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Enhancing RFID Data Quality and Reliability

by

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Abstract

Radio Frequency Identification (RFID) is gaining significant thrust as the preferred choice of automatic identification and data collection system. RFID technology has been increasingly deployed in a wide range of applications, such as animal tracking, automatic toll collection and mass transportation. A RFID system consists of a transponder (i.e., tag), which is attached to the objects to be identified, an interrogator (i.e., reader) that creates an RF field for detecting radio waves, and a backend database system for maintaining expanded information on the objects and other associated objects. While RFID provides promising benefits in many applications, there are serious data management issues that must be overcome before these benefits can be fully realized.

In this thesis, we address the RFID data quality and reliability problems. RFID data is fundamentally different from the traditional relational and data warehouse technologies. These differences pose great challenges and they need to be fully considered in RFID data management systems. Also, RFID uses radio waves to capture data automatically. Unfortunately, despite vast improvements in the quality of RFID technology, a significant amount of erroneous data is still captured in the system. The observed read rate in real world RFID deployments is often in the 60-70 % range. Such level of error rates render raw RFID data essentially useless for mission-critical applications such as healthcare and inventory management systems. Moreover, RFID data are large, dynamic and time-dependent. Therefore, missed and unreliable readings are very common in RFID applications and often happen in situations of low-cost, low-power hardware and wireless communications, which lead to frequently dropped readings or with faulty individual readers. RFID data stream is full of duplicate readings. The duplicate data results in unnecessary transmissions and consumes network bandwidth.

In this thesis, we studied the issues contributing to the low quality and unreliability of the RFID and propose several approaches to enhance the RFID data quality and reliability. RFID naturally generates a large amount of duplicate readings. Duplicate readings can produce conflicting information to the system such as tagged object being counted twice. Removing these duplicate readings from the RFID data stream is paramount as it does not contribute any new information to the system and wastes the system resources. In this thesis, we present a data filtering approach that efficiently eliminates the duplicate data from RFID data streams. We will also present experimental results of the data filtering algorithm to show that the proposed approach provides a significance improvement in the quality of RFID data processed. Another problem with RFID systems is that the captured data has significant percentage of errors particularly as a result of miss reads. Unreliable readings are often happen due to low-power, faulty individual readers and wireless communications. We studied the problem of faulty readings due to faulty readers that continuously send readings and developed an approach to detect and remove such faulty readings from the RFID data stream. We also developed an energy-aware RFID data filtering approach to address the frequently dropped RFID readings due to low-power.

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Chapter 1

Introduction

RFID (Radio frequency identification) systems are vastly emerging as primary object identification mechanism especially in the supply chain management. Automation is one of the RFID advantages compared to the traditional barcodes [1]. The manual work of scanning is omitted with the use of RFID. Take the example of items replenishment on the shelf. In practice, employees need to monitor manually every shelf in the store to ensure the item quantities are sufficient. This task is repeated for a number of times in a day. This is not efficient as it is time consuming and not all the shelf needs regular monitoring. By using RFID, no manual monitoring is required. Monitoring is carried by readers that will alert the system for shelf replenishment if the items quantity falls below the threshold.

Figure 1.1 shows the typical components of an RFID system. The lowest layer of the system consists of RFID tags. A tag contains the Electronic Product Code (EPC) that is the unique ID for the tag. Tags are attached to an item and can be read by the reader. The RFID readers query tags to obtain data and forward the resulting information through the middleware to the backend applications or database servers.

The applications then respond to these events and application processes orchestrate corresponding actions; such as ordering additional products, sending theft alerts, raising alarms regarding harmful chemicals or replacing fragile components before failure.

