bar code systems and they are listed below [7].

- Active and dynamic data
- Direct line of sight is not required as is the case with bar codes.
- Higher read range
- Capacity to store data a the tag
- Multiple reads and survivability
- Programmability
- Accuracy
- Much higher read rates
By comparing both technologies, it is very evident that RFID has much higher potential to overtake the existing bar code system; however there are some factors that would put the RFID system in the back seat. Mainly, its cost differential is too high when compared to bar code system; therefore, RFID is highly unlikely to replace the bar code system in item level tagging. On top of that, the existing bar code system is too successful, reliable and widely deployed and the privacy issues are very minimal as compared to RFID tags. This does not mean that the RFID technology is a failure. Due to its infancy, the technology is just not widely available as well as acceptable. Therefore, upgrading the current bar code system with RFID system would take time.
CHAPTER THREE

EPC GLOBAL NETWORK

EPC global network was originally developed by the Auto ID center and it is a platform to facilitate identification, tracking, sharing and tracing of every possible object in the supply chain. This particular architecture has the capability to uniquely identify and record all significant modifications such as change of location, status and the ownership of assets as they move along through the various phases of their supply chain. The EPCglobal network was originally invented by Dr. Sajay Sarma and Dr. David Brock of MIT [18]. According to them, the EPCglobal architecture consists of four main core designs and they are as follows:

- The Electronic product code (EPC)
- The ID system
- EPC middleware
- EPCglobal network information services

This chapter will explore the duties of the above components of the EPCglobal network and how these components function together as one system. Figure 3.1 represents the typical architecture of the ECPglobal network.
3.1 Electronic Product code

An electronic product code is a number that is electronically encoded in the RFID tag, which uniquely identifies the particular item. The scope of the network is decided by the size of the EPC. An EPC is available at many different scales. For example, the 96 bit long EPC can uniquely identify and track several trillion items. Every item will have its own description and a history of its movement recorded on its manufacturer's database and would only be accessible to authorized users in the supply chain.
There are two identification systems currently available for commercial auto identification such as Universal Product Code (UPC), which is used in the United States and the European Article Number (EAN) that is used in the Europe [10]. Currently all the consumer goods as well as the industrial goods are almost all identified by these two systems around the world. They are usually available in bar codes, and they enable identification of the type of article being identified.

In order to adopt these two identification systems into the electronic product code, EPCglobal has facilitated all the companies in the world to contribute their present UPC and EAN numbers within its structure. This particular structure is called the Electronic Product code (EPC) and also it is called the first generation identification system specification know as GEN-1. This is the most widely used standard in the RFID field.

Electronic product codes are available in total length of 64 bits, 96 bits and 256 bits. It is very flexible due to its structure and consisted of a variable length header trailed with a series of value fields. Header is the most important value in the EPC, since the length, structure and function is entirely determined by this value. Basic format of the header is illustrated in the following figure [7] [8].

<table>
<thead>
<tr>
<th>Header</th>
<th>EPC Manager Number</th>
<th>Object Class</th>
<th>Serial Number</th>
</tr>
</thead>
</table>

Figure 3.2 Basic EPC structure of a typical tag
3.1.1 Header

The header indicates to the reader the overall length, identity type, current structure, version and the generation of the EPC. Headers are typically either two bits or eight bits while a two bit header can have three possible values and eight bit header can have 63 possible values.

3.1.2 EPC manager number

This is also known as EPC manufacturer number based on the UPC company prefix number. Upon the customer’s requirements they can use their existing UPC number in the space. Also, this entity is responsible for maintaining the following partitions of this EPC format.

3.1.3 Object Class

Object class, which is similar to the stock keeping unit and also refers to the class of the product that is capable of identifying the class of objects.

3.1.4 Serial Number

Serial number is the last field of the EPC frame format that identifies the specific item within the object class.
3.2 Identification System

In the RFID system, the identification system is a specification for categorizing tags and readers of the EPCglobal. Also, it is capable of classifying the way they communicate with each other. This special communication condition is also called the “air interface protocol” and can be described as GEN-2 which illustrates a new set of technologies and the modern way in which RFID readers and tags communicate. This new identification system was published by EPCglobal on December 2004 and it represents great promise to the world RFID community [18].
2.1 Advantages of Gen-2 ID systems

EPCglobal claims to have the following advantages as well as the new features that the Gen-2 ID system sustains [18].

- Capable of quicker and more flexible read rates
- Potential to interoperate with other standards
- Robust tag counting
- Improved security as well as privacy
- Ability of high-function structure
- Reader sessions to control parallel counting with multiple readers
- Fast and High accuracy with the use of advance anti-collision protocols

3.3 EPC Middleware

EPC middleware is a phrase that is generally used to refer to a software application that is located on a server between readers and the enterprise applications. EPC middleware is responsible for serving four main functions in the EPCglobal network and these particular functions bridge the gap between devices and the system that processes data between low level collection of data and useful business information, and between remote devices and software applications. The main four functions are as follows: [18]

- Resolving EPC number
- Filtering and collection of raw data
- Managing readers
- Reformatting data
3.3.1 Resolving EPC Number

As the reader reads the tag information from the item, it passes it on to the middleware to convert that particular raw tag data into EPCglobal specified URI (unified resource identifier) format. In this way, the particular item can be identified from its appropriate EPC information service. The EPC middleware uses this URI to query the ONS (Object Name Server) to locate any available information of item. This is the typical description of how the EPC number gets resolved in the EPC network.

