International Journal of Electrical and Computer Engineering (IJECE)
Vol. 14, No. 6, December 2024, pp. 6583~6599
ISSN: 2088-8708, DOI: 10.11591/ijece.v14i6.pp6583-6599

Real-time management and processing of RFID events based on a new RFID middleware architecture

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Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyy

Keywords:

Big data
Complex event processing
Logistics data-processing
Middleware
Radio frequency identification

ABSTRACT

Radio frequency identification (RFID) is a contemporary technology that enables the identification of objects and facilitates the transmission of additional information, making it possible to achieve real-time object tracking in a mobile object network and to report information on the object's current state at each step. RFID devices continuously generate large amounts of data, and collecting, filtering, and consolidating these data are therefore crucial tasks, which characterize RFID data management by a set of challenges. However, one of the greatest challenges in this field is managing large volumes of data in complex applications, where real-time operation is vital, given that the volume and speed of RFID data often exceed the capacity of the existing technological infrastructure. The aim of this study is to propose an RFID middleware that manages both the RFID hardware network and the large amounts of data that are captured, in order to process and transmit the collected data under the right conditions for ultimate use by an information system. This new RFID middleware architecture, named BTMiddleware combines complex event processing (CEP) with a MongoDB database to offer large-volume data streaming, processing, and storage in real time, as well as better interoperability thanks to the use of the JavaScript object notation (JSON) format for data presentation.

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1. INTRODUCTION

The internet of things (IoT) has emerged as a result of the rapid expansion of affordable technical applications, including radio frequency identification (RFID) [1]. RFID technology utilizes radio frequency waves to remotely access data stored in tags' memories, enabling automatic object identification without human intervention [2]. This process facilitates real-time traceability in a flexible, reliable, and permanent manner [3]. This RF communication can be done via long-distance transmission in ultra-high frequency (UHF) (far field), or in high frequency (HF) (near field) or in low frequency (LF) (very short distance, 8-10 cm being a maximum) [4].

RFID technology has recently been a prominent area of research [5], and its significance and efficacy are evident in the increasing attention it has generated. RFID technology finds applications in various sectors [6], including supply chain management (SCM), military, anti-counterfeiting, transport, security, healthcare, and IoT applications, especially in sensors and sensing systems [7]–[11]. This technology provides substantial advantages for supply chain management due to its versatility and cost-effectiveness [12]. Lee *et al.* [13] summarize the important impacts of RFID based on the three factors of inventory visibility, stock accuracy and policy replenishment throughout the supply chain. The demand for RFID systems continues to grow, and Albany [14] reports that by 2030, the global market for RFID tags is expected to show considerable development, reaching a total of US$ 29.4 Bn.

The need to combat theft, counterfeiting, and diversion has driven the pharmaceutical supply chain industry to focus on integrating RFID technology in order to increase safety and visibility [15]. In this context, the Auto-ID center [16] has introduced the concept of a unique RFID code called the electronic product code (EPC). The integration of this approach into logistics operations has proven that RFID can greatly improve visibility and accuracy [17].

RFID technology can offer promising efficiency gains not only in the management of the supply chain but also for the airport sector. Baggage is one of the most important elements in terms of improving the satisfaction of airline customers; however, baggage problems represent major setbacks for airlines, and the costs associated with the repatriation of luggage to the passenger are estimated by International Air Transport Association (IATA) at $100 per bag. In the aviation industry, the use of RFID technology will allow airports and airlines to track baggage at each stage of the travel itinerary and ensure that the correct bag is loaded on the correct flight.

In principle, RFID systems are formed of two or three components: in the simplified version, they consist of an RFID reader plus a tag/transponder, while in a complex system architecture, there is a need for the addition of middleware. We concentrate on the application side in the present work, and focus on the information system (IS) and middleware components. The middleware, which plays the role of an intermediate software layer between the RFID devices and the IS (backend applications), is in charge of reading, filtering, processing, aggregating and grouping the events generated by an RFID network, which contain a large amount of information, formatting them, and sending them to business applications.

The RFID data stream arises as a result of the RFID tag interrogation cycle in a recurring time interval at each reader, which characterizes the management of RFID data by a set of challenges. Regardless of the domain of application, RFID data share common fundamental characteristics; however, one of the biggest challenges in this area is dealing with large data volumes in complex applications, where real-time operation is vital. The volume and speed of RFID data often exceed the capacity of the existing technological infrastructure. As an illustration, a medium-sized retail chain implementing RFID technology for traceability purposes may generate 300 million RFID scans every day [18]. Consequently, retrieving the pertinent information from this extensive data stream is challenging, highlighting the significance of the middleware layer.

There have been many attempts to address the problem of luggage handling at airports using RFID technology. Zhang *et al.* [19] introduced a system called traceable air baggage handling system based on RFID Tags in the Airport, which was composed of an RFID tracking node, a control center, and distributed monitors that could display query results on a geographic information system (GIS) map. An RFID tracking node contained a TCP/IP-compatible reader and two or three fixed antennas, which transmitted RF signals with diverse orientations. The control center contained a database, a switch, an SMS gateway, and an IS. An information server provided application programming interfaces (APIs) and service interfaces via web services to the applications in relation to human interactions. All of these elements were combined to provide location tracking for baggage. Singh *et al.* [20] presented a luggage tracking and handling system that used intelligent RFID and the IoT, based on a cloud server. A prototype was tested at two locations with both check-in and check-out processes. The tags used for the bags were generated using a secure algorithm, and stored information about the passenger and the airline. In order to facilitate the baggage tracking process and avoid the loss of luggage, RFID readers were placed in the registration area. Prajapati and Mishra [21] proposed a system that controlled each stage centrally and made a decision based on the available data collected through various sensors. To meet the need for high levels of availability and real-time operation, the system was designed and controlled using a Raspberry Pi, which gave sufficient flexibility to scale and process critical sensor data in real time.

Despite these studies, little research has been devoted to realizing a baggage traceability system that includes a middleware layer, which can solve the problem of the large data flow arising from data acquisition from mobile object networks. In contemporary large data RFID systems, the capacity to promptly respond to unforeseen circumstances in the system atmosphere has emerged as an essential necessity. This applies to many different applications, including aviation. For example, in an airport, real-time baggage tracking between check-in and departure can enable the rapid deployment of an intelligent lost baggage identification system. In such applications, streams of low-level data arrive from heterogeneous sources at a high rate, and must be processed in real time to allow more complex situations to be detected.