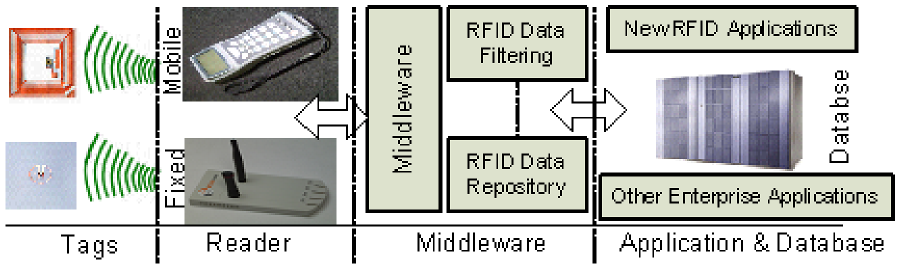

Figure 1.1: RFID System Architecture

In many applications such as manufacturing, distribution logistics, access control, and healthcare, the ability to uniquely identify, real-time product track, locate and monitor individual objects is indispensable for efficient business processes and inventory visibility. The use of RFID technology has simplified the process of identifying, tracking, locating and monitoring objects in many applications. RFID uses radio-frequency waves to transfer identifying information between tagged objects and readers without line of sight, providing a means of automatic identification, tracking, locating and monitoring. Many organizations are planning to or have already exploited RFID to achieve more automation, efficient business processes, and inventory visibility. For instance, after implementing RFID system, Wal-Mart reportedly reduced out-of-stocks by 30 precent on average.

An increasing number of major retailers such as Wal-Mart, The Home Depot, Kroger, and Costco have installed RFID based inventory management systems in their warehouses and distribution centres. Take the example of items replenishment on the shelf. In practice, employees need to monitor manually every shelf in the store to ensure the item quantities are sufficient. This task is repeated for a number of times in a day. This is not efficient as it is time consuming and not all the shelf needs regular monitoring. By using RFID, no manual monitoring is required. Monitoring is carried by readers that will alert the system for shelf replenishment if the items quantity falls below the threshold.

1.2 Research Significance

Although RFID systems are vastly emerging as primary object identification mechanism, the raw data collected by RFID readers are inherently unreliable [23, 17]. Since data unreliability would lead to inaccurate decisions or responses, it is imperative that the data is cleaned before being sent to the back end system for use by RFID applications. There are several factors that lead to the RFID data unreliability: noise reading, missed reading, duplicate reading. A noise reading at one's check-out point will trigger false alarm to a customer who has paid for the purchased items. The system here can be considered not reliable and useless because it cannot detect the purchased item correctly. The system should be able to filter noise readings completely to avoid such thing from happening.

Another unreliability of the RFID data is due to duplicate readings. A reading is said to be duplicate when multiple readings of the same tagged object are observed simultaneously due to multiple readers or by a single reader over a period of time. For instance, in the items replenishment example, multiple RFID readers are needed to achieve shelf replenishment. However, multiple readers could generate duplicate readings. The duplicate reading would represent in incorrect quantity of items on the shelf. For instance, the system will have views that the shelf still have enough quantity of items and does not need replenishment while the real case it is not.

Another class of unreliability of RFID data occurs due to missed readings. This occurs for a number of reasons including faulty readers and readers with low power. In such situations, it is important to ensure that the system received all the readings on the tagged objects. The existence of missed readings will affect the system reliability such that the system is unable to monitor or record the object accurately. Therefore a mechanism to detect missed readings in RFID data stream is a must to ensure that the system operate correctly.

1.3 Research Problems

This thesis deals with RFID data unreliability problem and proposes energy efficient RFID data stream filtering techniques. In particular we address the following four research issues in this thesis:

- *How to filter noise readings in efficient manner:* Noise reading is one of the major problems in RFID data management [4][5]. Noise reading or false positive reading, is a reading on a tag that has been corrupted, due to some reasons, making out new tag ID that actually did not exists in the reader vicinity. The new tag ID, if not filtered, will be considered and process as a correct reading, causing application to have inaccurate record on objects. This record then will be used to generate important information such as current number of items or a record on object's location. Thus, noise reading must be filtered out from the data stream to avoid any misleading information being generated in the system.