3.3.2 Filtering raw data

Usually, the RFID reader queries three times per second on average in order to obtain tag information from the EPC tag. Therefore, this would create a flood of low-level raw data which is typically not useful business information. For instance, what if a business application requires information such as which tags passed through the entrance, which were suppose to go on the shelf, which were packed in what carton and sent to which customers and etc. The above business information can be obtained from the raw data stream and this procedure is called “filtering and collecting”. Auto-ID center has realized this requirement at the early stages of EPC network and named it as “savant” but today, we call this function as EPC middleware [13][14].

On the other hand, an application level event known as ALE was introduced to the middleware in order to filter and sort the raw data in such way that a particular
application sees only its relevant data and events. By using this method, it ensures that applications are not overwhelmed by a flood of inappropriate data. The function of ALE is also capable of eliminating duplicate reads, accumulation over periods of time, counting, grouping and filtering.

### 3.3.3 Managing readers

Data management function is provided by middleware products, which usually offers a management structure that facilitates centralized management of the reader network. This function includes operations such as tracking the reader’s read rates, changing settings and monitoring its health. However, currently there are no specifications defined for the reader management [15].

### 3.3.4 Reformatting data

Reformatting data is a technique which provides a capability to adopt data into a standard format. In the EPC network, there are so many various middleware products from different vendors or manufactures. Therefore, the middleware has to have a mechanism to distinguish different types of data, in order to successfully communicate with each middleware. Different applications run on middleware need data in different formats and specifications such as record structure, delimiters, spacing, punctuations, blanks, leading zeros and how the metadata is managed and utilized [7][9]. EPC middleware is designed in such way that it has the capabilities to exchange the data in a form that the intended middleware application would be able to recognize and distinguish the data.
3.4 Functionalities of EPC global network information services

The electronic product code can be considered as a typical license plate of a vehicle which does not indicate any useful information other than just bunch of meaningless numbers or letters. However, it is a powerful pointer which points to a database record located in a protected server in the department of vehicle registration where they hold all the valuable information related to that particular unique license plate number. Similar to this scenario, the main function of the EPC is to look up the database that facilitates the server to locate and provide useful information about the requested item in the supply chain. The particular item’s information is provided by the EPC manager or the organization of that item as the item traverses its way through the supply chain. EPC global network information service functionality is divided into three components as following [14][18].

- Object Naming Service (ONS)
- EPC Information Service (EPCIS)
- EPC discovery service (EPCDS)
3.4.1 Object Name Service (ONS)

Object name service is the trustworthy directory for EPC information sources accessible to illustrate the EPC in the supply chain. In other words, ONS is capable of indicating to the local EPCIS, where to locate the information of the EPC in the supply chain. ONS holds an entry for every EPC that is registered and it has pointers to all identified sources of information about that EPC.

ONS follows the same infrastructure as the current domain name service (DNS), in order to resolve the unified resource identifier (URI) into a machine readable IP address. ONS is controlled and managed by Verisign, the company that administered the root domain system for the whole internet. ONS locates two forms of information such as static information and dynamic information. While static information illustrates the item and provides characteristics of the item such as name, source, weight and maintenance instruction, dynamic information is extended across a number of databases and this information describes date and time of item’s arrival or departure at a given warehouse. Dynamic information is updated by the appropriate authorities or organizations while the item moves through its supply chain [13][22].

The structure of the ONS is similar to the DNS; it is implemented hierarchically, in such way that an ONS record will point to other ONS servers that contain more pointers to obtain the required information.

The following procedure will indicate how the EPC gets resolved and retrieved when there is a request for information from the manufacture in the supply chain.
Reader interrogates the necessary EPC tag and acquires the EPC information in binary format. E.g.: 00000000000000000010100100000000 (96 bit long EPC)

Acquired EPC information would be passed on to the local server for further processing. e.g.: 00000000000000000010100100000000

At the local server, EPC is translated into URI. Eg: urn:epc:1.2.24.400

URI is translated into domain name form.

Remove urn:epc e.g.: 1.2.24.400

Serial number of the EPC is removed. e.g.: 1.2.24

Whole string is inverted. e.g.: 24.2.1
Join “onsroot.org” e.g.: 24.2.1.onsroot.org

- The ONS would generate a set of possible URL's.
  e.g.: http://www.example.com/request.php
       http://www.example.com/service/info_request.asp

- The correct URL is selected and extracted.

- Finally, the server sends a request to the URL in order to receive the appropriate
  information from the intended server where the information for the tag is held.

### 3.4.2 EPC Information Service (EPCIS)

An EPC information service is a specification of a standard interface for accessing
EPC shared information. It can also be referred as a set of data repositories that have the
capability to store and share information efficiently about all the items in the supply
chain. The EPCIS has a distributed structure and it is owned and operated by different
companies. Each company has its own business model that is able to read and write data
to and from EPCIS in a standardized method.

Another feature in the EPCIS is the Physical Markup Language, which facilitates
storing data in the servers, these particular server where PML data is stored are called
PML servers. PML is a language for describing physical objects and this language which
is based on XML. This particular feature would make the data of one computer system or
organization readable by a different system and allow organization or storage of any
related information about the item.
3.4.3 EPC Discovery Service (EPCDC)

The main role of the EPC discovery service is to provide tracking and tracing of resources throughout the supply chain. EPCDC can also be referred as a directory service due to its capability to locate the appropriate EPCIS based on information provided by the local services. All the EPCIS that share information throughout the supply chain must be registered with EPCDC in order to facilitate locating information on the EPC network. Upon request of an item’s information, EPCDC will provide a list of possible EPCIS instances with useful information, so that information can be combined into a total chain of custody. However, currently there are no particular specifications and standards defined for the EPC discovery services [17][18].
3.5 Operation of EPCglobal network

At the initial stage, the tag information is attached to the item; this is the point where an item begins its life in the EPC supply chain. After tagging this information to the item, the main information of this tag is recorded with the ONS.

