RFID DATA RELIABILITY OPTIMISER BASED ON TWO DIMENSIONS BLOOM FILTER

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In the name of Allah, Most Gracious, The Most Merciful

All praises to Allah SWT, May Allah sends His peace and blessings upon the beloved Messenger, Prophet Muhammad S.A.W and upon his companions, his family, and all who follow his guidance until the Day of Judgement.

I would like to give a special dedication to my parent,
Hj. Yaacob Bin Md Saat and Hjh. Salipah Binti Kamran, my siblings,
Shamsol Yazlie Yaacob, Yuszaimi Yaacob and Ismail Yaacob, my sisters in law,
my nieces and nephew.

Thank you for your love, your encouragement, supports, prayers, everything since this journey started until the final stages. All of you are the main reason for me to always strive to give the best.

This thesis is dedicated to all of you.

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ABSTRAK

Teknologi Pengenalan Frekuensi Radio (RFID) merupakan teknologi pelaksanaan yang fleksibel yang telah diterima pakai dalam banyak aplikasi terutama sekali dalam pengurusan rantaian bekalan. Ia menyediakan beberapa ciri-ciri seperti memantau, mengenal pasti objek dan menjejaki objek tertentu yang tersembunyi dalam kelompok besar objek dalam masa yang singkat. Sistem RFID menggunakan gelombang radio untuk melaksanakan interaksi tanpa wayar untuk mengesan dan membaca data dari objek tag. Walau bagaimanapun, aliran data RFID mengandungi data yang salah dan data yang berulang-ulang. Kedua-dua jenis bacaan ini perlu ditapis untuk memastikan kebolehpercayaan maklumat yang dihasilkan daripada aliran data RFID. Sekiranya timbul bacaan yang salah dalam kuantiti kecil, ia boleh mengubah seluruh maklumat yang akan diterima. Manakala bacaan data yang berulang-ulang pula boleh menyebabkan pemprosesan maklumat menjadi kompleks dan memenuhi storan. Banyak kaedah telah dicadangkan untuk mengeluarkan kedua-dua jenis data tersebut, tetapi ia dilakukan secara berasingan. Dalam tesis ini, pendekatan yang berkesan berdasarkan penapis Bloom telah dicadangkan untuk menghapuskan kedua-dua data tersebut dari aliran data RFID. Terdapat dua penapis Bloom pada satu algoritma di mana setiap penapis memegang fungsi sama ada untuk menghapuskan data yang tidak wujud dan untuk mengenalpasti data yang benar dari data yang berulang-ulang. Hasil kajian menunjukkan pendekatan yang dicadangkan telah mengatasi pendekatan lain yang sedia ada dari segi kebolehpercayaan data.

ABSTRACT

Radio Frequency Identification (RFID) is a flexible deployment technology that has been adopted in many applications especially in supply chain management. It provides several features such as to monitor, to identify and to track specific item hidden in a large group of objects in a short range of time. RFID system uses radio waves to perform wireless interaction to detect and read data from the tagged object. However, RFID data streams contain a lot of false positive and duplicate readings. Both types of readings need to be removed to ensure reliability of information produced from the data streams. A small occurrence of false positive can change the whole information, while duplicate readings unnecessarily occupied storage and processing resources. Many approaches have been proposed to remove false positive and duplicate readings, but they are done separately. These readings exist in the same data stream and must be removed using a single mechanism only. In this thesis, an efficient approach based on Bloom filters was proposed to remove both noisy and duplicate data from the RFID data streams. The noise and duplicate filter algorithm was constructed based on bloom filter. There are two bloom filters in one algorithm where each filter holds function either to remove noise data and to recognize data as correct reading from duplicate data reading. In order to test the algorithm, synthetic data was generated by using Poisson distribution. The simulation results show that our proposed approach outperformed other existing approaches in terms of data reliability.

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RFID	Radio Frequency Identification	1
LF	Low Frequency	8
HF	High Frequency	8
UHF	Ultra-High Frequency	8
CMOS	Complementary Metal Oxide Semi-Conductor	10
EPC	Electronic Product Code	11
DTSW	Dynamic Threshold Sliding Window	18
DDSW	Denoise Duplicate Sliding Window	19
HTB	Hash Table Approach	19
DUBF	Duplicate Removing Bloom Filter	21
LGBF	Local Global Bloom Filter	21
TIBF	Time Bloom Filter	23
LGBF	2 Layer Local Global Bloom Filter	24
CCBF	Counting-Chain Bloom Filter	24
DUP_FA	Duplicate Filter	25
TTTR	Three Tags Two Readers Model	25
CBA	Cluster Based Framework	27
SFA	Smooth Filtering Approach	27
2BF	Two Bloom Filter	33
DBF	Duplicate Bloom Filter	33
NBF	Noise Bloom Filter	33

CHAPTER 1

INTRODUCTION

1.1 Introduction

Radio Frequency Identification (RFID) technologies has been broadly applied in many applications such as supply chain management (Yan *et al.*, 2015), healthcare management system (Hu *et al.*, 2014), public transport system (Frick, 2014), and library management system (Kushal *et al.*, 2012). RFID is a technology that uses radio waves to transfer detecting information between reader and tagged object from a distance without line of sight. Through radio frequency waves, readers can read tags in a short range of time.

A typical RFID system consist of tag, reader, middleware and application (Kour *et al.*, 2014). A tag is a package that can be attached to the physical object. While reader, also known as interrogator will communicate with the tag by transmitting radio waves. The tag then sends the radio signal back to the reader and sends to the server for further analysis and processing of data. The RFID data is generally in the form of reader_id, tag_id and timestamp (Hu, Li, & Lu, 2013).

As the tag is unique, the readers are able to detect the information of RFID tag items from a certain location at different times. While for RFID data are generated quickly and automatically (Zhong *et al.,* 2014), it can be used for real-time monitoring (Kranzfelder *et al.*, 2012; Wang *et al.*, 2014; Zhang *et al.*, 2012; Zhong *et* *al.*, 2013), or accumulated for object tracking (Cheng, Ni, & Li, 2014; Chung, Chu, & Li, 2014; Han *et al.*,2014).

Since the advancement of RFID technology has been broadened in many applications, RFID system still suffers from several problems that prevent it being implemented by the industry. The crucial part by implementing RFID system is to deal with the flood of data generated by the reader (Kwon *et al.*, 2014). For example, the Coca-Cola Company produced more than a billion bottles per day. An effective retail in-store logistics at Coca-Cola Company is necessary to ensure high product availability at minimum operating cost (Metzger *et al.*, 2013). The unreliable data reading such as noise, duplicate reading that were produced by RFID reader has become the primary factor limiting the widespread adoption of this technology.