RFID technology and associated data processing analysis methodologies can have a significant and positive impact in critical areas such as airports, where the notion of real-time processing is crucial. What characterizes these types of areas compared to old applications is that their architectures are becoming increasingly complex. Big data analytics infrastructure components are therefore needed to support the massive data processing required by big data applications, including: i) Specialized computer tools for data analysis (such as complex event processing); and ii) Not only structured query language (NoSQL) databases for storing and processing big data. In this context, we propose a luggage tracking system based on RFID technology that incorporates RFID middleware capable of massive data processing and provides passengers with real-time baggage location tracking at airports to allow the aeronautical sector to benefit from the advantages and performance of RFID technology.

The remainder of this paper is as follows. Section 2 discusses related work. Section 3 gives some background to the RFID system. Section 4 describes some existing RFID middleware architectures and implementations, compares them in the form of a table of the distinctive functions, and describes the components of our proposed middleware architecture. Section 5 introduces the proposed luggage traceability system. Section 6 concludes the paper.

2. BACKGROUND

2.1. RFID systems

As shown in Figure 1, an RFID system can be visualized as consisting of three modules: an RFID tag, an RFID reader, and an RFID middleware [22]. The RFID tags (also called transponders [23]) are programmed with data that uniquely identify the object on which they will be placed. Readers, often referred to as "interrogators" [24], are responsible for reading the labels and transmitting the information they contain and possibly other information to the next level of the system (middleware).

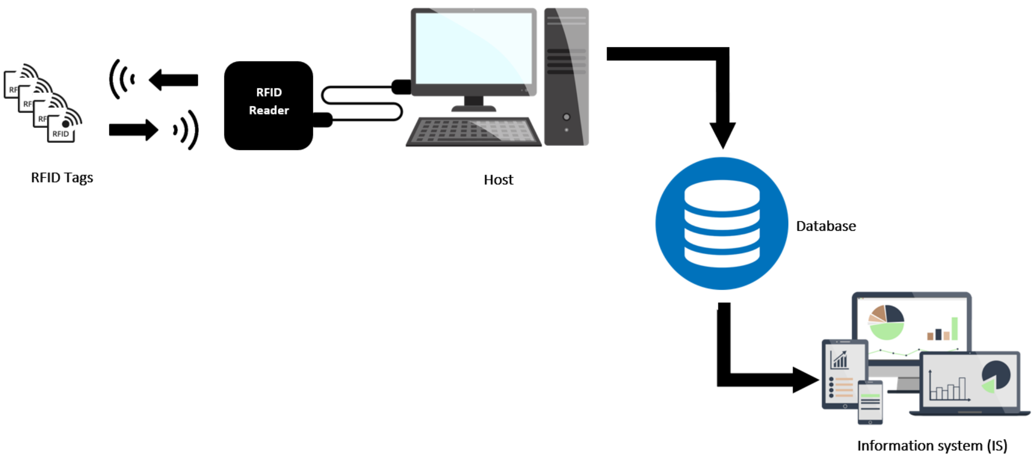


Figure 1. Fundamental components of an RFID system [25]

2.1.1. Elements of an RFID system

a. RFID Tag

Sometimes called an RFID transponder, this includes a microchip coupled to an antenna [26], and may also have a built-in power source and additional sensors linked to the main circuit. A microchip has the capability to store a distinct series of numbers. Depending on the type of memory utilized in the tag and the application's requirements, it may provide more information. The tag's antenna is responsible for transmitting the data from the chip on the tag to the interrogator. RFID tags can be categorized based on several factors. One such parameter is the type of memory employed in RFID tags, which might include write-once-read-many, read-write, read-only, electrically-erasable programmable read-only memory (EEPROM), or static random-access memory (RAM) [27]. Tags can be categorized as active, passive, or semi-passive based on their power source. Although RFID technology offers numerous benefits, its implementation is hindered by various economic, technological, and societal reasons [28], such as the exorbitant price of tags, mostly attributed to the requirement for RFID chips. Recently, there has been a growing body of research focused on the development of a novel approach known as RFID chipless innovation [28]. In this technology, a planar encoder and occasionally an antenna are included in the tag to facilitate communication with the reader [29].

b. RFID Reader

This is a fundamental component of RFID technology and emits radio frequency signals to detect all of the tags that enter its reading field. The waves impart energy to the tags, allowing them to communicate with the RFID reader. When an RFID tag is within the field of the RFID reader, it makes an information request, receives the response, and transmits it to the middleware. The communication between the reader and the tag is established through the reader and the tag antennas [30]. An RFID reader may be stationary or mobile [31].

c. RFID Middleware

This is an intermediary software layer that connects the RFID equipment network, which is often diverse, to the business applications [32]. It is responsible for managing the events that occur as a result of the data collection equipment, specifically the RFID readers [33]. This software layer is responsible for the fundamental tasks of transferring data, filtering it, and converting data formats between RFID technology and the IS [34].

2.1.2. Comparison of identification technologies

Due to the significant advantages offered by traceability systems, interest in their application has steadily increased over the past few decades. Figure 2 illustrates a chronogram showing the evolution of these technologies, reflecting their growing importance and widespread adoption. This increasing interest underscores the role of traceability systems in enhancing efficiency and ensuring quality across various sectors.