At this stage the information about the tag is put in to its respective EPC information system of the manufacturer of the item. The manufacturer’s EPCIS will register this tag information with EPC discovery service.

As the tag or the item moves through the supply chain, tag will be read at the point of leaving as well as the point of entrance of each stage of its locations such as

Figure 3.5 Overview of the supply chain [14]
as manufacturer’s location, distributor’s and finally the retailer’s and that particular information will be registered with EPC discovery.

- When the retailer gets the product at the final stage, it records the product information in its EPCIS server and the EPC discovery will be notified with this information.

- Upon a retailer’s requirement, the tag will be queried for information of the product. Initially the query will be sent to the ONS in order to fetch the information associated with the EPC tag.

- At this final stage, the root ONS would point the retailer to the manufacturer’s local ONS which in turn points to the manufacturer’s EPCIS. Then the retailer would contact the manufacturer’s EPC server in order to retrieve the appropriate information related to that queried item tag.

As illustrated, the above steps will be repeated for every product in the world for every step in the supply chain. This entire process would allow all the retailers, distributors and manufacturers to authenticate their products, determine the accuracy of the inventory, optimize logistics and prevent counterfeits as well as loss and thefts in the entire supply chain.
3.6 Current issues with EPCglobal network

The current architecture of the EPCglobal presents exceptional opportunities to manufactures and retailers, to overcome challenges in the supply chain and it is designed to function as a robust, extensible, scalable, secure and platform independent system. Currently, EPCglobal network does achieve the majority of its objectives. However, the implementation of the RFID is limited to specific groups and to a certain level, in other words, not all the manufactures, distributors and the retailers in the world use the RFID in their supply chain. As an example, Wal-Mart stores have implemented RFID in their supply chain to the pallet level but not to the item level. Therefore the EPCglobal network has been able handle this amount of traffic with out any major issues. In future, if the RFID technology is implemented throughout the whole supply chain, it will have to face some major issues that would lead to deterioration of the performances of the EPCglobal network.

Mainly, the performance of the EPCglobal is degraded to absence of a data aggregation mechanism in the middleware. When a query goes out to the internet in order to retrieve its information from the manufacturer’s database, it goes to query every single RFID tag and along with that query, the appropriate headers such has TCP, IP and PML headers are carried in order to reach its destination. Due to this, it introduces a delay in the EPCglobal network. Overall, the following are the main issues of the current EPC network and will be described in detailed in the following sections [21][23].
Internet delay and lack of bandwidth utilization

DNS delay

Single point of failure

3.6.1 Internet Delay and the lack of bandwidth utilization

Internet delay also can be referred as end to end packet delay, which is the sum of all the delays experienced by the packet at each hop on the way to its intended destination. This particular delay is consists of two main components such as fixed delays and variable delays. While fixed delays include transmission delay and propagation delay, variable delays include processing and queuing delays.

Transmission delay determines the amount of time needed to place all the bits in the packet onto the wire and it has nothing to do with the distance between the two nodes. While propagation delay is determined by the amount of time required for one bit to travel between two hops. Therefore distance between two nodes will be the main factor in the propagation delay.

When considering the variable delay, queuing delay would be the most important factor when dealing with internet delay. It determines the time that the packet has to wait in the queue before it gets served by processing devices such as routers, switches and other networking devices. This particular delay is proportional to the buffer size. In other words, it depends on the size of the queue and also depends on the amount of the traffic of the network. Finally, the processing delay determines the time it takes to process a packet at the network node that mainly depends on the processing speed of the device and
the congestion of the network. The following figure indicates all the delays that can take
place in typical network.

![Diagram showing network delays](image)

**Figure 3.6** Types of delay on a network

On the other hand, the typical RFID architecture is designed in such way that
every single query will be sent to its respective database via the internet in order to
retrieve the appropriate information. This EPCglobal architecture does not have any
query aggregation protocol to prevent each query being sent over the internet. A typical
query is usually 64 bytes in size and when it carries over the internet, the query goes
along with its headers as nearly the size of its payload. This is not a healthy factor for the
bandwidth of the public network. Due to numerous amounts of queries on the order of
millions, this could easily bring down overall bandwidth efficiency and even could end
up dropping packets that carry valuable information. Especially during the peak usage of
the public network, this would definitely cause a huge havoc in the EPCglobal network
due to the above factors. Mainly, this thesis is focused on the internet delays and the lack
of being capable of managing the public bandwidth, which would cause the EPCglobal
network to function in an unacceptable manner, these factors will be discussed in detail in
the 4th chapter of this thesis.
3.6.2 Delay in DNS

Domain Name System is a well recognized protocol that resolves hostnames and domain names to IP addresses. As mentioned in an earlier section, EPCglobal network’s architecture is designed to convert each tag’s information into a URL and will be sent as a DNS query to the appropriate DNS server or the root DNS server to fetch the corresponding destination’s IP address in order to retrieve data related to the tag. However, originally the DNS infrastructure is designed to resolve Address RRs (Resource Records), Mail Exchange RRs and PTR (Pointer) RRs for reverse DNS lookups but recently internet service providers have expanded these services of the DNS to offer DDNS (Dynamic DNS) to dynamically update name servers, TXT records for Domain Keys and Sender Policy Network, and NAPTR RRs to resolve ENUM (tElephone NUmber Mapping) records for translating telephone (PSTN) numbers to IP addresses which have already placed a heavy load on the Current DNS infrastructure [6][14]. These above factors would add more latency in the response of a DNS query.