In that case, it is compulsory to filter the original data to maintain its reliability of data reading for business process. This is because, a small decrease of effective read rate will reduce the accuracy and reliability of further data process (Liu *et al.*, 2014). Therefore, it is necessary to implement filtering technique to provide quality RFID data.

1.2 Problem Statement

Despite all the promises surrounding RFID, the technology's potential has yet to be fully realized. The problem of existing data such as data redundancy and noise data causing raw RFID data become unreliable (Wang *et al.*, 2014; Zhang, Li, & Chen, 2011). These have become an issue and it requires filtering technology capable to determine which data is important and which data is unimportant to maintain the reliability of data.

Data redundancy or duplicate readings occurred when the similar RFID data readings generates repeatedly due to multiple readings cycle and multiple readers implemented to cover specific area (Mahdin, 2014). The duplicate readings problem is recognized as a serious issue in RFID and sensor networks (Vahdati, Javidan, & Farrahi, 2010). For example, in a storage room in the supermarket, readers will generate hundreds of useless readings that are useless in the enterprise application. In a real process, we are only interested in the reading that indicates the occurrence of events such as when a new stock arrived or being picked up.

Noise data happens when reader detects a tag, but it is not in the reader's field (Ma *et al.*, 2014). This happens because of tag collisions (Fritz *et al.*, 2011) and reader collisions (Zhang *et al.*, 2013). Reader collision occurs when the signals from two or more readers overlap. Tag collision occurs when many tags are present in a small area. Although the occurrence of noise reading is low (Bai, Wang, & Liu, 2006), noise reading can mislead important business decision-making.

In the previous research on RFID data filtering, most of the approaches treated duplicate reading issue and noise reading issue in separate problem. In this research, a new single approach is proposed to solve these problems together to enhance the efficiency in order to get a reliable data in RFID data stream. It is important to preserve correct data in the database as it will consume the space of the storage and it can mislead the decision making especially in supply chain management. Therefore, to maintain the reliability of data, it is necessary to ensure only accurate data are stored in the data center.

1.3 Aim

The aim of this study is to provide novel solution to address the above-mentioned issues and propose reliable method to filter noise and duplicate readings that will enhance RFID data reliability.

1.4 Research Objectives

In order to investigate the research aim, several specific objectives are set as follows:

(i) To propose a new algorithm that filters noise readings and duplicate readings in RFID data streams.

(ii) To simulate the algorithm that filter duplicate readings and noise readings.

(iii) To evaluate the performance of the proposed algorithm with existing methods in term of data reliability within the simulated environment.

1.5 Scope of Research

The research will be focusing on noise and duplicate data filtering problem, which is a common issue in RFID system. In the literature, both issues often are treated as separate problems. It is paramount to have a new single approach to solve these problems together in order to minimize effort done to get a clean data stream. Therefore the research objectives are clearly relevant to the above criteria, which aim to develop a new approach to established research topic.

1.6 Significance of Research

Although RFID systems are vastly emerging as a primary object identification mechanism, the raw data collected by RFID readers are inherently unreliable. Since data unreliability would lead to inaccurate decisions or responses, it is imperative that the data is cleaned before being sent to the backend system for use by RFID applications. There are several factors that lead to RFID data unreliability: noise and duplicate readings. For example, a noise reading at one's checkout point will trigger false alarms 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 factor that caused the unreliability of the RFID data is due to duplicate readings. A reading is said to be duplicated 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 the 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.

1.7 Research Organisation

The research consists of five (5) main chapters. The chapters are as follows:

(i) **Chapter 1**: Introduction

This chapter consists of introduction to research, problem statement, aim, research objectives, scope of research, significance of research, research organisation and summary of the chapter.

(ii) **Chapter 2**: Literature Review

Chapter 2 discussed a brief overview of RFID and issues of data unreliability. This chapter also presents the relevant background information regarding the previous approaches in RFID data filtering approach.

(iii) **Chapter 3**: Research Methodology

Chapter 3 discussed a brief steps and strategy on how to filter noise reading and duplicate reading in RFID data streams.

(iv) **Chapter 4**: Results and Findings

This chapter presents the result and analysis of the simulation proposed algorithm. The proposed algorithm was tested to measure data reliability based on the RFID data criteria as discussed in Chapter 3. Comparison result of proposed algorithm with other algorithm is also discussed in Chapter 4.

(v) **Chapter 5**: Conclusion and Recommendations

Chapter 5 concludes the research study and some recommendations were given for future works in order to improve system efficiency and data reliability in RFID.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

RFID technologies in industries has been significantly implemented in large scale and distributed network especially for inventory checking (Qu et al. 2012) and object tracking (Zhong et al. 2013). Despite the benefits that has been discussed in Chapter 1, there were many issues arises that needs solution before the benefits can be realised. This chapter provides the theoretical perspective of RFID system and architecture.

This chapter will also discuss the type of RFID readers and type of RFID tags that is used in RFID system. The characteristics of RFID data and issues were also discussed in depth in order to understand the current problems in industries. The fundamental concept of data filtering in RFID was visualised in order to comprehend the basic concept of data filtering. Previous proposed solutions of various data filtering approach in RFID were also presented and also discussed in comprehensive. At the end of this chapter, a conclusion was made to conclude the overall literature review in this chapter.

2.1 RFID System and Architecture

This section outlines the architecture of an RFID based solution, typical components and the functional usage of each component. Figure 2.1 shows the typical components of RFID system architecture. There are four main functional components; tags, reader, middleware and database and application (Wu, Cheng, & Chang, 2013). Each of these components provides specific functions and these components integrate to form RFID-enabled system as in Figure 2.2.

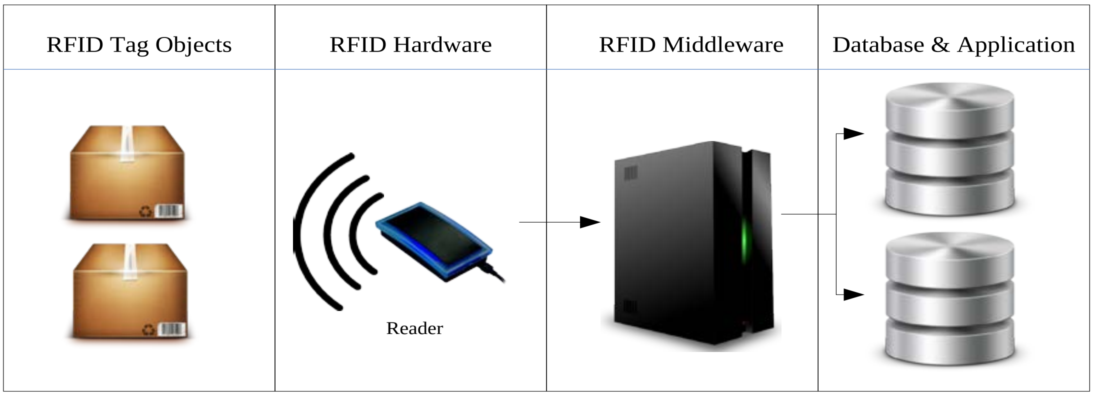

Figure 2.1: RFID Architecture

Tags are the most fundamental components in RFID system (Good and Benaissa 2013). RFID tags that contain tagged data are physically attached to the objects. The tags will generates a signal containing respective information that is read by the RFID reader as in Figure 2.2. The RFID reader will create radio waves to detect tag information at the tagged object. Then reader query tags to obtain data and forward the data information through the middleware to the backend database and application servers.