- *How to filter duplicate readings in efficient manner:* Duplicate readings are considered as a serious problem in RFID. Duplicate readings detection and elimination is a part of data cleaning problem. It detects and removes errors and inconsistencies from data and improves its quality. Presence of similar duplicate records causes over representation of data which is unnecessary. The source of the problem originate from (i) RFID reader continuously read tags even there is no event occurred (ii) Multiple readers are use for the same vicinity, and (iii) Multiple tags used on the same object to increase reading reliability. This thesis present ideas for making duplicate detection algorithms faster and efficient with aim to preserved readings to the authorized reader.
- *How to detect missed readings:* Missed readings can occur in RFID system without being noticed by the user. This happen when the reader experience faulty either temporarily or permanent. The reader still generates readings which make it looks still working properly. However, the reader missed a majority of the reading and the reader must to be quarantined from sending new readings. The events of faulty reader need to be detect quickly to control the potential damage it can bring to the system.
- *Energy savings mechanism:* The problem of RFID is it will keep reading on tagged object as long the object is in its vicinity. This cause duplicate readings and energy consumption for unnecessary readings. There is also other reader that reading on the same tag that makes the duplication problem worst and wasting the energy. It is critical to ensure this will not happen especially when RFID is used in emergency cases [5] while the reader and tag has limited power supply on its board. The power might have been fully consumed before

the tag can complete its mission. Therefore a mechanism for energy savings is very important and addressed in this thesis.

1.4 Research Objectives

To achieve the research aim, three main research objectives are identified and need to be fulfilled:

1. To develop a taxonomy of RFID data filtering system that contributes understanding towards current approaches, issues and challenges related to the topic;
2. To develop an efficient approach to filter noise readings in an efficient manner.
3. To develop an efficient approach for filtering duplicate readings in RFID data stream;
4. To propose an approach to detect missed reading that may be caused by faulty reader in order to ensure the system is working correctly; and
5. To propose mechanism to achieve energy aware RFID data stream filtering approach.

1.5 Methodology

The proposed work will be carried out based on the experimental computer science method [6]. This method examines the research work to demonstrate two important concepts: proof-of-concept and proof-of-performance.

To demonstrate the proof-of-concept, some important steps were performed. First, the research area within RFID data filtering is critically reviewed to provide the overview that leads to the formulation of valid problem statements. From this review, the research work in is justified. Then, the proposed approach of RFID data filtering is designed and analytically analysed.

Proof-of-performance is demonstrated by conducting the implementation for the filtering algorithm using simulations. In those simulations, various parameters and workloads were used to examine and demonstrate the viability of the proposed solutions compared to the similar baseline solutions. Also, analytical analysis of some proposed algorithms is performed to evaluate the correctness.

1.6 Research Contributions

We detail the thesis contributions as the following:

1. *RFID data filtering taxonomy*. This thesis presents taxonomy of RFID Data filtering. It investigates related concepts, describes the design themes and identifies implementation components required. The presented taxonomy is mapped to current RFID system to demonstrate its applicability. Also, the mapping assists to perform a gap analysis in this research field.
2. *Noise filtering.* The thesis introduces approach to filter noise data in RFID data streams. The noise is detected by the number of its occurrence which is normally less than correct readings. The approach is compare with other baseline method and proves that it performance is superior to others.
3. *Duplicate filtering*. The thesis presented an efficient mechanism to remove duplicate reading from RFID data streams. The proposed algorithm used landmark windows structure to store more readings for better comparison to produces more reliable results compare to other existing approaches.

4. *Missed reading detection*. The thesis presents a mechanism to detect missed reading that caused by faulty reader in the system. The detection of missed reading is extremely important to ensure that the readings does not go through into system and be treated as correct readings.
5. *Energy Savings Mechanism*. This thesis introduces mechanism to achieve energy savings in RFID system by reducing a number of readings to be made. Energy saving is very important as some RFID is depending on onboard battery that have limited life time. In some cases the hardware is expected to perform longer especially in the case of emergency.

To summarize, the work presented in this thesis is in line with the current trends that enable RFID data filtering without having to build a dedicated infrastructure [5, 14]. Therefore, it is our thesis to present RFID data filtering solutions that are scalable and efficient.

1.7 Thesis Organization

The chapters of this thesis are derived from various papers published during the PhD candidature. The remainder of the thesis is organized as the following:

- *Chapter 2: RFID Data Filtering System*. This chapter provides an in-depth analysis and overview of existing RFID data filtering approaches, presented within a comprehensive taxonomy.
- *Chapter 3: Noise Filtering*. This chapter presents an approach to filtering noise and duplicates reading in RFID data stream. This chapter is derived from the following publication:

    - Hairulnizam Mahdin, Jemal Abawajy (2009). An Approach to Filtering RFID Data Streams. 10th International Symposium on Pervasive Systems, Algorithms, and Networks, pp. 742-746.
- *Chapter 4: Filtering Duplicate Readings from RFID Data Streams*. This chapter presents an approach to filter duplicate reading in RFID . The results presented in this chapter are derived from the following publications:
    - H. Mahdin, and J. Abawajy (2010). An Approach to Filtering Duplicate RFID Data Streams, Lecture Notes on Computer Science: U- and E-Service, Science and Technology, pp. 125-133. Springer: Heidelberg. This paper has won best paper award at UNESST 2010, Jeju Island, Korea.
    - Mahdin, H.; Abawajy, J. An Approach for Removing Redundant Data from RFID Data Streams. *Sensors* 2011, *11*, 9863-9877.
- *Chapter 5: Missed Reading Detection*. This chapter presents an approach to detect missed reading in the system. The mechanism and the simulation results presented in this chapter are derived from the following publications:
    - H. Mahdin, and J. Abawajy (2011). An Approach To Faulty Reader Detection. In Internet and Distributed Computing Advancements: Theoretical Frameworks and Practical Solution, Jemal Abawajy, Mukaddim Pathan, Al-Sakib Khan, Mustafizur Rahman and Mustafa Deris (eds.). IGI-Global: USA.
- *Chapter 6: Energy-Efficient Filtering Mechanism*. This chapter presents an approach to energy saving via reader scheduling in RFID system.

- *Chapter 7: Conclusion and Future Directions*. The concluding chapter provides a summary of contributions and a future research challenges.

Chapter 2

Literature Review

This chapter provides comprehensive review about the various data management issues in RFID. It serves the purpose to understand the current undertakings to ensure data quality in RFID. It focused on three major RFID data issues which are noise readings, duplicate readings and missed readings. The chapter include in-depth analysis on existing approaches, listing the advantages and disadvantages of each approach that specifying on solving the data problems. The literature can be used by researcher to understand the background of RFID data filtering, the challenges and expectation in the future.

2.1 Introduction

RFID identification works by reader reading ID on tag and send it to the middleware for processing. Before readings can be transformed into information, it needs to be filtered. The RFID data stream contains unreliable data such as noise reading and duplicates. Noise reads will produce incorrect information such as incorrect stock quantity. Duplicate readings needs to be removes because it over-represents the data and does not contain new information for the system. It needs to be removed to avoid unnecessary processing being performed.

There are two types of filtering: (i) low level data filtering and (ii) semantic data filtering [7]. Low level data filtering clean raw RFID data streams. For examples removing duplicate and noise readings from the data stream. The semantic data filtering filters data based on demands from system such as list of manufacturers that did shipment in July. In this thesis we worked on low level data filtering with focus on noise and duplicate readings. We also focus on detecting faulty reader and energy savings in data filtering.

The RFID data stream is different from the common relational and data warehousing because of (i) large size of data (ii) simple tuple structure (iii) inaccuracy and (iv) temporal and spatial information that make it require new data management approach [8][9]. The size of the data stream is very large because the reader can read multiple tags in seconds and repeat it for indefinite times. To illustrate the RFID data size, consider small store that have 10,000 items. In single reading cycle there will be 10,000 readings generated. If the readings are repeated for every 10 minutes, in eight hours there will be already 480,000 tuples. It is not easy to dig up information by using query to this large data.

The tuple structure actually is very simple and has very few attributes. Basically it has three attributes which is <tagID, readerID, time>. The tuple contain the identification for the item, the location of the item is based on the reader ID (because the reader is usually have fixed location) and the time when the reading took place. This simple tuple can provide valuable information to the businesses when being analyse with the whole data stream. For example, the data stream can represent visually the movement of the items from one place to another. However, the filtering process must be carried out to ensure only correct readings are used to produce information. It also must be done in efficient way to ensure the performance is up to par and fulfil the system needs. This chapter presents and analyse the existing filtering approaches has been proposed in order to achieve these objectives.

2.2 RFID System Architecture

A typical RFID system consists of a transponder (i.e., tag), which is attached to the objects to be identified, an interrogator (i.e., reader) that creates an RF field for detecting radio waves, and a backend database system for maintaining expanded information on the objects and other associated objects. Figure 2.1 shows RFID-enabled a generic system of interest. Generally RFID system architecture is made of four layers: tags, readers, middleware and database and enterprise applications.