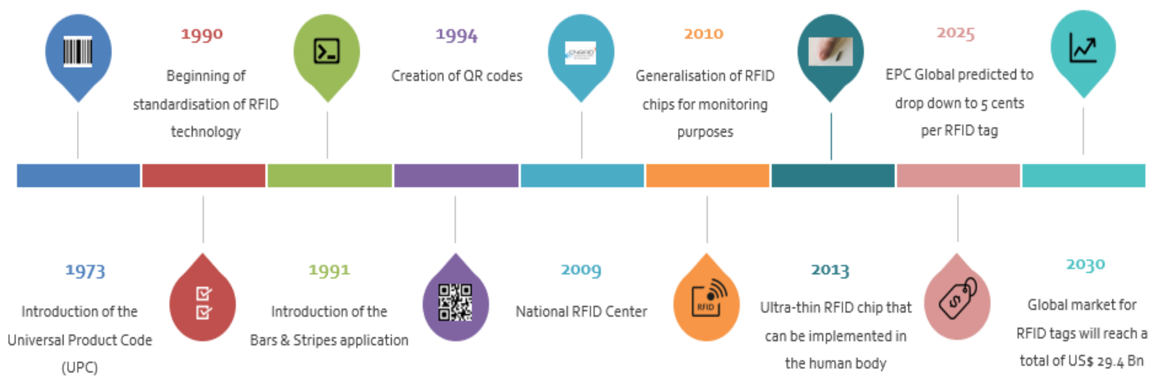


Figure 2. Chronological evolution of traceability systems and projections

a) RFID vs. Barcodes

As we can see from Table 1, RFID technology offers multiple advantages compared to barcodes, for example: i) An RFID system does not need a line of sight to capture information from RFID labels [35]; ii) Tag reading accuracy reaches up to 100% [36]; iii) An RFID system can automate the traceability process; iv) Several tags can be read simultaneously; v) RFID offers a higher read rate compared to barcodes; vi) RFID technology can be used in harsh environments without the need for human intervention; and vii) An RFID reader can interact with RFID tags over a reading range of up to a few hundred meters.

It should be noted that RFID readers can only interrogate one tag at a time. However, there are special anti-collision algorithms that allow readers to communicate to one tag at a time, but in very rapid succession. This happens so quickly that it seems like the reader is reading more than one tag at once [37].

Baggage handling based on barcode technology has a number of limitations; for example, barcode readers require a line of sight to be able to read labels correctly. Labels may be obscured or damaged, which may result in non-identification of luggage when moving on the baggage carousel, and hence loss of baggage. The use of RFID technology for baggage handling can therefore offer airlines considerable advantages in terms of baggage handling time and lost baggage costs.

RFID technology offers several advantages, but it also has a set of constraints, especially in the RFID data processing part. For example, i) RFID systems are frequently more expensive than barcode systems, ii) Interferences and this collision phenomenon occurs when numerous tags in the same area respond at the same time; and iii) Perturbations: most RFID tags perform well in free space, but suffer performance degradation when attached to different materials such as metal or liquid.

Table 1. Comparison of identification technologies

	Barcode	RFID
Line of sight	- Required. - All items need to be in plain view. Hidden items can be difficult to find or may be lost during inventory [38].	- Not required as long as tags are within the read range and appropriate shelving materials are used (certain metals may shield some tag types). - Items can be oriented in any manner [38].
Cost	- Low. - Costs approximately $0.02 per label [38].	- Moderate to high. - Cost range from $0.07 to $70.00 [38].
Reusability	- No	- Yes
Read rate	- Slow throughput, labels have to be read one at a time. - Reading overlapping or multiple tags can lead to errors [38].	- Multiple tags can be read simultaneously [38].
Tag lifetime	- Depends on carrier material [39].	- More than 10 years [39].
Security	- Low. - Labels are easy to reproduce or counterfeit.	- Moderate to high. - Data can be encrypted and password protected so the information stored is secure [40]
Reading range	- Up to 4 m.	- 1 km [41].
Application areas	- Inventories - Library - Logistics	- Animal tracking - Access control - Cold chain monitoring in the food sector - Vehicle fleet management

2.2. Method
2.2.1. Existing RFID middleware

Table 2 summarizes and compares a number of existing middleware architectures, based on an illustration the advantages of each architecture and the applications or case studies in which it is implemented. One of the conclusions is that although many middleware architectures have been suggested for RFID applications, many of them have not implemented or tested specifically for baggage tracking applications.

Table 2. Comparative analysis of existing middleware

Middleware	Institute	Characteristics	Technologies	Open source	Applications	Implementation	Standards
FlexRFID [42]	Alakhawayn University, Ifrane, Morocco	Supports a variety of readers	N/A	-	Library SCM and logistics	N/A	PC Gen2, ISC 15693 ıd ISO14443/
MedRFID [43]	International University of Rabat, Morocco	Compatible with IATA and EPCglobal standards Supports mobile device:	-	N	Airports	Y	EPCglobal standards
TagCentric (2006) [44]	University of Arkansas, USA	Supports a variety of readers User-specified database (Oracle or MySQL) Contains a simulated reader	Java and extensible markup language (XML)	Y	Small and medium-sized enterprises (SMEs) RFID test centers and universities	Y	Low-level reader protocol (LLRP)
SafeRFID (2013) [45]	Grenoble Institute of Technology, France	Provides two fault-tolerant mechanisms using a diagnosis algorithm called DiagAlgo.	Java	Y	SCM and Logistics	Y	LLRP
ECDSA middleware (2017) [46]	Henan Jniversity of Scien and Technology (HAUST), China	Uses an elliptic curve digital signature module	N/A	-	E-commerce	N	-
Lightweight RFID middleware for warehouse management system (2013) [47]	Tianjin University of Tech., China	Applied to a Warehouse management system Jses a MySQL databas	Java	N	SMEs Warehouse management system	Y	ALE
Lightweight-ALE-based embedded RFID middleware (2009) [48]	South China University of Tech., China	Fast data processing Low consumption of resources Scalability Reconfigurable Can be applied in a mobile computing environment	N/A	N	-	Y	Lightweig ht ALE

2.2.2. Analysis

Figure 3 shows that a big percentage of middleware architectures are not open source, which limits the modification, development, and improvement of current architectures because they can only be modified by their original designers. As indicated in Figure 4, middleware architectures are increasingly affecting a range of application fields, with a concentration on SCM and logistics. Figure 5 illustrates that the bulk of middleware architectures (72%) are implemented. This finding indicates that most RFID middleware advances from the modelling phase to the implementation phase.