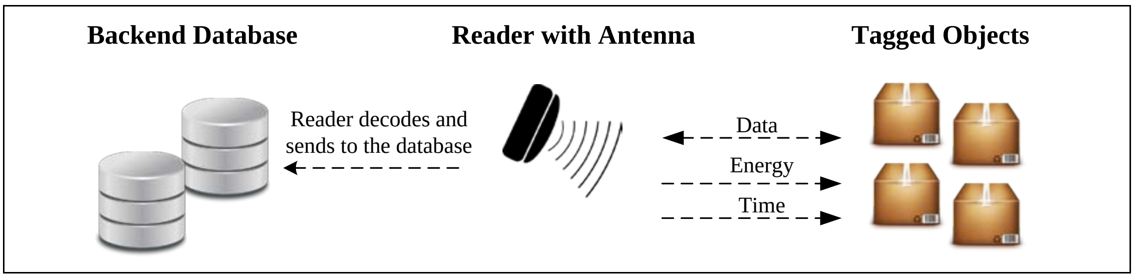

Figure 2.2: RFID-Enabled System

RFID system can be classified based on the frequency band the system operates. There are three types of RFID systems (Zhu, Mukhopadhyay, & Kurata, 2012); low frequency (LF), high frequency (HF), and ultra-high frequency (UHF). Frequency refers to the size of waves that is used to communicate between reader and tagged object. Each frequency has its own sensitivity and operates differently based on type of frequency.

(i) **Low Frequency (LF)**

The LF band covers frequencies from 125 – 150 kHz (Bonter and Bridge 2011). This frequency band provides a short read range of 10 cm. The LF band has slower read speed than the higher frequencies, but is not sensitive to radio wave interference. This LF RFID application system includes access control (Kaur *et al.*, 2011) and livestock tracking (Barge *et al.*, 2013).

(ii) **High Frequency (HF)**

The HF has range frequencies 13.56 MHz. This frequency provides read ranges between 10 cm and 1 m (Koskinen, Rajagopalan, and Rahmat-Samii 2011). HF systems experience moderate sensitivity to harsh environment (Fritz et al. 2011). HF RFID is commonly used for identification, ticketing, and payment system (Menghin et al. 2013).

(iii) **Ultra-High Frequency (UHF)**

The UHF frequency has range between 860 – 960 MHz (Choosri, Yu, and Atkins 2013). The maximum read range of UHF system can be long as. 2.9 – 3.3 m (Wang *et al.*, 2011). Based on the frequency range, UHF has a faster data transfer rate than LF and HF. UHF RFID system has the most sensitive to interference (Papapostolou and Chaouchi 2011). This UHF RFID is used in a wide variety of applications such as location tracking (Sarkka *et al.*, 2012).

2.1.1 Tag

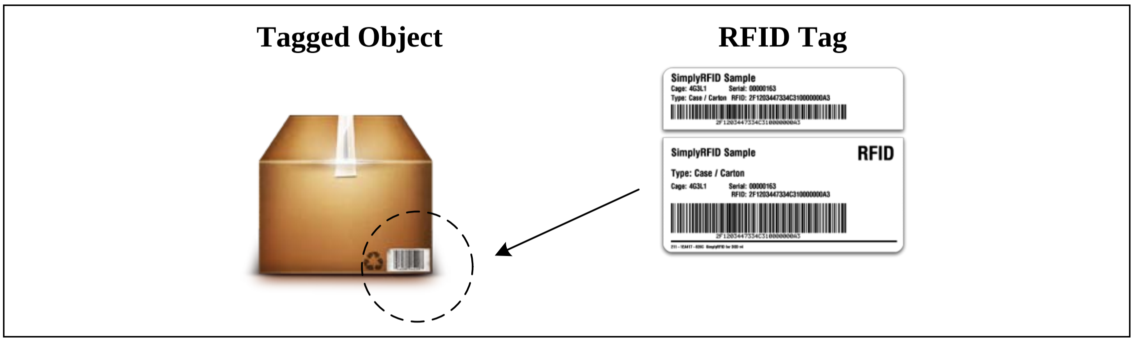

Figure 2.3: RFID Tag Object

Figure 2.3 shows tag that is attached at the object to track its location and information sent using radio waves. The RFID tag was made up of antenna, a wireless transducer and encapsulating material (Reig and Avila-Navarro 2014). There are several types of tags that commonly used in RFID (Wang *et al.*, 2014); active tag, passive tag and semi-passive tag. These tags are categorised based on their power source.

Active tag and semi passive tag requires internal power source, usually a low volt current. While passive tags do not need internal power source because it will only become active when a reader is near to re-energize the tags. Active tags usually larger and expensive as it need power source. Generally, active tags are more reliable and accurate, as the tags will broadcast their signal to the reader. Passive tags have no internal power source and rely on the RFID reader to transmit data. Small amounts of electric current is received through radio waves by the RFID antenna, and triggers the complementary metal oxide semi-conductor (CMOS) in the tag to power up and transmit a response (Nilsson and Svensson 2013). Semi-passive tags are similar to active tags as it has its own internal power source. But it does not broadcast the signal until the RFID reader transmits.

Table 2.1: Comparison of Active, Passive and Semi-Passive Tag

Type of Tag	**Power Source**	**Responsiveness**	**Cost**	**Example**
Active	Required	Broadcast	Expensive	• Container tracking
Passive	Not required	Response only	Cheaper	• EPC • Credit card
Semi-passive	Required	Response only	Expensive	• Electronic toll • Pallet tracking

Inside tag layer contains the Electronic Product Code (EPC), which is globally unique identifier for the object being tagged (Chen *et al.*, 2015). There are numbers of different encoding formats. These formats can be specific to each individual asset of the company. Usage for every particular tag depends on the tagged object.