On top of that, introducing RFID to the existing DNS infrastructure would absolutely add more latency for the response of the DNS query. Some researchers have indicated that end to end latency of 29% was observed, and the DNS lookup exceeded two seconds which is not an acceptable factor. Therefore, the delay in DNS plays an important role in the EPCglobal network.[6] [23][24]
3.6.3 Single point of failure

Another major vulnerability that could affect the EPCglobal network would be the single point of failure. Single point of failure can be considered as an interruption in the internet or DNS. Interruption of one of these would cause the entire local network to go down which would bring the entire business to a halt due to inaccessibility to the RFID tag information via internet. Therefore, if the business does not carry a local copy of the RFID tag information, there would not be any other option in order to continuing to operate.

In addition to that, another indirect vulnerability to the EPCglobal would be internet attacks such as the numerous worms, denial of service (DOS) and viruses which are capable of bringing the entire business network down. Therefore, in order to prevent these kinds of vulnerabilities, businesses should adopt appropriate security strategies in their system [6] [14] [21].

Overall, having indicated all the issues in the EPCglobal system, the main issue of this thesis is focused on the delays in the internet and the public bandwidth utilization, the following chapter will describe the proposed solution to the issue that the author have observed in the EPCglobal.
CHAPTER 4

PROBLEM DESCRIPTION AND THE PROPOSED SOLUTION

As stated in the previous chapter, there are multiple factors that deteriorate the overall performance of the EPCglobal network. The main factors that lead to the degradation of the performance are Internet delay, the lack of efficient bandwidth utilization of the EPCglobal architecture, delay in DNS and finally the single point of failure. However, the most significant factors are the Internet delay and the lack of bandwidth utilization of the EPCglobal network. This thesis is mainly focused on this particular issue and the solution is proposed in order to minimize the Internet delay and facilitate optimization of the bandwidth utilization of the EPCglobal network to enhance the performance as much as possible.

4.1 Introduction to the problem description

Over the past years, due to the rapid growth of computer technologies as well as computer networks, research has indicated that the number of Internet users have increased in a tremendous amount. Currently, Internet statistics show that nearly 1.24 billion people use Internet. Due to this great deal of Internet usage, and the rapid increment in the future, it is quite clear that the existing Internet infrastructure will unquestionably have issues keeping up with this sort of traffic load.

However, on top of this, the innovation of RFID along with its EPCglobal network has introduced a new field of Internet traffic to the current Internet
infrastructure. As stated in the above section, RFID is technology that is used to uniquely identify tagged objects, either living or inanimate items. In order to accomplish its task in the supply chain, it has to exchange information over the Internet; this particular virtual network is also known as EPCglobal network originally invented by the Auto ID center.

The EPCglobal network architecture was originally designed in such way that the information in each RFID tag would be sent as a query over the Internet in order to obtain the appropriate information related to that particular item. The Internet is a public network where we do not have any control over it, in other words we are not capable of controlling queries that are traveling over the Internet. Due to high congestion of the Internet, there would be a large number of these queries being delayed or dropped in the process of traveling to or from its appropriate manufacturer's EPCIS which would cause apparent havoc in the supply chain. This is mainly due to the absence of any data aggregation mechanism at the EPCIS and will be discussed in detail in following sections.

4.2 Real world scenario related to the issue in the EPCglobal

In the case of the EPCglobal network introducing the RFID traffic into the existing Internet infrastructure, the EPC accessing application will put the network under a considerable load. For example, it may introduce up to 140,000,000 packets or 34 GB of data into the network for every single store inventory [6], and will experience issues such as transmission delay, propagation delay and queuing delay of up to a few minutes under certain circumstances and these figures will grow with time. The retail giant Wal-Mart has already implemented RFID technology in their supply chain at the pallet level,
but that amount of traffic is not significant compared to item level tagging. According to sources, if Wal-Mart alone queried for every single item in its inventory, it would generate 7 million terabytes of data. On top of that, by 2010 half a trillion RIFD tags will be implemented and the growing number of Internet user would absolutely put the existing Internet infrastructure under tremendously heavy pressure [6].

4.3 Analyzing the main issue

As mentioned in the above section, every query goes to its appropriate database as a single IP packet in order to retrieve its information. This particular packet carries the HTTP query as payload and all the appropriate headers along with the packet in order to get delivered to the destination where it belongs. The following information indicates the detailed description of the typical RFID application packet.

Payload = 64 bytes

Headers = XML header (2 byte) + TCP header (20 bytes) + IP header (20 bytes)
= 42 bytes

Total packet size = Payload + Header = 106 bytes

When analyzing, we see that 42 bytes of header is always carried with each 64 bytes payload. When considering the previous stated example in this section, which mentioned that if the RFID is completely implemented in the supply chain, it would introduce nearly 34 gigabytes of data from each store. This number would be equivalent to 140,000,000 packets.
Pay load of the 140,000,000 packets in bytes  = 8,960,000,000  
Headers of the 140,000,000 packets in bytes  = 5,880,000,000  
Proportion of payload to header  = 8960000000/5880000000  
≈ 1.5  

From the above example we evidently observe that the amount of header carried with the packet is nearly equivalent to the amount of bytes carried in the payload. This amount of header introduces an extra delay in terms of propagation, transmission as well as queuing delays. Accumulation of such a delay would cause the bandwidth utilization issue as well as wastage of network resources in the public network.