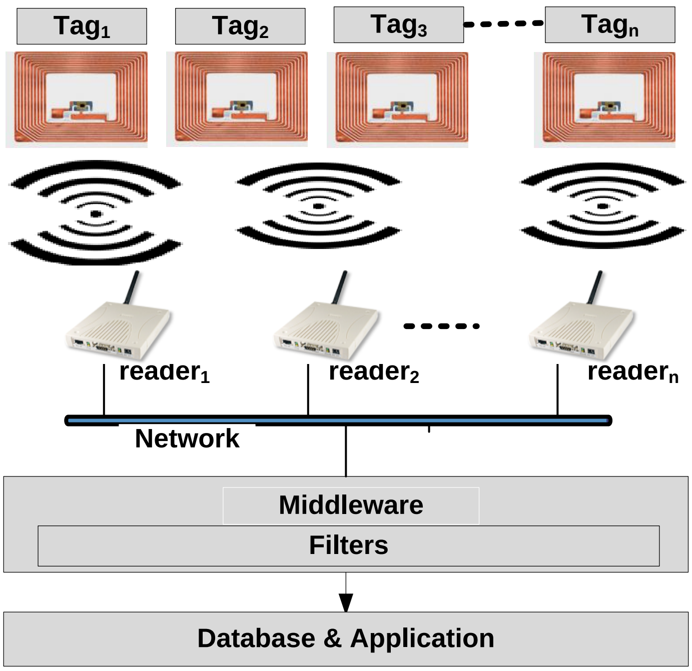

Figure 2.1: An RFID-enabled system architecture.

2.2.1 Tag

In RFID environment, objects to be tracked and monitored are attached with an RFID tag. A tag contains memory to store the identifying information of the object to which it is attached and an antenna that communicates the information via radio waves. Tags can be classified based on their power sources: passive, active and semi-active tags. Active and semi-active tags have their own battery on-boards. Active tags can emit their signal to the reader to start the communication while semi-active and passive tag needs to wait the signal from the reader to power them up before replying to the signal. The battery on boards owned by semi-active tags is only used for processing purposes. For passive tags, it uses the power supplied from the reader for both processing and communicating. Passive tag is the most commonly used tags in the market and has an indefinite operational life compare to other tags. Relative to both active and semi-active tags, passive tags are very cheap and they are widely used in very large quantities in many applications such as supply chain management.

Table 2.1: Tags read ranges

Tag Types	**Read Ranges**
Low Frequency Passive	4-15 ft
Low Frequency Active	8-100 ft
High Frequency Passive	6-23 ft
UHF Passive	8-21 ft
UHF Semi-Passive	15-100 ft
UHF Active	100 – 1500 ft
Microwave Passive	1-10 meters
Microwave Active	More than 1000ft

The size for a tag can range from 1 bit (EAS tag), 64 bits to 1 kb for passive tags and up to 128 kb for active tags. The type of tags affects the read ranges and the type of interference that it has effect to. Low frequency (LF) tag is used to tag animals because it has good penetration over the flesh [10]. In the area that has many metal objects high frequency (HF) tag is the best. For environment that contains water, metal and human body use ultra high frequency (UHF) tag. It is importance to deploy the right tag to increase the chances of getting the correct readings.

Table 2.2: The advantages and disadvantages for each type of tag

Type of tags	**Advantages**	**Disadvantages**
Passive	Unlimited life-time	Short read range distance
	Cheap	Not possible to integrate with sensors
	Small size: make it easy to be used with any object	The tag remains readable for a very long time, exposed user to privacy breach.
Active	Longest read range	The tag cannot function without battery power, which limits the lifetime of the tag.
	Capability of initiating communications	Expensive
	Capability of performing diagnostics	Larger in size. Limit application
	Highest data bandwidth	Long term maintenance that is costly if need to replace battery
	Capability to determine the best communication path.	Battery outages in an active tag can result in expensive misreads.
Semi-passive	Longer read range than passive tag	Limited life-time

Generally, passive tags are most used tags in many applications because of its cheap price than the others [11]. They were use massively mostly in the supply chain application. However, due to the low-powered hardware and the massive number of the tags, it raises many issues in data management and security. Most of the researches discussed in this thesis are based on the passive tags. Table 2.2 list the advantages and disadvantages of each type of tag.