To guarantee that each EPC code is unique, the organization driving standards for EPC allocates each company a unique number (GLOBAL 2008). The code is standard and follow universal numbering scheme for physical objects. The EPC identifies each tag individually and it has standard structure as Figure 2.4. The first field in the header defines the coding schemes in operation with the remaining bits providing the actual product code. The manager field is responsible for identifying the product manufacturer. The object class defines the product class itself. The serial number is unique for an individual product class.

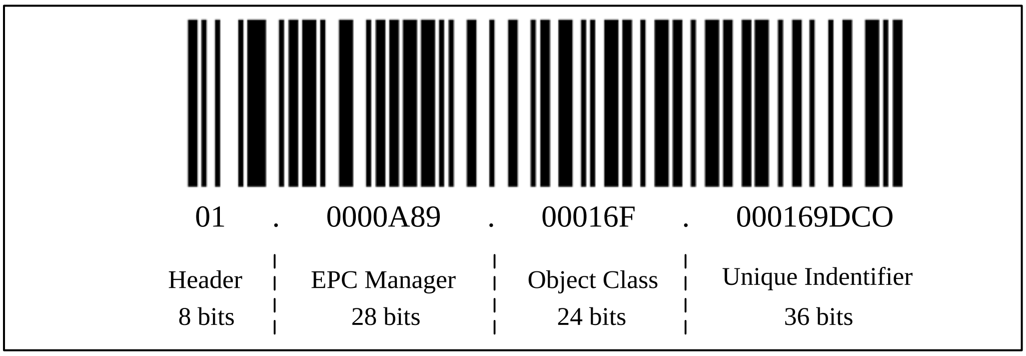

Figure 2.4: EPC Structure 96-Bit

2.1.2 Reader

RFID reader is a scanning device that consists of antenna, transceiver and decoder (Irfan, Yagoub, & Hettak, 2012). The function of reader is to send and receive radio frequency data to and from the tag via antennas. A reader may have multiple antennas that are responsible for sending and receiving radio waves.

There are two types of RFID reader: fixed and mobile (Deking, Iyer, & Pappu, 2014). Fixed RFID reader is mounted at specific area or location to read object passing by. It is also can be mounted on moving object such as forklifts to read the object that the forklifts carrying. Mobile RFID reader is a handheld device that 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.

2.1.3 Middleware

RFID middleware is the interface that operates between the RFID hardware and RFID applications. It focuses on processing the massive RFID data before it is routed to the specific applications. The middleware functions to collects and processes the readings from readers for the use of enterprise applications and enterprise database. The process such as filtering, logic and aggregation transform raw data into the required format for the application.

2.1.4 Application

Application or enterprise applications and database is the topmost layer of components in RFID architecture. In this layer, it actually interacts with user as it consists graphical user interface. The readings that have been filtered into required format are sent to this layer. This layer converts the data from middleware into meaningful information. It then delivers information to other application system or database.

2.2 Characteristic of RFID

RFID is an automatic data capturing technology that generally used in large distributed systems (Zhu *et al.*,, 2014). RFID has many valuable operations (Leema, Sudhakar, & Hemalatha, 2013) such as, it is contactless and able to detect tagged objects at distance in a short range of time. Besides, mobile tracking can be either reused or disposed depends on the operation requirement of RFID. RFID is readily deployable in harsh environment. RFID technology is a low maintenance cost technology and it does not require human interaction. Some of RFID are able to store data, exchange data, in tag objects during data processing.

The RFID systems are being used in variety of applications. Despite of its diversity of implementation, the data generated from RFID application shares some common characteristics. The characteristics of RFID data are described as follows;

(i) **Uniform data.**

The RFID data generated from the RFID reader is in uniform view (Chen *et al.*, 2014).

(ii) **RFID data is massive.**

The biggest challenge of RFID is the system generates large data volumes (Chen, Mao, & Liu, 2014). Thus, to deal with such big data is a challenging task.

(iii) **Real time RFID data.**

The RFID data are generated in real time (Li *et al.*, 2015; Qin, Feng, & Dong, 2015; Zhang *et al*., 2015; Zhong *et al*., 2015). This real time data is used for different purpose in RFID such as when identifying existing items captured in store.

(iv) **RFID data contains defects data.**

The massive data generated contains defects data (Zhu *et al.*, 2014). Defects data exists because of the collision between readers. The RFID system has parallel transponders and receivers, thus information generated every second may not be reliable. Sometimes, it is combined with other tag values or other environmental hindrances.

2.3 RFID Challenges and Issues

Despite of various advantages of RFID system, there are issues and challenges in data management level. RFID system generates massive amount of data, which often contains errors and unimportant readings (Liu *et al.*, 2015). These errors can be classified into three types of error readings that caused by hardware in RFID system (Leema & Hemalatha, 2013); noise reading, missed reading and duplicate reading.

Noise readings consider the tag is absent but unexpectedly captured by the reader. This happened as the RFID system consist a lot of parallel transponders and receivers. The radio frequency of information contained in RFID tags may collide with other tag value and produce a new unexpected reading (Chigozirim & others, 2013). Besides tag collisions, the presence of environmental interferences such as water and metal generates unexpected data especially by implementing UHF RFID systems (Bong, Chang, & Oh, 2014).

Another error that caused by the reader is missed reading. The missed read error is one of the factor that makes the widespread adoption of RFID technology become limited. It is because the readers are unable to detect the tagged objects while the tags are actually exist in the vicinity of readers. There are 30-40% missed reading rate in real world RFID deployment and there is higher drop rate probability in other particular environment (Hu et al., 2013).

Duplicate readings happened when several readers read several tags at the same time. It can also occurs when the tag remains in the same vicinity of reader for a long period of time and has been captured several times. The impact of duplicate readings can cause huge loads at the centre server (Zhu et al., 2012). This implication makes the database growing larger in size storing the unimportant anomalies.

Based on these issues, there are several types of readings that the reader encounters (Leema & Hemalatha, 2013); true positive reading, true negative reading, false positive reading, false negative reading and duplicate reading. Figure 2.5 below shows the condition of readings the reader encounter based on the characteristics and issues of RFID.