4.4 Standard procedure of querying the manufactures EPCIS (Scenario 1)
Figure 4.1 Standard data transmission

As indicated in the above diagram A, the retailer is querying its RFID tags from the manufacturer in order to retrieve the necessary information. While querying the manufacturer’s EPCIS, each query travels to the manufacturer as a single packet and it carries the appropriate HTTP query as the payload along with its headers. As an example, I have chosen to query 9 million items from the same manufacturer which are assumed to be intended to the same EPCIS to obtain the appropriate information related to those 9 million RFID tags. While these queries pass through the public network from point A to point B, it would introduce network latency to each packet. This is also known as end to end packet delays and can be categorized as propagation delay, transmission delay and queuing delay. These delays are calculated according to the following specifications and assumptions.
4.4.1 Propagation delay

As mentioned the previous chapter, propagation delay can be defined as the total time required to transmit all the data from the source to the destination. In Author’s scenario, this is the total time needed to transfer data from the retailer’s EPCIS to the manufacturer’s database. The propagation delay is considered as a type of network latency. This delay mainly depends on two factors; primarily the distance between the two locations and other is the physical medium of the link—such as twisted pair copper wire, coaxial, fiber optic or wireless mediums. While the distance between the two locations is measured in meters, the speed of all physical medium is considered approximately as the speed of light. The distance between two locations divided by the propagation speed would give the total propagation delay in the link.

In scenario 1, the distance between the retailer and the manufacture is taken to be 5000 kilometers and the speed of the physical medium is assumed to be the speed of light. The calculation of the propagation delay is indicated in the below section under calculations of the standard procedure of the data transfer.

\[ D_p = \text{total delay of the propagation delay}, \quad D = \text{Distance between the manufacturer’s and the retailer’s location of EPCIS}, \quad C = \text{the speed of light} \] [26].

\[ D_p = \frac{D}{C} \]
4.4.2 Transmission delay

Transmission delay is another type of network delay and it can be described as the total time required to transmit the entire packet’s bits on to the link. This delay is also known as the store and forward delay. This particular delay depends on the total length of the packet and the bandwidth of the link. Total length of the packet (in bits) divided by the bandwidth is known as the transmission delay [25] [26].

In scenario 1, in order to calculate the transmission delay, the author has considered the total packet size as 106 bytes which includes the header and the payload, and the bandwidth is considered as regular Ethernet which is 10 Mbps.

\[ D_T = \frac{L_p}{B} \]

4.4.3 Packetization delay

Packetization is a significant contributor to total end to end delay and this delay can be described as the time needed for a specific application to load an IP packet with data to a certain level. Packetization delay is determined by dividing the amount of payload size in the packet by the rate at which it is filled. This rate is considered as the rate...
of the emulated circuit of the hardware. The following equation derives the packetization delay of the inventory [26].

\[ D_q = \text{Packetization delay} \quad PL_p = \text{Pay load of the packet}, \]

\[ Rate = \text{The rate at which the payload is filled} \]

\[ D_q = \frac{PL_p}{Rate} \]

4.4.4 Queuing Delay

Queuing delay is the most significant factor of all the network delays; it can be described as the amount of time that a particular packet waits in the queue of a router before it gets executed.

In other words, when a packet arrives at the router, each packet takes time to get processed and transmitted. According to the function of a typical router, one packet can be processed at a time, if the arrival packet rate is much higher than the router’s packet processing rate the router would keep the extra packets in its queue before those packets get executed. This waiting time in the queue is called the queuing delay which is measured in seconds; this delay mainly depends on the load of the communication link and the size of the buffer. As stated earlier, if the packet arrival rate is much higher than the packet departure rate of the router, packets would be placed in the queue. The longer they are in the queue, the larger the average queuing delay. If the size of the queue is not sufficient to hold the amount of extra packets that are waiting to be processed, some will be dropped and those dropped packets will need to be retransmitted. These retransmitted
packets would add more delay to the overall delay which would lead to a degradation of the performance of the public network.

In order to calculate the queuing delay for the scenario 1, the author has followed the following specifications and assumptions.

The author has chosen to query 9 million items from a Super Wal-Mart store and assumed that all 9 million items belong to the same manufacturer. When queried, each query would travel to the manufacturer’s EPCIS as a single packet in order to retrieve the appropriate information related to each queried RFID tag. In this scenario, 9 million queried items would travel as 9 million packets to its database where the information is held, related to the RFID tags. Assuming an arbitrary average of 1000 items per product and an inventory time of five minutes (300 seconds), within these 300 seconds, all the 9 million items will be inventoried. The capability of the packet processing of the router has been chosen as 1 million packets per second and the length of the queue is considered as 50000 packets. Since this packet processing router is in a public network and it has to cater to other Internet traffic as well, the author has assumed that 1% of the router’s total processing capability is accessible to our queue.

In calculating queuing delay, an assumption is made in such way that if the queue is overflowed and does not have any room for the next arriving packets, these arriving packets will be dropped and the dropped packets are immediately retransmitted by the sender and that extra retransmission queuing delay would be again added to the to the total queuing delay in order to calculate the total queuing delay. In reality, these packet drops would be prevented by the transport layer by adjusting the window size in such a way that the queue would not get overflowed. According to TCP flow control located in
the transport layer, it would adjust the flow of the packet in order to be able to manage packet flow to the receiver [14][26].

\[ Q(t) = \text{Length of the Queue at the Router at time } t. \]

\[ A(t) = \text{Arrival rate at time } t \]

\[ D(t) = \text{Departure rate at time } t \]

Router capacity = \( S \);

\[ P = \text{Available processing capacity at the router} \]

\[ = A(t) - D(t) \]

\[ = \frac{N}{T} - s \times \rho \]

\( \delta(t) \) = Number of dropped packets

\[ = Q(t) - Q_{\text{max}} \quad (\text{where } Q(t) > Q_{\text{max}}) \]

\( Q_{\text{max}} \) = Maximum length of queue at the router.