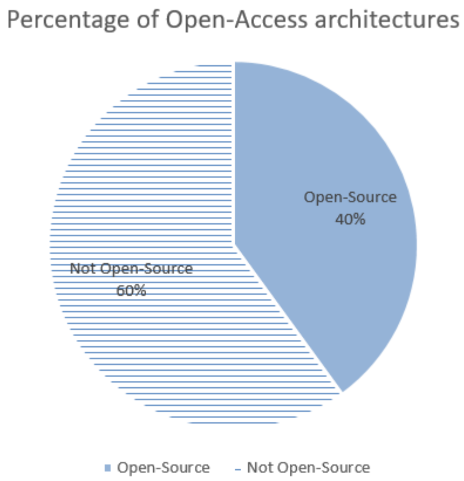


Figure 3. Open-source architectures percentage

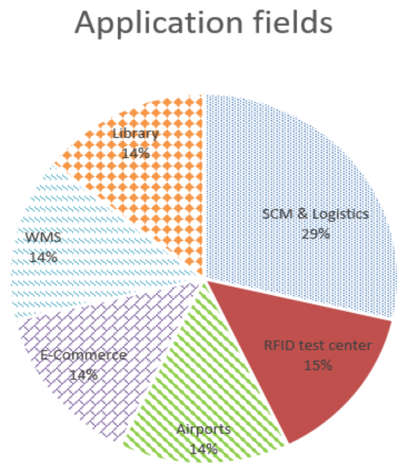


Figure 4. Middleware application domains

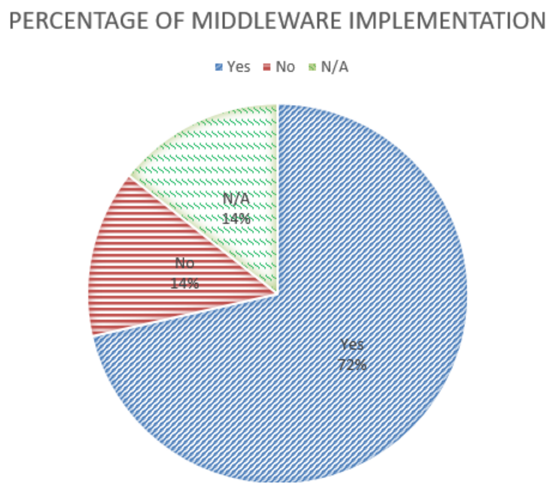


Figure 5. Percentage of middleware implementation

From an examination of Table 2, it can be seen that existing middleware architectures do not take into consideration the real-time processing or storage of the massive data coming from the RFID equipment network, bearing in mind that today RFID technology is being integrated into new areas, such as the IoT and sensing applications. So, to harness the power of RFID requires changes in methods of data collection, processing, storing, and sharing in a distributed device environment. In this scenario, processing and storing the massive amounts of data coming from different channels require specific techniques, and our middleware architecture for processing and managing RFID data is therefore based on two essential points:

a. Real-time RFID data analysis: In this case, we need solutions that can cope with the time constraints of the analysis process, as the processing of RFID events must be done in real time. complex event processing (CEP) captures information from databases or data streams in real time, and defines business rules and processes, supporting their identification and automatic actions to be taken.

b. Storage technologies: SQL databases and traditional computer architectures do not follow the technological advance of RFID hardware components as well as the data volume that can be produced, meaning that it is necessary to use repositories that are able to store huge volumes of data and which have the characteristics of distribution, scalability, and performance. A NoSQL database represents a simple and lightweight mechanism for data storage and retrieval that offers scalability, availability, distribution, and high performance in terms of load and query time [49].

3. PROPOSED MIDDLEWARE ARCHITECTURE

As shown in Figure 6, our scheme mainly uses: i) a NoSQL database, based on MongoDB, to ensure that a large volume of RFID events can be stored [50]; ii) CEP, which enables real-time and efficient processing of RFID data; and iii) the JavaScript object notation (JSON) format to ensure a high level of interoperability [51]. The components of our proposed middleware architecture are as:

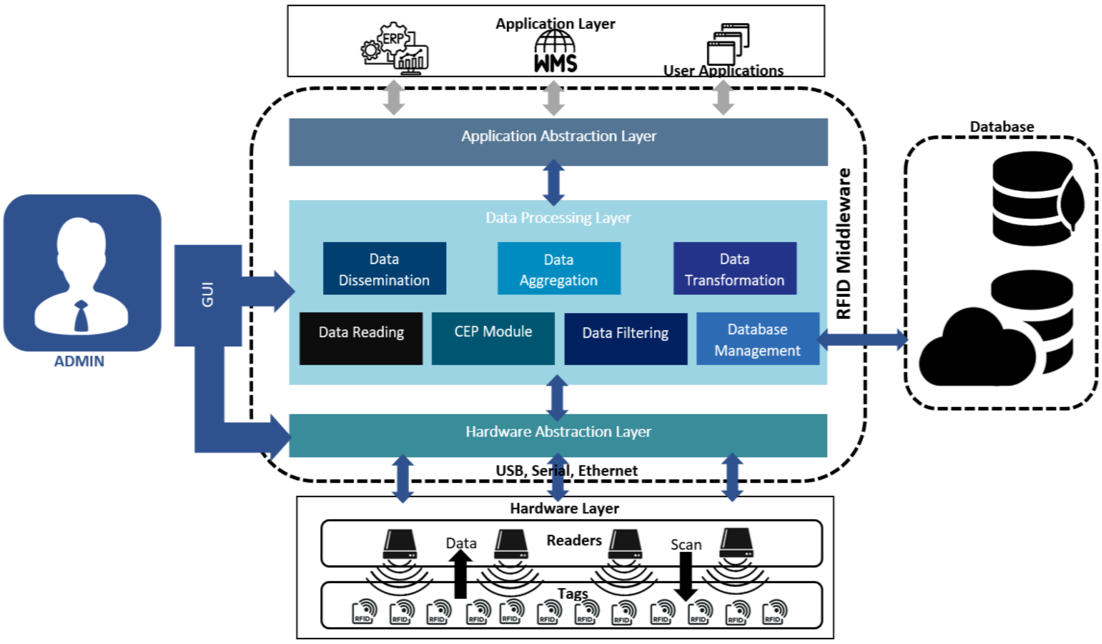


Figure 6. Constituent elements of the suggested middleware architecture

3.1. Application layer (AL)

This layer represents the information system. It is responsible for delivering services to end-users. Depending on the unique requirements of each firm, the application may take the form of a warehouse management system (WMS), a mobile/desktop application, or an enterprise resource planning (ERP) system.