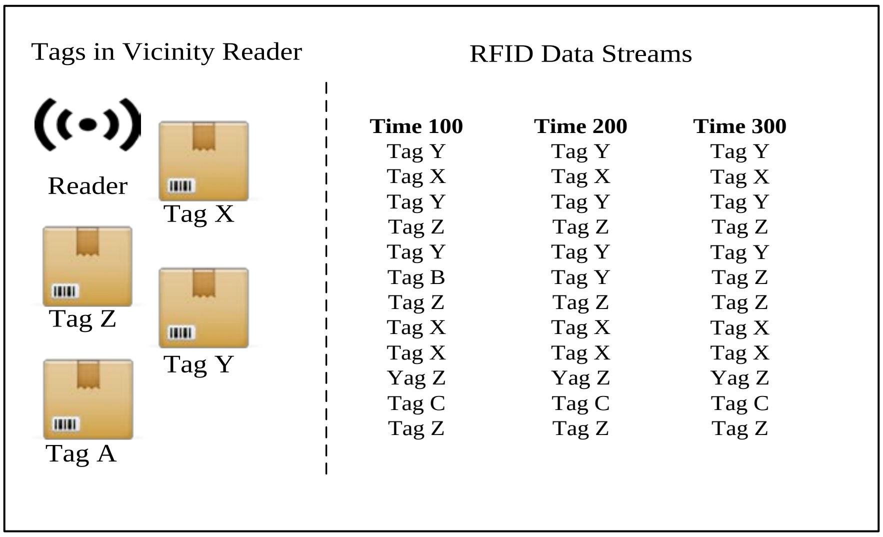

Figure 2.5: RFID Data Streams

(i) **True Positive Reading**

(a) This reading refers to the case where the reader identifies the tagged object to be present while it is in the vicinity of the reader. This represents Tag X, Tag Y and Tag Z in Figure 2.5.

(ii) **True Negative Reading**

(a) This reading refers to the case where the reader is reading the tag as being absent and it is truly not in the vicinity of the reader.

(iii) **False Negative Reading**

(a) The tag is considered to be absent when it indeed is present in the vicinity of reader. Based on Figure 2.5, Tag A is unable to be detected by the reader while it is actually in the vicinity of the reader. This scenario represents as missed read in RFID data streams.

(iv) **False Positive Readings**

(a) The tag is considered to be present by the reader when it is really not in the vicinity of the reader or the reader accidentally reads a distant tag. Refer to Figure 2.5, Tag B is unexpectedly exist in the data stream while it is not actually exist in the vicinity of the reader. This situation considered as noise where it accidentally recorded in the data streams.

(v) **Duplicate Reading**

(a) The same tag generates repeatedly are considered as duplicate readings. Based on Figure 2.5, Tag X, Tag Y and Tag Z in the data streams consider as duplicate readings as it is repeatedly occurred in the data streams.

Table 2.2 shows the types of RFID readings that the reader encounters and the acceptance of readings. Based on this discussion, true positive, true negative reading and duplicate readings are considered as true readings. Although duplicate readings is a true reading, it needs to be filtered so that only one true reading is saved and sent to the application. It is important to identify the presence of tag correctly because the RFID environment contains false positive readings false negative readings and duplicate readings. These incorrect data such as false negative readings and false positive readings in RFID data stream needs to be filtered before it is sent to the applications and databases.

Table 2.2: Type of Readings in RFID Data Stream

Readings	**Acceptance**	**Description**
True Positive	True	Tag is being identified
True Negative	True	Tag is not being identified
False Positive	False	Tag being identified but reported as inaccurate data
False Negative	False	Tag is not being identified but it is in the vicinity of reader
Duplicate Readings	True	Multiple readers

2.4 Fundamental Concept of Data Filtering

As RFID data arrives rapidly and in high capacity, RFID readers play critical role in order to filter out incorrect RFID data readings. It has been the major limitation for RFID to be implemented in large-scale as it can caused 30% of incorrect data reading (Aggarwal & Han, 2013). Its detection usually demands efficient processing, especially for those real time monitoring. Such data cannot be used directly by applications unless they are filtered and cleaned.

As the process of data filtering takes place at RFID middleware, there are two types of filtering discovered: (i) low level data filtering (Wu *et al.*, 2013) and (ii) semantic data filtering (Wu, Sheng, & Zeadally, 2013). At low-level data filtering, it cleans raw RFID data streams. For example, removing duplicate and noise readings from the data streams. The semantic data filtering filters data based on demand of applications such as list of soft drinks sold in a specific month.

In RFID data stream filtering, common research often focus on the low level data filtering. For example, research that focus on the filtering uncertainties data such as noise reading and duplicate reading. Previous research shows that the process of filtering noise readings, such as (Hu *et al.* 2013) and duplicate readings, such as (Lee & Chung, 2011) are done separately. Figure 2.6 depicts the basic filtering concept of noise reading and duplicates readings.

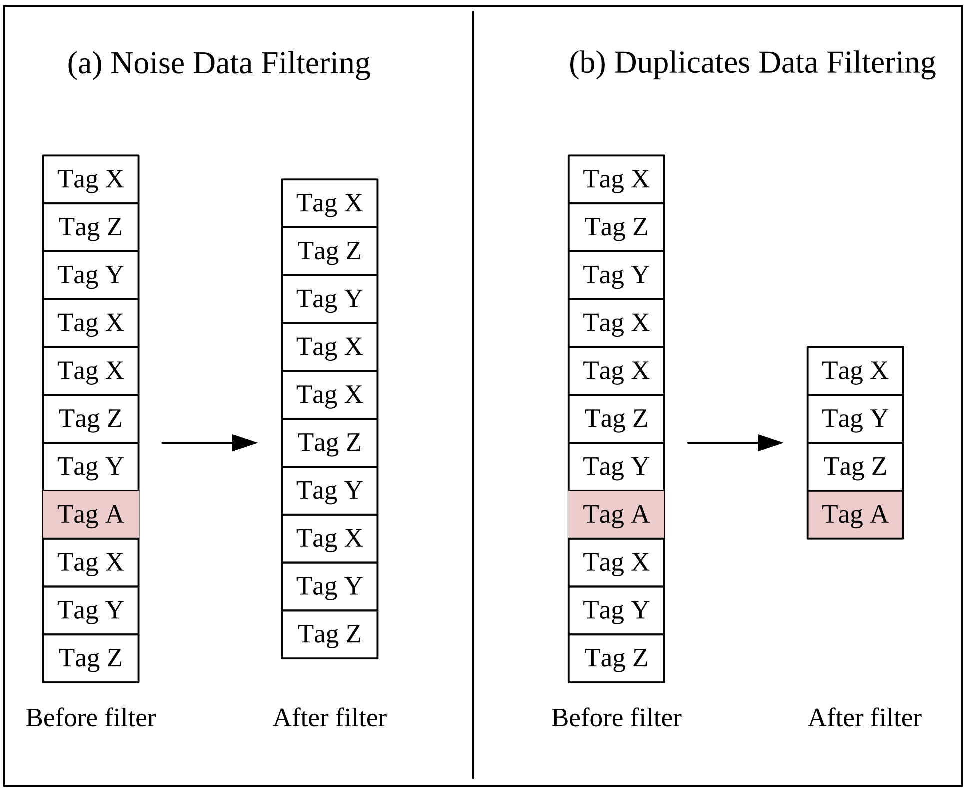

Figure 2.6: Noise Data Filtering and Duplicate Data Filtering

The problem of noise data filtering in (A), is when noise Tag A has been removed the duplicate readings of Tag X, Tag Y and Tag Z are still exist in the data stream. The same scenario occurred in (B), where the noise reading is still exist as the duplicate readings Tag X, Tag Y and Tag Z has been removed.