Dropped packets are retransmitted and will be added to the original arrival rate.

\[ \therefore A(t) = A(t) + \delta(t - 1) \quad (Q(t) > Q_{\text{max}}) \]

Total delay of whole inventory = \[ \sum \left[ D_{\rho} + D_{T} + D_{Q} + D_{r} \right] \]

The calculations of all delays are indicated as below.
4.5 Calculations and simulations for standard procedure of transmitting data from retailer’s (local EPCIS) to the manufacturer’s EPCIS.

1) Distance between the manufacture and the retailer \( D = 5000 \text{ km} \)

   Speed of light \( C = 2.998 \times 10^8 \text{ m/s} \) [1]

   Propagation Delay \( D_p = \frac{D}{C} \)

   \( D_p = 16.67ms \)

2) Header \( H_p = 42 \text{ bytes} \)

   Pay Load \( PL_p = 64 \text{ bytes} \)

   Total length of the packet \( L_p = H_p + PL_p \)

   \( L_p = 106 \text{ bytes} \quad L_p = 848 \text{ bits} \)

   Bandwidth of the link \( B = 10 \text{ Mbps} \)

   Number of packets destined to the manufacture \( N = 9 \times 10^6 \)

   Total transmission delay \( D_T \)

   \( D_T = \frac{N \times L_p}{B} \)

   \( D_T = 763 .2 s \)

3) Number of packets destined to the manufacture (inventory) \( N = 9 \times 10^6 \)

   Total time for a one inventory \( T = 300 \text{ s} \)
Arrival time \( a = \frac{N}{T} \quad a = 3 \times 10^4 \text{ bits/s} \)

Capacity of the router \( S = 1 \text{ Mbps} \)

Available processing capacity available for our queue (%) \( p = 0.01 \)

Departure time \( d = p \times S \)
\[ d = 0.01 \text{ Mbps} \]

Assuming that the queuing delay is the total time that the last packet takes to leave the queue and the last packet arrive after 5 minutes, the queue delay could be given as below.

\[
\text{Queuing Delay} = T_{\text{departure of last packet from the queue}} - T_{\text{arrival of last packet to the queue}}
\]

Using Mat lab (refer the attachment)

Total Queuing delay \( D_Q = 451 \text{ s} \)

4)

Since the arrival rate of the queries is higher than the departure rate, a delay is formed in the server.

Calculation of the delay at the server = \( D_r \)

Query arrival rate to the server \( A_q = 35000 \text{ queries/s} \)

Departure rate at the server = Router arrival rate

\( D_R = a \)

Using a Matlab simulation:

\( D_r = 96 \text{s} \)
Total one-way end to end delay = 
\[ \left[ \frac{D}{C} + \frac{L_P}{B} + D_Q + D_r \right] \]

Total one-way end to end delay \[ D_P + D_T + D_Q + D_r = 1310 \text{ ms} \]
4.6 Proposed Solution

As stated in the problem description, standard data transfer in the EPCglobal network between the retailer and the manufacturer requires an extensive amount of network resources and congests the public network. As a matter of fact, there is a very high likelihood of data packets being delayed or even dropped in the process of data transferring in the public network. Especially after introducing RFID technology, the amount traffic formed in the public network has developed in a rapid manner. The Author has proposed a solution in such a way as to minimize the RFID traffic and enhance the performance of the ECPglobal network.

The key issue of the EPCglobal network is the absence of a data aggregation method in order to aggregate RFID queries. Since there is no aggregation technique, every query would go to its appropriate manufacturer’s database as a single packet in order to pickup the master information of its tag. The author has introduced the following data aggregation method at the EPCIS of the retailer's as well as manufacturer’s location in order to minimize the traffic in the EPCglobal network.

Consider the example that has been taken into account to illustrate the standard procedure of data exchange in the problem description in the above section. The Author has considered querying 9 million items that belong to the same manufacturer. As stated in the standard procedure, each query would travel to its manufacturer’s database as a single packet. In the packet, the HTTP query will be carried as the payload along with the appropriate packet headers. According to the above indicated example, since all the
queries belong to the same manufacturer, we already know that all 9 million queries would travel to the same EPCIS in order to retrieve the tag information.

The typical size of an Ethernet data packet is 1500 bytes, including the network as well as the transport layer headers and the total capacity of the payload would be 1460 bytes. Generally, when a standard RFID query goes to its appropriate database, it carries 64 bytes of HTTP payload along with the 42 bytes of headers; here we evidently see that the amount of header carried with the payload is high, and considering the above example, querying 9 million items would carry a tremendous amount of header data, which would cause the public bandwidth to be depleted and degrade the performance of the public network. In order to prevent the wastage of public network resources, the author has proposed the following data aggregation method in the EPCIS.

### 4.7 Proposed technique of data aggregation

While querying the 9 million items of inventory, we have already recognized that the entire 9 million items of inventory belong to the same manufacture and are destined to the same database; therefore, it is not essential to send each query as a single packet. According to the propose technique, multiple queries are inserted into a single packet until it reaches its maximum capacity of the payload. As an example, the maximum transmission unit (MTU) size of the packet is 1500 bytes, which includes the TCP and IP headers. When considering the payload of the packet, it can carry up to 1460 bytes of data in the payload. As stated in the above section, the size of the typical HTTP query would be 64 bytes, therefore it is possible to carry up to 22 queries in a single packet.
According to the author’s proposed method, the aggregation can be performed on a per-manufacturer basis and handle a bulk of inventory querying. All the HTTP queries are sorted depending on the destination and the queries that are departing to the same destination or same manufacturer would be placed on a separate queue in the local EPCIS; those queries are then encapsulated until the packet reaches its limit of 1460 bytes. After it reaches its limit, the subsequent packet would get served with queries until it reaches its limit. This process repeats until all the queries of the inventory come to an end for that particular manufacturer. Also, each manufacturer has its own queue in the local EPCIS; therefore an equivalent number of separate queues will be created depending upon the number of manufacturers from one inventory. But in this thesis, the Author has considered of only one manufacturer’s items being queried. While calculating the one way delay between the each retailer and the manufacturer, the following specifications and assumptions are taken into consideration. In addition to that, the Author considers the identical example that has been used to calculate the standard procedure of querying between the retailer and the manufacturer.