2.2.2 Readers

The RFID system is assumed to contain multiple networked RFID readers deployed to collaboratively collect data from tagged objects in their vicinity. The reading distance ranges from a few centimetres to more than 300 feet depending on factors such as interference from other RF devices [10]. The RFID readers query tags to obtain data and forward the resulting readings to the middleware. The middleware processes these data and then send it to the backend applications or database servers. The applications then respond to these events and orchestrate corresponding actions such as ordering additional products, sending theft alerts, raising alarms regarding harmful chemicals or replacing fragile components before failure.

There are two types of RFID reader: fixed and mobile. Fixed RFID reader is installed at specific checkpoint to read objects passing by. It is also installed to monitor objects around them such as items on the shelf. The reader also can be mounted on moving object such as forklifts to read the objects that the forklift is carrying. The mobile RFID reader is a handheld device and usually used to read fixed tag. It can be carried around to read tags in a larger area that needs number of fixed reader to do that. However it is not suitable to be used for constant monitoring as it needs humans to operate and moving it around which is not cost effective. One of issues that always been discussed with mobile reader is the energy saving approach. Mobile reader has limited life time because it depends on the battery. The energy saving become critical when mobile reader is going to be used in critical condition such as in emergency and natural disaster. During an emergency mobile reader might be used for a long time which requires efficient energy usage to prolong the reader life time.

The most important thing in choosing reader and tag for the system is the compatibility between the two. Each reader in a market has different read range and frequency they can operate. It is important to ensure that the reader’s signal is able to read the tags and the tag’s signal also able to reach back to the reader.

The typical reader's read rate on EPC Class1 Generation 2 tags is 1600 reads per second [10]. This contributes to the problem of duplicate readings. Although we can increase the distance between each reading cycle, there is opposing challenge on it. There are objects that are going to stay for a short while in the vicinity. By increasing the distance between reading cycle, the reader will missed to read this object which increase the false negative. This issue are among the main challenges in providing reliable and efficient RFID systems.

2.2.3 Middleware

The middleware acts as the centre of RFID systems [12][13]. The primary function of RFID middleware is to process large amounts of data within a short period. It collects and processes the readings from readers for the use of enterprise applications and enterprise database. The process such as filtering and aggregation transform raw data into required format for the application. Both low level filtering and semantic data filtering can be performed at the middleware. The semantic data filtering is based on the requirement given by the application from the next layer. It also provides custom format for data storage before it is sent to the database. The middleware also coordinate the readers' activities, ensure reliability in data transmission, improving network communications and allowing heterogeneous devices to collaborate together [12]. It also provides user interface to allow the user control and configure the process.

2.2.4 Enterprise Application & Database

The highest layer in RFID system architecture is the enterprise applications and database. After readings have been filtered and convert into required formats, it will be sent to this layer. Examples of enterprise applications include the Supply Chain Management (SCM) and the Enterprise Resource Planning (ERP). This layer converts the data from middleware into meaningful information. It then can delivers information to other application system or database. Therefore, a user can refer to the designation database or obtain data in the XML format [12]. The system makes business decision based on this information. For example user can gather check the objects that are below threshold in their stock. From this information they can make decision to order new stock from the supplier.

2.3 RFID Data Filtering Approaches

In this section, we provide in-depth analysis on current data filtering approaches. We categorized the approach based on their technique and data problem. First, we look at the type of reading classes in RFID.

2.3.1 Reading Classes

The type of readings generate by reader could be generally classified into four classes: true positive, false positive, false negative and duplicate readings. Each of these readings can be possibly generated when a tag tries to reply a signal to reader. That is basically the only data that being sent from the tag. The reader ID and time are recorded when the tag ID reach the reader.

Only true positive reading is acceptable in the RFID system. The other types of reading are the three major anomalies that need to be removed or smoothed from the data stream [14]. Each anomaly has different impact to the RFID system. The unreliable data is considered as one major concern by businesses before acquiring RFID into their system. They are being listed as one of the major hindrance in achieving widespread adoption of RFID technology [15].