2.5 RFID Data Filtering Approaches

The methodologies for improving RFID data reliability proposed in previous research can be divided into three categories (Massawe, Vermaak, & Kinyua, 2012); physical solutions, middleware solutions, and deferred solution. Physical solution focusses on improving hardware performance to improve the reliability data such as to minimize tag collisions to prevent the occurrence of noise readings. While middleware solution focusses on the development of the algorithms such as an algorithm to remove noise readings and duplicate readings in the data streams. The deferred solution is a solution that proposed an intelligent technique to correct data in the data storage. This research focusses on middleware solution that is to discover techniques and approaches that used to filter noise readings and duplicate readings in the data streams.

2.5.1 Window Based Approach

One of the approaches that used to filter data is by implementing sliding window technique. There are two types of window-based approach discovered; sliding window and landmark window (Rui, Guoqiong, & Guoqiang, 2014). Based on Figure 2.7, a sliding window is a window with certain, size that moves with specific time. While landmark window is a window that move with time.

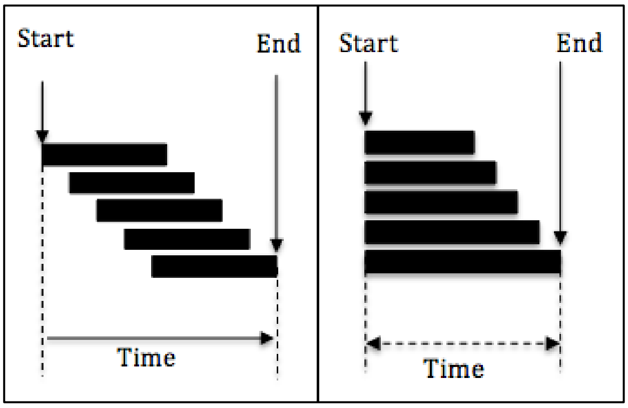

Figure 2.7: (a) Sliding window, and (b) Landmark Window

Bai *et al.* (2006) has conducted a research that focuses on reducing noises, false positive readings, false positive readings and duplicate readings. To overcome noise problems, they have proposed a technique where any tag below the threshold value will be discard. Else, if the number of the readings with the same tag EPC values appears equal to or above threshold, then the EPC value is not noise and need to be forward for further processing. While in the duplicate elimination process, they proposed a technique by keeping a sliding window of size exist another reading in the window with the same key, then it issue (max_distance) in time from the previous reading with the same key, then this reading is considered a new reading.

Tyagi, Ansari, & Khan (2010) proposed dynamic threshold sliding-window based approach (DTSW) to reduce false positive reading and false negative reading by adding time scheduling on threshold value. This means after a period of time, the data will recognize as a tag or else it will consider as a noise. They also proposed a technique to inspect data format of RFID and associate values such as header information by introducing CheckEPCHeader(). After recognizing data as a tag, CheckEPCHeader() will inspects all tags whether it is a real tag or it is a noise.

Mahdin & Abawajy (2009) proposed an approach denoise and duplicate elimination algorithm (DDSW) to filter noise and duplicate readings in one algorithm that make one filter. This approach used number of occurrence per time as the basis of filtering data in the data stream. Figure 2.8 portrays how the filtering works in order to filter noise and duplicate readings in one algorithm. Thus, eliminating one of the filters reduces the time required to filter duplicate readings

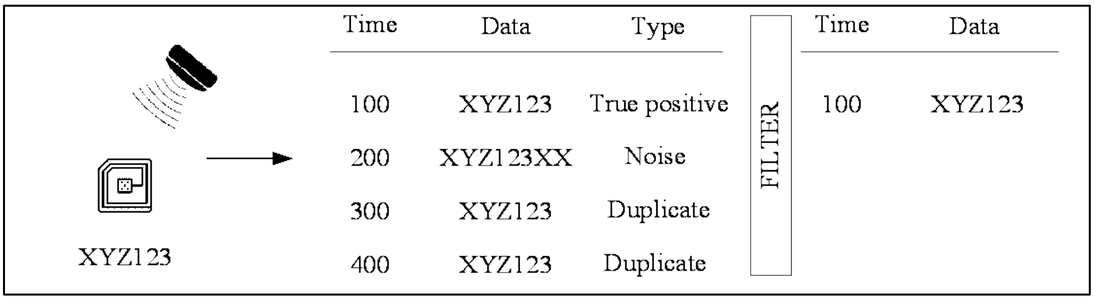

Figure 2.8: Noise and Duplicate Filtering Approach

Then the author focuses their works to filter duplicate reading filtering in RFID data stream (Mahdin & Abawajy, 2010). However, this approach has low false positive rates, which illustrates the improved correctness of the filtering process. It is more efficient in terms of time and memory usage.

Hu *et al*. (2013) has proposed HTB algorithm as a solution to filter noise data in RFID data streams based on hash table approach. They solve the problem of sliding window when the size of data getting bigger, the RFID reading has not been outputted until it expires in sliding window. Although the research focuses on filtering on false positive reading, they are actually filtering the duplicate reading by applying time tolerance threshold in hash table technique.

2.5.2 Bloom Filter Approach

Another approach that used to filter data in RFID is Bloom filter approach (Bloom, 1970). A Bloom filter is a space-efficient probabilistic data structure that tells either the data is in the set or not. Figure 2.9 shows a basic structure design of bloom filter.

It represents data in its bit array of size *m* using *k* number of hash functions. Whenever the data has been hashed, all bits in array that are initially set to 0 will be substitute to 1.

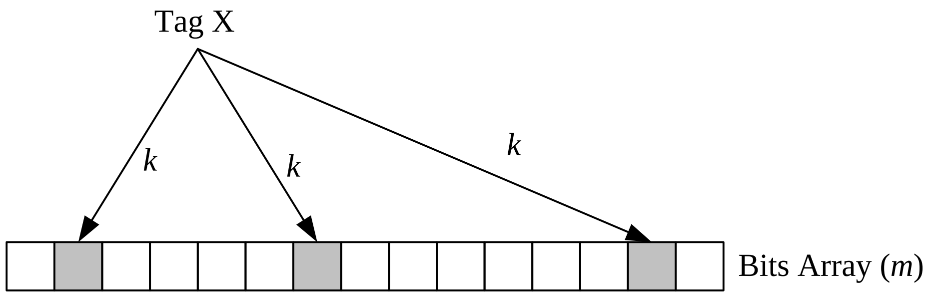

Figure 2.9: Basic Structure of Bloom Filter

The basic bloom filter supports two operations: test and add (Dillinger and Manolios 2004). Test is used to check whether a given element is in the set or not. If it returns false, then the element is definitely not in the set. If it returns true, the element is probably in the set. The false positive rate is a function of the bloom filter's size and the number of independence hash functions used. Add, simply adds an element to the set. To add an item to the bloom filter, we feed it to the k different hash functions and set the bits at the resulting result. To test if an item is stored in the filter, again we feed it to the same *k* hash function. If one or more of these bits is not set then the queried element is definitely not present in the filter. The more data are added to the bloom filter, the higher the probability to filter false positives.