3.2. Hardware abstraction layer (HAL)

In order to unify the interfacing of RFID equipment with the IS, the EPCglobal organization has introduced the LLRP standard. Although there are several different brands of readers on the market today, there are still some that do not apply LLRP and use their own protocols instead. By abstracting the physical parts of the system, the HAL will facilitate the implementation of RFID solutions with a heterogeneous network of equipment (from different manufacturers or operating on a variety of frequency ranges, including low frequency (LF), ultra-high frequency (UHF) or high frequency (HF)).

3.3. Data processing layer

This layer lies between the hardware abstraction layer (HAL) and the application abstraction layer (AAL), where it processes data received from the HAL, transforms them accordingly, and transmits them to the upper layer (AAL). The data processing layer (DPL) is composed of multiple sub-layers or modules, each responsible for one or more specific functions. These functions include data filtering, validation, and formatting to ensure seamless communication between the hardware and application layers. The HAL is composed of:

a. Data reading module

It receives data from the device abstraction layer. This module that allows the retrieval of RFID data, and is an indispensable element of RFID middleware.

b. Data aggregation module

This module allows for the grouping of RFID data based on the specifications requested by each element of the AL. For example, in the case of baggage flow management, the data can be grouped based on the location. This module facilitates the categorization of RFID data based on the specific requirements set by each component of the AL. For instance, when it comes to managing baggage flow, the data might be categorized according to the location.

c. Data dissemination module

Normally, in solutions based on RFID technology, the objective is for the IS to receive data on each identified object. The role of this element is to transmit the formatted RFID events to the client applications.

d. Database management module

The current areas of application for RFID technology have undergone significant growth in terms of data volume. Although database management systems (DBMS) were developed to try to solve this constraint, it still poses a challenge [52]. Our database module integrates a NoSQL database called MongoDB, as NoSQL systems allow for fast processing of big data [53].

e. Data filtering module

In solutions adopting RFID technology, the generated data stream is not always important to the IS, as it may contain data that are unwanted or redundant with regard to the application. The data filtering module is therefore important, as it allows the system to extract only useful information from the huge RFID data flow.

f. Data transformation module

Raw RFID events are incomprehensible to backend applications, and there is therefore a need for a structuring format. Most RFID middleware uses the XML format, but this is subject to a set of limitations. The JSON format, which is lighter than XML, has performed well in this context, unlike XML, and in recent years has rapidly begun to replace XML [54]. The data transformation module transforms the data as required by the applications.

g. CEP module

As mentioned above, the events from RFID systems are growing exponentially, and specific technologies are needed to automate their processing. The concept of CEP represents a domain that is not yet well exploited by RFID applications. A middleware architecture that includes CEP has the capability to record the real-time stream of RFID events, analyze it, and initiate a business rule (alert an administrator and start a process). The CEP module in our middleware architecture receives and processes the filtered event streams. The general procedure is detailed in Algorithm 1, and the aim is to select for each suitcase all the events occurring over the last 15 minutes. Algorithm 1 gives partial pseudo-code for the part of our system that represents the functioning of the CEP module. The algorithm has four main steps:

- Line 1: Initialize the parameters.
- Lines 2 and 3: Read the input RFID event stream and group the events based on baggage ID.
- Lines 4 to 10: As long as the execution conditions are verified (in our case, this is a time limit of 15 min for each piece of luggage), judge whether the algorithm accepts the RFID event. If so, the algorithm goes to step 6; if not, it goes to step 2.
- Line 11 to 16: If we are here, this means that for a given baggage item, the elapsed time has exceeded 15 minutes. The algorithm judges whether the value of the event counter is equal to five. If so, it goes to step 1; if not, an event will be triggered in the system and the algorithm goes to step 1.

Algorithm 1. CEP algorithm

```
Input: Luggage ID: LID, RFID Stream Events: S, Rule Engine: R, Reader ID: RID
Output: Decision D
      1.  Initiation;
      2.  Read (S);
      3.  Create (Group LID);
      4.  while (R criteria have not been met) do
      5.     if (IsNew (RID)) then
      6.            Count ← Count + 1;
      7.     else
      8.            Go to (2);
      9.     end if
      10. end while
      11. if (Count != 0 AND Count != 5) then
      12.    Generate Warning Event D;
      13.    Go to (1);
      14. else
```

```
15.    Go to (1);
16. end if
```

h. Application abstraction layer (AAL)

The heterogeneous components of the AL request the services and functionalities of the middleware via the AAL, and if authorization is granted, their requests will be processed.

i. Hardware layer

This layer includes the hardware components of the RFID system, i.e. the RFID readers and tags.

j. Admin GUI

To allow the administrator to visualize the RFID data in real time and to manage the parameters of the readers (such as the communication protocol, the business rules, the type of formatting), a dedicated graphical interface is provided.

4. RESULTS AND DISCUSSION

4.1. Implementation of BagTrac system

According to International Society of Aeronautical Telecommunications (in French: *Société Internationale de Télécommunications Aéronautiques (SITA)*), the number of travelers is continuously increasing, and so too is the amount of baggage. Since lost baggage costs airlines billions of dollars annually and RFID has demonstrated strong benefits in multiple areas, a baggage handling system based on RFID technology is expected to decrease the amount of lost baggage. This requires developing a robust tracking system in terms of the large data streams that can be collected, and one that is capable of receiving and transferring the formatted tracking data to the IS. The objective of this project is to develop a luggage tracking system specifically designed for airports in Morocco. To the best of our knowledge, this is the inaugural groundbreaking university research study on this issue in Morocco. By implementing this technology, Moroccan airports will have access to a proficient instrument that may be used to retrieve missing baggage.

The capacity of an RFID tag varies from 100 B to 8 kB [55], so integrating this technology into environments such as airports, which contain a network of mobile objects, will generate a large data flow. Thus, to ensure that the IS receives only the information it needs from this huge RFID data stream, our middleware architecture has the capability to be seamlessly included into an airport's luggage tracking system. By utilizing the method outlined in this article, airports can take advantage of the extensive connectivity and accessibility of RFID data, that will be seamlessly included into the IS. The components of our suggested system (BagTrac system) are depicted in the image as shown in Figure 7.