(i) True positive

True positive is correct readings made by the reader. It returns the actual ID on the tag to the reader. The structure of tag ID according to the EPC Tag Data Standard consists of four parts: Header, EPC manager, Object Class and Serial Number as shown in Figure 2.2 [10]. Header identifies the length, type and structure of EPC, EPC Manager identifies the manufacturer, Object class identify the type of product and Serial Number is the unique identifier for the item.

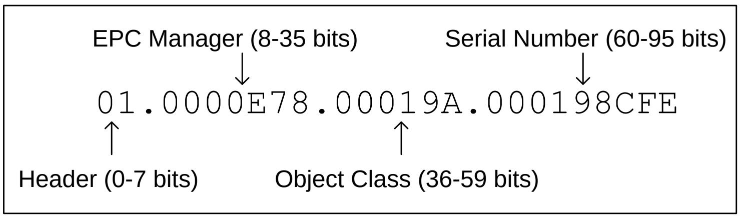

Figure 2.2: Structure of EPC tag data

(ii) False positive

The second reading class in RFID readings is false positive, also known as noise reading. The reading returns tag ID that does not exist in the system. The corrupted reading can be caused by: (i) low power signal, (ii) signal interference, (iii) signal collision, and (iv) infrastructure obstacle [8]. Low power signals occur when the tag is located at the end of reader's vicinity or the reader trying to read too many tags at the same time [16]. The tag will not be having sufficient power to reply the signal back to the reader successfully. The radio signal also can be weaken by interference from metal and water [16].

The third cause of noise reading is the signal collision which is common in RFID. Signal collision occurs when two or more tags responding to the reader at the same time [17]. It also occurs when the tag is being read by more than one reader [18]. The signal collision can change the content of the signal which creates new ID that did not exist in the system.

Another source of noise readings is the infrastructure obstacle such as the orientation of the objects and obstacles from the surrounding environment. When numbers of pallets are coming together, some of the tags can be buried deep in the pallet arrangement, which made them hard to be read. The amount of power coming to them is not enough for the tag to responds to the reader correctly, which results in noise readings.

The effect of false positive or noise readings is it reports an existence of an object that is not exists, causing the system to take wrong decision opposing the reality. For example a noise read at the security check-out in a shopping mall will trigger alarm indicating that a customer did not pay for an item. The noise read also can indicate inaccurate number of items available in the store which causing delays in ordering new stock. The noise readings need to be removed from the data stream to avoid such confusion in those examples. A pro-active step that can be taken to reduce the noise readings problem is to ensure that the right tag is used for the application. For example it is better to use high frequency (HF) tag to read object that is build up from metal compare to ultra high frequency (UHF) tag because HF tag have good performance with metal.

(iii) False negative

The third type of reading is the false negative or missed reading. False negative is a reading that supposedly performed by the reader but is being left from entering the data stream. The source of problem can be the same as noise reading, in this case the signal did not reach the reader at all to transmit the data. False negative also can occur due to the filtering process itself. Some of the filtering process put a threshold for a reading to be counted as correct reading within a specific time period. When the object only resides in the vicinity for a short time period, the number of readings made on it is less than the threshold. Therefore it is being removed from the data stream and left undetected. The effect of false negative to the system is opposed to false positive errors. While false positive add the quantity ups from the reality, the false negative reduces the real quantity. There problem with the incorrect quantity is like business loss because some of the items shipped to customer is not being detected. Simple ways to increase the chances of the tag being read is by increasing the number of read cycle or use more than one reader to read the same area [19].

(iv) Duplicate reading

The next reading class that considered as anomaly is duplicate reading. Duplicate reading is common problem in RFID. It is exists because RFID reader has the ability to read the same tag number of times as long the tag's is still the reader's vicinity. Duplicate reading need to be removed because it over represent the data, unnecessarily occupying the memory space and require unnecessary processing. We are only interested on the data that indicate the occurrence of events. For example on smart shelf application, the readings that are most important are when the item is put on the shelf and when it is being pickup by customer. That can indicate the current number of items that are currently available on the shelf. Another source of duplicate readings is because more than one reader is covering the same vicinity to increase the reliability of the readings. In some cases, the reader's vicinity was overlapped with each other that causing the redundancy. Figure 2.3 shows the RFID types of readings and Table 2.3 represent the summary of anomalies reading classes in RFID.