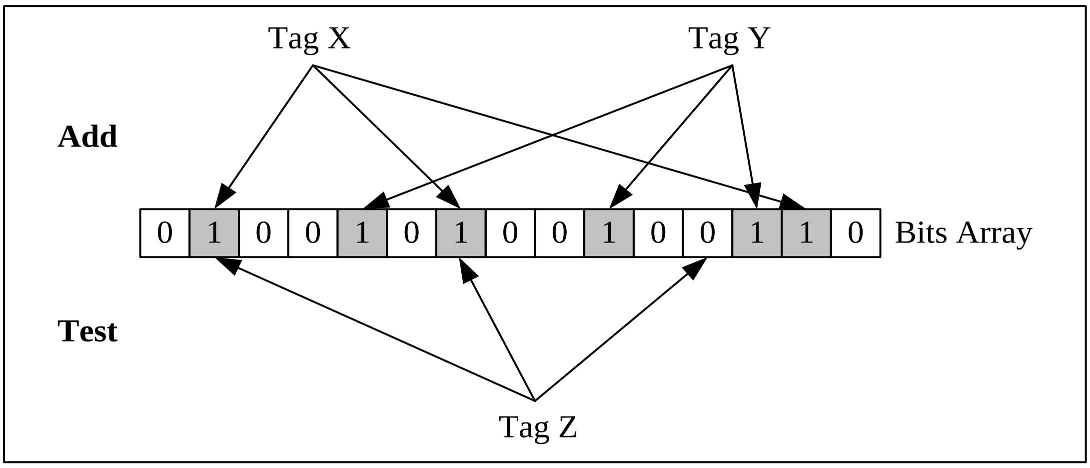

Figure 2.10: The Operation of Bloom Filter

Figure 2.10 visualizes how a bloom filter operates. The bloom filter simply adds data such Tag X and Tag Y in the bloom filter. If any of the bits are zero (0), for example Tag Z, then the string definitely does not exist in the filter. If all of the bits are 1, there is probability that the string exists in the filter. Generally, bloom-filter has been used to filter duplicate data. Removal and deletion is not allowed in normal bloom filter. This is for the reason that a single counter in bloom-filter can be hashed number of times by different data. Turning counter to 0 will disturb other data that is not involved in the deletion.

Previous research shows that bloom filter has been extended to allow deletion and implemented many research in order to filter duplicate readings and noise in RFID data streams. In this research, we will discuss various researches that used bloom filter as a technique to filter RFID data stream in chronological order. (Deng & Rafiei, 2006) has proposed an algorithm (DUBF) using bloom filter approach to eliminate duplicate data in the data stream applications. The bits in the regular bloom filter are change into cells consisting one or more bits. In order to eliminate old data, each cell is set to the maximum value and decrease the values of randomly selected cells whenever data arrives. However, this approach is still producing false positive errors and false negative errors.

Wang, Zhang, & Jia (2008) has used bloom filter technique and proposed two algorithms (LGBF) that each for local duplicates filtering and global duplicates filtering in order to filter duplicates within each stream and to overcome their space and time cost feasibility for high-speed data streams.

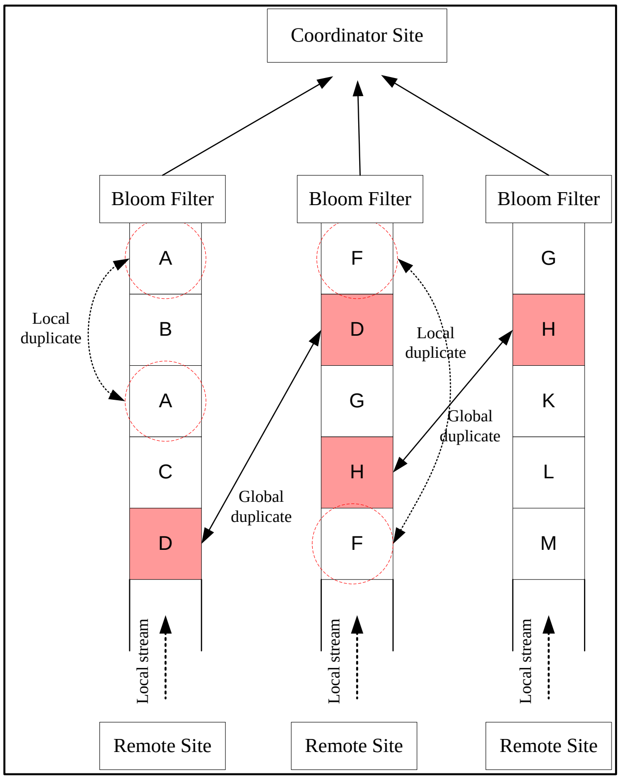

Figure 2.11: Local Duplicates and Global Duplicates

Figure 2.11 shows that there are remote sites and coordinator site. Each remote site, the duplicate data readings are filtered by using bloom filter technique and then send clean data to the coordinator site. Each local stream has both local duplicates and global duplicates. Each local filtering can only filter all local duplicates but not global duplicates. In order to filter both local and global duplicates, each remote site must maintain the history of stream because each remote site can only communicate with the coordinator site. The remote site must share global history via the coordinator site. To share the global history, the coordinator site must update its filter with the new reading and sent it to the other remote site. If the same reading being produced again at any of the remote sites, it will be ignored because it has been inserted in the filter. As RFID generates flood of data, this approach is not suitable because it need to update the coordinator site each time new reading is entered. This process can cause bottleneck as data at the remote site need to be filtered before send clean data to the coordinate remote for querying process.

Mahdin & Abawajy (2011) has proposed an approach to filter duplicate readings in RFID based on Bloom filter. The proposed approach stores the information such as time of tag detected in the filter units to compare which reader a tag belong to. However, the algorithm might complicate the selection reading cycle and the time of clearing data in the filter. Thus, the algorithm may delete the true reading and cannot be used in the filter.