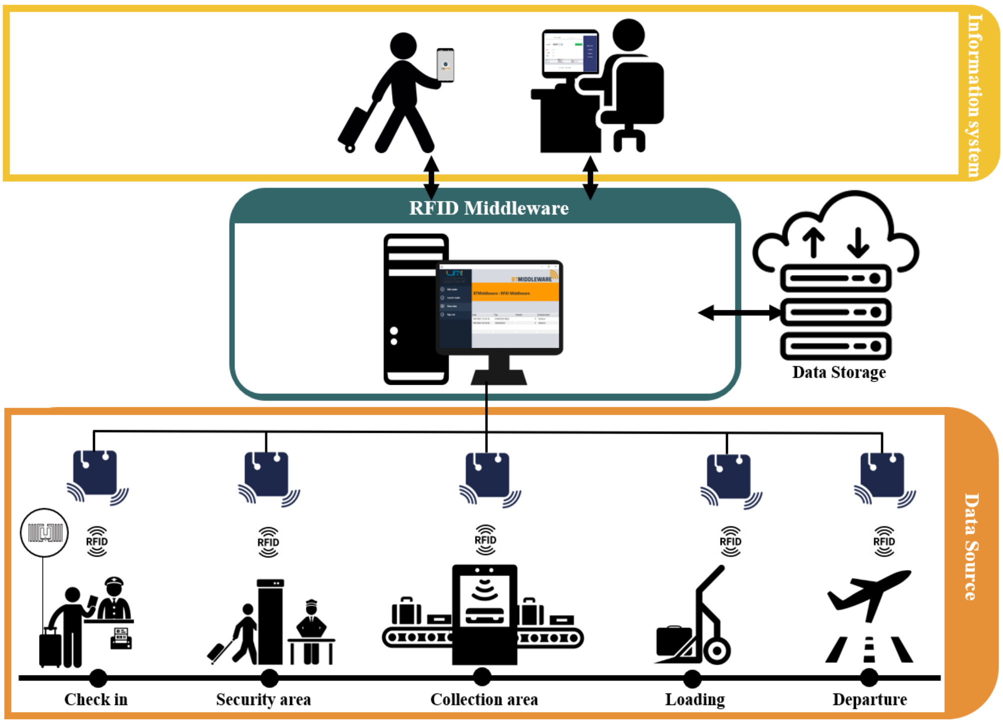


Figure 7. Implementation of the proposed BagTrac system

Upon arrival at the airport, passengers proceed to the check-in area to submit their luggage. During the check-in process, the server records the specific information of each traveler on their allotted tag ID. RFID readers are positioned at various locations throughout the airport, with each stage of the baggage handling procedure being associated with an RFID reader. These readers transmit data streams to the middleware, containing the ID and location of the baggage they have identified within their perimeter, and the time. The readers track the position of each suitcase bearing an RFID tag throughout its journey. Our proposed approach allows customers to track their bags in real time throughout the entire baggage handling process, from any location and at any stage

To identify potential issues promptly, we establish a maximum duration of n seconds for a "trip" on the conveyor. If the baggage exceeds this period, it is classified as missing. Our approach involves confirming that the identical luggage has been scanned by all five scanners within the designated time frame, so ensuring that five occurrences have been recorded for this luggage within the recent n seconds.

The flowchart in Figure 8 shows the communication between the lower layer (the data source in Figure 7) of our proposed solution for baggage traceability and the middleware. It illustrates the configuration of the reader and the RFID data collection process. Once the readers are configured and the ports opened, each reader checks for the existence of tags within its interrogation area. If any are found, it scans them to retrieve the data recorded on the tags' chips and sends the data stream to the middleware.

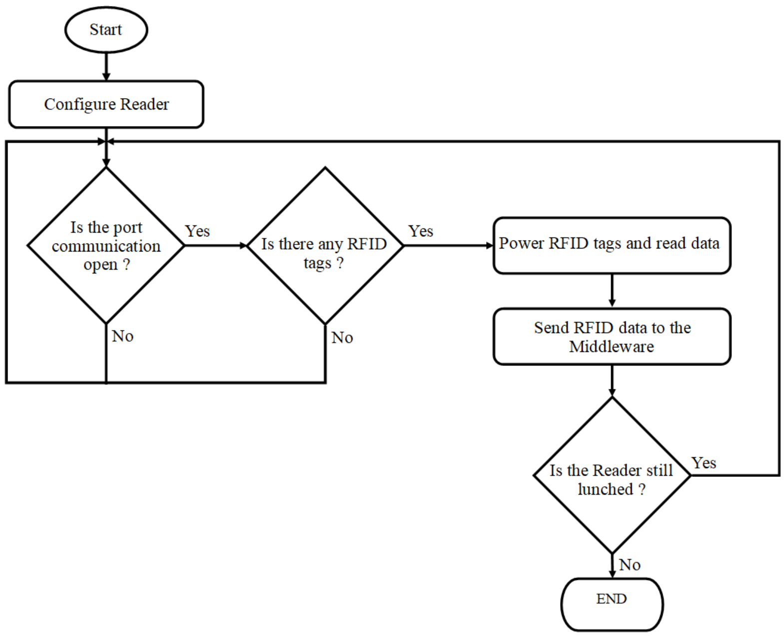


Figure 8. Communication between the RFID network and the middleware layer

Figure 9 shows a flowchart of the internal functioning of the communication between the IS and the middleware. The middleware listens continuously on the configured ports, so that any data sent by the readers will be collected. If an event stream is detected, the middleware layer applies a filtering process to retain only the useful information: each received event is defined as a tuple (ID, location, timestamp), is recorded in the database, and is sent to the CEP module for processing. The CEP module verifies if a particular piece of baggage has been detected by all five readers within the designated time period. If this condition is met, it records the state of the baggage and remains attentive for further events. Alternatively, it initiates an event to notify the airport personnel of a missing suitcase, and remains attentive for subsequent occurrences.