Readings

Time	ID	Reading Types
100	100E	True Positive
200	300E	False Positive
300	-	False Negative
400	100E	Duplicate
500	100E	Duplicate

Figure 2.3: Types of reading possibly generated when reader reads tag 100E

Table 2.3: Summary of reading classes considered as anomalies in RFID

Reading Classes	**Descriptions**	**Sources**
False positive readings	Additional unexpected readings are generated.	RFID tags outside the normal reading scope of a reader are captured by the reader.
		Unknown reasons from the reader or environment.
False negative readings	RFID tags are not read by the reader at all.	When multiple tags are to be simultaneously detected, RF collisions occur and signals interfere with each other, preventing the reader from identifying any tags.
		A tag is not detected due to water or metal shielding or RF interference.
Duplicate Readings	Numbers of same readings by the reader(s)	Tags in the scope of a reader for a long time and read by the reader multiple times.
		Multiple readers are installed to cover larger area or distance, and tags in the overlapped areas are read by multiple readers.
		To enhance reading accuracy, multiple tags with same EPCs are attached to the same object, thus generate duplicate readings.

2.3.2 Basic of RFID Data Filtering

Figure 2.3 depict the basic pattern in RFID data stream that need to be filtered. It contains true positive, noise, missed and duplicates reading. At time 100 the reader read the tag correctly which it generate the ID 100E. However at time 200 it produced noise reading where it generate tag ID 300E, which is not exists in the reader interrogation area. At time

300 it misses to read the tag but at time 400 and 500 it read the tag correctly which create duplicate readings in the data stream.

Basically, the occurrence of true positive is higher than false positive [19]. The false positive can be filtered by removing readings that have low readings. The problem now is how to set the threshold and how to perform the filtering efficiently. The second anomaly, the false negative can be solved by adding more reading cycles, so that tag have more chances to be read. By filtering the duplicate reading too, the missed reading can be recovered. For example, it has gone missing at time 300, but at time 400 and 500 it is being read again. That's mean the tag exist in the reader interrogation area from time 100 to 500. Based on this, the problem of false negative has been solved. The problem now when we increase the reading cycle, there will be higher probability on false positive and duplicate readings occurrence. Our research will be focusing on filtering these anomalies which in the same time recover the missed readings.

2.3.3 Filtering Approaches

We divide filtering approaches into seven categories: (i) windows-based, (ii) query processing (iii) Bloom filter (iv) peer to peer filtering (v) slotting algorithm (vi) data modelling and (vii) in-network filtering. The first category is the window-based which segment readings using a window. By using windows we can have only the latest *N* readings to be filtered together to ensure the freshness of the results. The second category, query processing uses Structure Query Language (SQL) and its variance such as Expressive Structure Language (ESL) to filter the data stream. Next category is by using Bloom filter and its variance. Bloom filter achieve space efficiency by allowing some false positive. The fourth category is peer comparison, where the approach takes the advantage of reader networks by comparing the reader's readings with each other. The approach can filter noise reading and recover missed reading. Then we have the slotting algorithm, which aim to put reader into different slot to avoid signal collision, which is the main source of noise reading. The sixth category is by using data modelling. By having specialized data model for RFID, the filtering of anomalies data can be done automatically. The storage of the readings needs to follow the data structure in the model that does not allow duplicate data. The last category is the in-network filtering. The filtering is done in-network. One of the approaches is to eliminate redundant reader to save energy. In the same time it reduces the duplicate readings by letting less reader to operate.

2.3.3.1 Windows-based

The incoming readings from reader can be filtered by comparing their number of occurrence. Noise readings are low in occurrence compared to true positive readings [19]. Therefore, a threshold can be set based on the occurrence rate of noise reading. For example if noise readings can occur no more than three times in 10 cycle readings, the threshold can be set to 4. Only readings that appear more or equal to 4 in the specified range can be verified as true positive. The specified range can be expressed in terms of the number of readings or time unit. A window can be used to realize the range based on either number of elements or using time unit. Generally two types of windows that usually use in data filtering are: (i) sliding windows (ii) landmark windows. Figure 2.4 shows the movement differences between each window.

(i) Sliding window

In general, a sliding window with size of N works by keeping N recent readings from RFID data stream. When new reading coming in, the current position P of reading R will change to (P+1). Therefore reading with position ($P > N$) in the sliding windows will be

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