Lee & Chung (2011) has extends original bloom filter to support sliding window and proposed time bloom filter algorithm (TIBF) in order to detect duplicate data reading on RFID data streams. As the process of filtering duplicates were takes place at the server side, a lot of bandwidth wasted during transferring the duplicates. Hence, three algorithms; bloom filter, time bloom filter and time interval bloom filter were proposed to eliminate each duplicates data arrive. Time interval bloom filter were used in fault detection and elimination and this algorithm need more space than the time bloom filter. In this research, the time interval bloom filter need more space compared to time bloom filter. Time bloom filter depends on time information to check whether the data duplicates or not. Even though it does not create false negative errors, the major problem of this technique is bottleneck will occurs, as the data has to pass through this module in the server side.

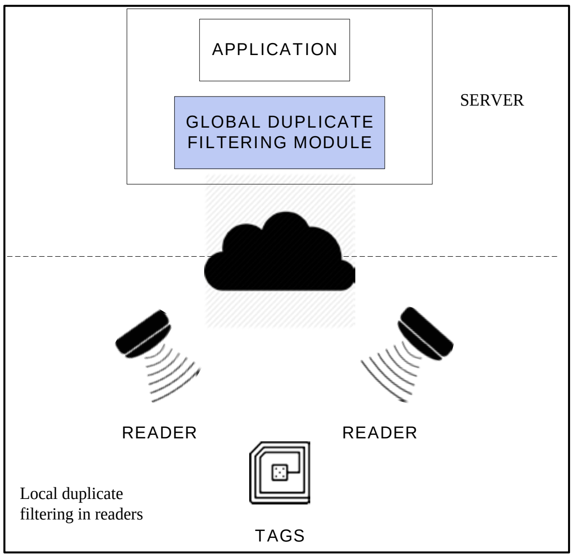

Figure 2.12: Two-Layer Filtering Approach

Jiang, Wang, & Zhang (2012) proposed two-layer filtering approach by introducing local and global bloom filter algorithm (2LGBF) to eliminate the local duplicates at the reader level then detecting the global duplicates in the server side as in Figure 2.12. The two-layer approach is proposed in order to reduce network bandwidth. However, this approach produce small error rate and caused latency at the reader level as it need to clean the duplicate reading before it have to pass through to global duplicate filtering. Yongsheng & Zhijun (2013) proposed a data filtering approach to detect and eliminates duplicates data reading in RFID. They proposed a technique that used counting bloom filters algorithm (CCBF) with the dynamic chain lists to detect and removed duplicates reading at the data level.

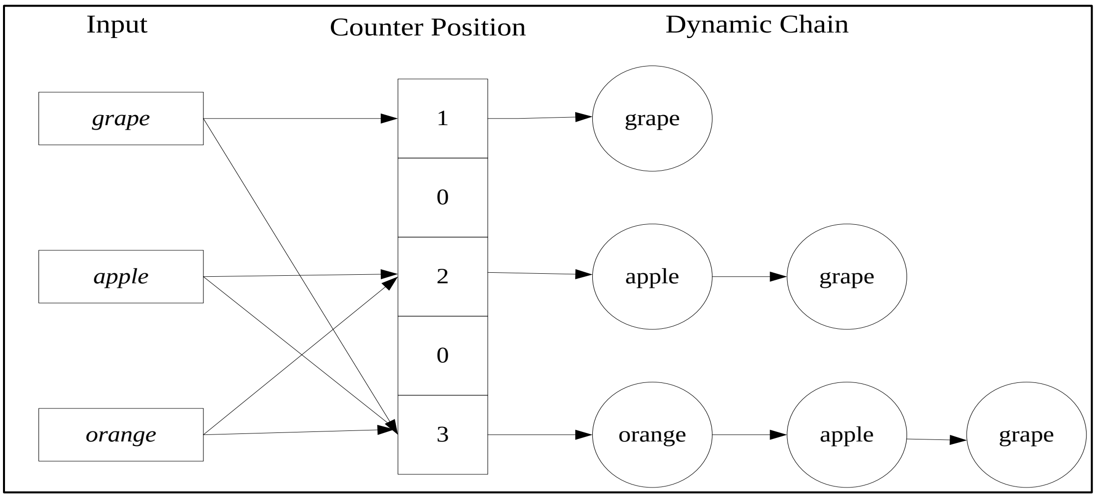

Figure 2.13: The Structure of Chain-Linked Counting Bloom Filter Algorithm

The dynamic chain is proposed as a linked list. They used array of time information to update the expired historical data. By this way, they can detect the duplicates in RFID. Figure 2.13 shows the structure of chain- linked counting bloom filter algorithm. The number in counter position will increment and decrement when input is added or deleted in the filter. Bit in the bit vector is set whenever counter change from zero to one. While bit in the bit-vector is clear whenever the counter changes from one to zero. However, this approach is still not suitable for RFID application because the reader will generate too many readings. Whenever a duplicate detected, they have to find a match in the double linked list. Hence, there will be a latency to find a match during searching duplicates data before they can eliminate the duplicate data.

Mezzi & Akaichi, (2013) has proposed an algorithm that detects and removes duplicates reading (DUP_FA) in data streams in order to store into data warehouse to enhance the decision making for supply chain. They proposed a technique to detect and eliminate the duplicate by looking at the difference of time of the flow detection and the time of the previous stream detection. However, the technique is not suitable to process massive data of RFID. The data has to process with the difference of time to detect and eliminate the duplicates of data. This will slow down the process of filtering and it will disturb the efficiency of decision making for supply chain.

2.5.3 Decision Support Model Approach

Decision support model is a structured process where it consists of several parts of manageable processes to filter RFID data stream. For example, majority-voting approach and smooth filtering approach are examples of decision support model where each technique consists of several parts of process to filter data. Majority-voting is an approach to determine whether the tag object is present. Tu & Piramuthu (2011) believed that by using majority-voting approach would reduce low false read rates in supply chain. The purpose of majority-voting is to detect false negative reading by identifying the presence of data reading in the data stream. They proposed Three Tag-Two Readers Model (TTTR) where all three tags are embedded in their object of interest. Each reader will identify either the presence of the object of interest whether it is present or absent. Table 2.3 shows the basic technique of majority-voting technique. There are several rules that have to be followed in order to detect the presence of the object of interest.

Table 2.3: Majority-Voting Table

	Reader 1			Reader 2			**Indicator**
Rule 1	Present	Present	Present	Present	Present	Present	1
	Absent	Absent	Absent	Absent	Absent	Absent	0
Rule 2	Present	Present	Present				1
	Absent	Absent	Absent				0
Rule 3	Present	Present	Present	Present	Present	Present	1
	Present	Present	Present	Absent	Absent	Absent	1
	Absent	Absent	Absent	Present	Present	Present	0

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