Our system represents a platform that is capable of processing the continuous data flow generated by RFID readers in real time. The various components of the infrastructure of the system are illustrated in Figure 7, and are grouped as:

a. Data source: An RFID tag is placed on each piece of luggage to identify it, and communicates with readers by sending the information stored in the RFID chip.
b. Data acquisition and processing: As shown in Figure 10, the proposed middleware is the element responsible for collecting and processing the raw data coming from RFID tags in real time.

c. Data storage: MongoDB is used for storage.
d. Information system: This takes the form of a mobile application for travelers as shown in Figure 11(a) and a desktop application for airport staff as shown in Figure 11(b).

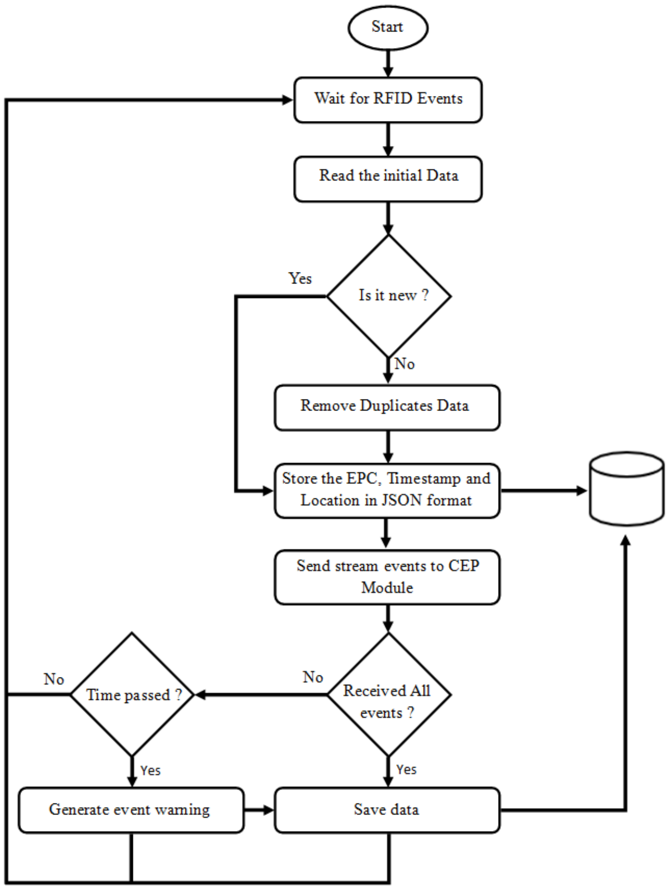


Figure 9. Flowchart showing the inner workings of the middleware

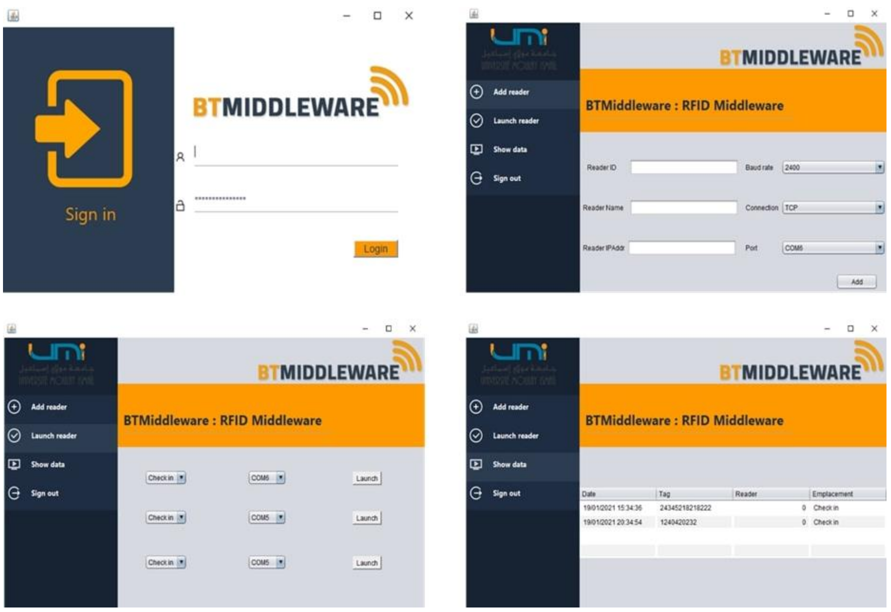
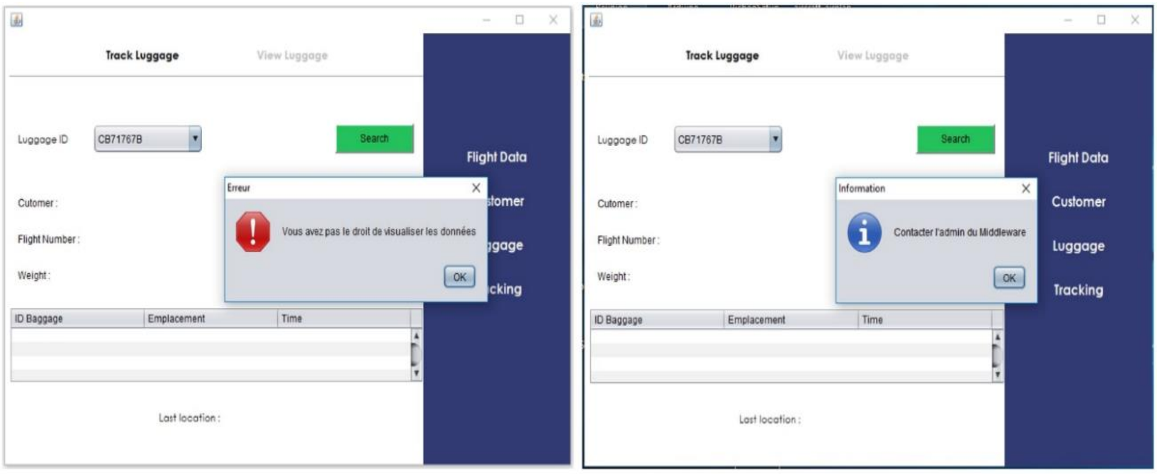
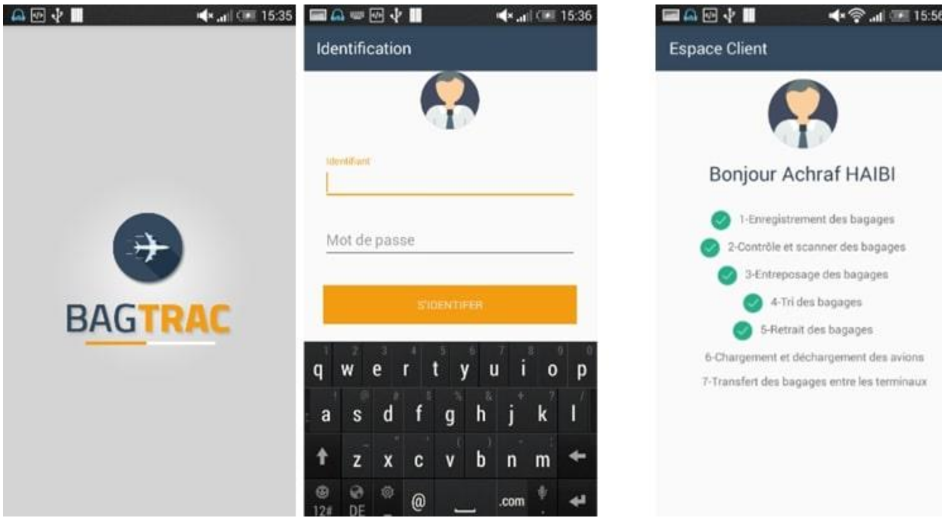