In this proposal the Author has assumed that the maximum transmission unit (MTU) of 1500 bytes will remain throughout the way to the manufacture. All the specifications and assumptions are similar to all delays such as propagation delay, transmission delay queuing delay that have been used in the standard procedure of querying data from retailer to the manufacturer. However, in the proposed technique, there is a special delay at the local EPCIS at the retailer while inserting queries into a packet. This delay is the delay that the other packets have to wait in the queue until a single packet gets filled with multiple queries. As the packet reaches the maximum limit
of the payload, this delay depends on the typical size of the payload—the bigger the payload, the larger the delay. This particular delay is called the packetization delay and it denoted by $D_q$ in the calculations. The standard data transferring procedure indicated in the above section has not considered this delay, and it is considered as a negligible amount of time since the payload is much less significant compared to the proposed technique and the processors are able to handle the incoming tag rate without a significant delay while packetizing a single query payload at the server. When calculating the total delay for the proposed technique, the other parameters remain the same as the standard data transfer procedure.

### 4.8 Calculations and simulations for proposed procedure of transmitting data from retailer’s (local EPCIS) to the manufacturer’s EPCIS

Length of the packet $L_p = 1500$ bytes

Maximum number of queries that can be inserted into the packet’s payload

\[ n_{\text{max}} = \text{floor} \left( \frac{L_p - H_p}{PL_p} \right) \]

\[ n_{\text{max}} = 22 \text{ queries} \]

- Queuing delay at the local server, this delay is also considered as the packetization delay, the time taken to fill 22 queries in one packet.

Packet filling rate = 1000000 Bps
\[ D_q = \left[ \frac{64 \times N}{1000000} \right] \]

\[ D_q = 576 \text{ s} \]

- Distance between the manufacture and the retailer  \( D = 5000 \text{ km} \)

Speed of light  \( C = 2.998 \times 10^8 \text{ m/s} \)

Propagation Delay  \( D_p = \frac{D}{C} \)

\[ D_p = 16.67 \text{ ms} \]

- Header  \( H_p = 42 \text{ bytes} \)

Pay Load  \( PL_p = 64 \text{ bytes} \)

Total length of the packet  \( L_p = H_p + n_{\text{max}}PL_p \)

\[ L_p = 1450 \text{ bytes} \quad L_p = 11600 \text{ bits} \]

Bandwidth of the link  \( B = 10 \text{ Mbps} \)

Transmission delay  \( D_T \)

\[ D_T = \frac{NL_p}{B} \]

\[ D_T = 475.92 \text{ s} \]
- Number of packets destined to the manufacturer (inventory)

\[ N = \text{ceil} \left( \frac{9 \times 10^6}{n_{\text{max}}} \right) \]

Assuming that the arrival rate does not change from the previous scenario

Total time for a one inventory \( T = 300 \) s

Arrival time \( a = \frac{N}{T} \)
\( a = 3 \times 10^4 \) bits/s

Capacity of the router \( S = 1 \) Mbps

Available processing capacity available for our queue (%) \( p = 0.01 \)

Departure time \( d = p \times S \)
\( d = 0.01 \) Mbps

Assuming that the queuing delay is the total time that the last packet takes to leave the queue, the last packet arrives after 15 seconds; the total queuing delay could be given by

\[
\text{Queuing Delay} = T_{\text{departure of last packet from the queue}} - T_{\text{arrival of last packet to the queue}}
\]

Using Mat lab (refer the attachment)

Total Queuing delay \( D_Q = 47 \) s

Total one-way end to end delay \( D_q + D_p + D_T + D_Q = 1230 \) s
Delay generated due the arriving rate of the queries and the departure rate of the queries are neglected since there is a packetization delay of 576 s, and due to this delay the arriving queries are buffered and wait to get packetsized in the queue.

4.9 Comparison and analysis of the delays between the standard and the proposed technique

As indicated below, a chart is generated for the delay on the y axis and the number of queries per packet on the x axis. In the graph, query number 1 denotes the delay for the standard procedure of querying the master data, one query per packet and the rest as the increment of the x axis indicates the number of queries being inserted per packet versus delay for the whole inventory, while the bandwidth is considered as 10 Mbps of the link.

<table>
<thead>
<tr>
<th>n = number of queries</th>
<th>Bandwidth (Mbps)</th>
<th>Delay in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>1310</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>1423</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>1303</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>1263</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>1243</td>
</tr>
<tr>
<td>22</td>
<td>10</td>
<td>1230</td>
</tr>
</tbody>
</table>
As indicated in the graph, according to the standard procedure of querying, the master data has taken 1310 seconds for all queries to reach its master database. However, when the numbers of queries that are being inserted into a single packet according to the proposed method has increased the delay will continue to increase the delay until the number of queries has increased to five. The cause of the increment of the delay is due to the transmission delay which has not affected the overall delay, until inserting up to 10 queries. Therefore, inserting 9 queries has not improved performance when compared to
the standard method. However, inserting the 10th query into the IP packet has gradually started to minimize the delay for the entire inventory. When inserting any number of queries past 10, the delay will start to improve gradually until it reaches the maximum queries of 22 per IP packet. When the max of 22 queries per packet is reached, the minimum amount of time is reduced to 1230 seconds of delay. These above delays are calculated assuming the bandwidth of the link between the local server and the manufacturer’s database is 10 Mbps.

The calculations above have been formed for the ideal situation. However, the situation above would only arise in a controlled environment such as a private network. However, in the real world, users are transferring data where there is no control over the bandwidth network which the data is being transferred through. So, having a bandwidth of 10 Mbps would be unrealistic; therefore, the following scenario is formed in such a way that it indicates realistic transfer rates in everyday situations.

<table>
<thead>
<tr>
<th>n = number of queries</th>
<th>Bandwidth (Mbps)</th>
<th>Delay in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
<td>5539</td>
</tr>
<tr>
<td>5</td>
<td>1.5</td>
<td>3777</td>
</tr>
<tr>
<td>10</td>
<td>1.5</td>
<td>3486</td>
</tr>
<tr>
<td>15</td>
<td>1.5</td>
<td>3388</td>
</tr>
<tr>
<td>20</td>
<td>1.5</td>
<td>3340</td>
</tr>
<tr>
<td>22</td>
<td>1.5</td>
<td>3325</td>
</tr>
</tbody>
</table>
The Author has generated the above graph considering the above facts and changing the bandwidth of the original link between the local server and the manufacturer’s database. After plotting the graph, it has been noted that the total delay for the entire inventory has taken 5539 seconds according to the standard method which is one query per packet. After applying the proposed technique, it has been indicated that there is significant amount of decrement in delay for the entire inventory for each instance of aggregation of query per packet. If the maximum amounts of 22 queries are inserted into an IP packet, the inventory has taken 3325 seconds to reach the database.
When compared to the standard procedure, the difference of the delay is 2214 seconds, which is a huge difference and superior enhancement in terms of reducing the delay.

By comparing the above two scenarios, it is quite evident that the proposed data aggregation technique performs much better under low bandwidths rather than high bandwidths. Also, it is quite obvious that in reality, we are unable to get such a high bandwidth in public networks or from wide area networks as indicated in the first scenario. Therefore, we can conclude that the Author’s data aggregation technique is exceptionally suitable for real world scenarios and would perform extremely well in such an unmanageable low bandwidth link as is in the public network.

4.10 Bandwidth Utilization

Bandwidth of a computer network can be defined as the amount of data that can travel in a certain period of time or the rate that is supported by the network connection. The performance of the network is measured by the key factor of latency or delay of the network. As the delay of the network increases, the network bandwidth is wasted and the overall performance is reduced.

While comparing the standard method and the proposed technique in the above section, it is quite evident that the standard method has taken a great deal time in order to query the master data. In other words, the total delay is much higher than the proposed technique to query the entire inventory. According to the above definition, the bandwidth has been wasted in the standard procedure and the bandwidth utilization is very poor compared to the proposed technique. Applying the Author’s proposed technique has reduced the total network delay and efficiently utilized the bandwidth of the local
network as well as the public network. Overall, we can conclude that the proposed technique has not only reduced the network delay, but also has enhanced the performance of the EPC network by utilizing the bandwidth efficiently.
5.1 Conclusion

In this research, the Author has carefully analyzed and identified an issue in the EPCglobal network and proposed a solution for the individual issue. In the proposed solution, the Author presents a data aggregation technique to enhance the performance of the EPCglobal network while efficiently utilizing the bandwidth in the public network.

The proposed technique has resourcefully aggregated multiple queries into a single IP packet that is traveling to the same manufacturer’s database. As indicated in the above chapter, the calculations and the simulations have been performed in order to analyze the differences in delay between the standard procedure and the proposed technique of querying the master data of the EPC tags. When comparing the two delays, it is evident that the proposed technique has provided a distinct improvement in minimizing the delay of the whole inventory. In addition to that, the proposed solution prevents network load and congestion by drastically minimizing the number of total packets that are being deposited into the EPCglobal network. Minimizing the number of total packets led to a minimization of the overhead that is being generated from each packet and helps to better utilize the public bandwidth. Overall, it is quite clear that introducing the proposed technique facilitates better with the existing EPCglobal network as well as the public bandwidth and it will also aid the field of RFID to develop in future without any obstructions.
5.2 Future Work

In the following section, the Author presents some potential future research that has been observed over the course of work on this thesis. The following ideas are mainly concerned with developing the field of RFID as well as providing potential ideas for future research.

As mentioned in an earlier section, the main goal of the RFID is to develop and implement a network called the EPC global network which is a set of standards and architecture designed to construct the idea of the “Internet of things”. The main purpose of this thesis is to aggregate data and reduce the network load, delay as well better utilize the public bandwidth. By accomplishing these main purposes, it will assist the overall performance of the EPCglobal. In addition to this, another potential idea would be a data compression technique. In this thesis, the proposed technique was to aggregate data. After aggregation, this data can also be compressed in a way where we can insert many more queries than the proposed technique's maximum query limit of 22 per packet. By inserting more queries into a single IP packet, it will continue to enhance the performance in the EPCglobal network as indicated in this thesis. Therefore, data compression would be another ideal future work project for the field of RFID.

Another major research would be to look into the core network issues from the perspective of RFID traffic. In the future, the implementation of RFID into the entire supply chain or to item level tagging would create a fairly large amount or high percentage of RFID traffic in the Internet. Therefore, in order to assistance to this RFID traffic without causing delay to the regular traffic in the Internet can be achieved by
implementing methods such as modification of separate routing protocols and policies in order to sustain separate network topologies and RFID devices. Also we can develop the TCP/IP protocol to assist the RFID traffic by prioritizing/ handling/policing/queuing the RFID traffic in the Internet. The above given ideas are the probable future work in the field of RFID and those can be accomplished and implemented in this particular field.
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