Figure 10. BTMiddleware GUI



(a)



(b)

Figure 11. BagTrac information system (a) mobile application (b) desktop application

4.2. Evaluation

One of the most prevalent approaches to assessing middleware is through the utilization of application examples, which quantify the system's performance according to the quantity of lines of code [56]. However, this methodology is not without its constraints [57]. One of the most effective approaches is to assess the middleware based on specific functionalities that are deemed essential. In our evaluation, we carried out a comparison analysis between our proposed middleware architecture and other architectures in Table 3. This comparison was based on eight features that we believe are crucial for any RFID middleware architecture intended for new types of application. The comparison consisted of checking whether a middleware adopted these features or not. This study highlighted that existing middleware architectures have some limitations, while our proposed architecture can support all application-related design issues characterized by the notion of real-time and big data. During our evaluation, we conducted a comparison analysis between our architecture and other middleware architectures as shown in Table 3.

4.2.1. Application evaluation

The ISO/IEC 9126 standard includes a portability metric that encompasses two evaluation factors: scalability and compatibility with heterogeneous systems. The initial criterion is employed to evaluate the resilience of a stable state in relation to the growth of application usage, specifically the influx of requests from apps and the capacity to connect multiple applications to the middleware layer. The second element is employed to evaluate the level of middleware abstraction to provide seamless connection with various backend applications.

We conducted tests on our proposed middleware using a prototype access control application and a luggage tracking application. Additionally, we explored scenarios for integrating the middleware in the supply chain management and healthcare sectors by linking it with a hospital information system (HIS). The authors of [58] state that heterogeneous system support is a crucial aspect in measuring portability. As a result, we have created a generic class employing the AAL, which can be incorporated into applications that utilize our proposed middleware.

Table 3. Comparison of different middleware architectures

Middleware	Scalability (hardware)	Scalability (applications)	Heterogeneous system support	Heterogeneous hardware support	Interoperability	Big data storage	Big data analysis	Real-time analysis
FlexRFID	✓	✓	✓	✓	Partial	×	×	✓
MedRFID	✓	✓	✓	✓	Partial	×	×	×
TagCentric	✓	✓	✓	✓	Partial	×	×	×
SafeRFID	×	×	×	✓	Partial	×	×	×
ECDSA middleware	×	×	×	×	Partial	×	×	×
Lightweight RFID middleware for warehouse management system	×	×	✓	✓	Partial	×	×	×
Lightweight-ALE-Based Embedded RFID middleware	✓	✓	✓	✓	Partial	×	×	×
BTMiddleware	✓	✓	✓	✓	✓	✓	✓	✓

4.2.2. Hardware evaluation

The ISO/IEC 9126 standard assesses middleware's scalability and ability to serve heterogeneous devices using the portability metric. Scalability refers to the ability of the middleware to maintain a stable state when the quantity of RFID tags grows. Typically, manufacturers usually supply RFID equipment along with a collection of brand-specific APIs to guarantee seamless communication with the middleware layer. Our suggested design involves the utilization of the hardware abstraction layer (HAL) to establish a communication interface with the diverse network of RFID equipment. The LLRP protocol is utilized to facilitate the operation of readers that are compatible with this protocol, alongside the application programming interfaces (APIs) offered by manufacturers. In order to evaluate the functionality of our proposed middleware architecture, we employed the available readers in our laboratory, specifically D-Logic, EM4100, and RC522.

4.2.3. Context evaluation

The assessment involved assigning metrics to the environmental circumstances under which the middleware system was installed. The context might manifest in various ways, including the movement of the items to be monitored, geographical position, temporal factors, and the activities of the user. situation assessment can be conducted by implementing scenarios and confirming that the program is responsive to the situation. The implementation of real-time luggage tracking can serve as a scenario to evaluate the middleware's ability to respond to contextual changes. In the context of baggage traceability, RFID technology is employed to ensure the real-time tracking of each suitcase. This is achieved by attaching an RFID tag to each suitcase. Through the utilization of the CEP implementation, in the case of an issue (such as misplaced luggage), the middleware disseminates contextually relevant information and notifies exclusively the individuals who are directly impacted.

4.2.4. Interoperability evaluation

We utilized the functionality metric from the ISO/IEC 9126 standard to evaluate the interoperability of our proposed middleware architecture. Interoperability was determined to be the primary alternative element affecting functionality [59]. The backend applications cannot comprehend the unprocessed RFID data until it undergoes formatting. The data transformation module plays a crucial part in this process, as it receives the raw RFID data and converts them into business events, enabling applications to utilize them effectively. JSON and XML are the predominant standards for data interchange. Nevertheless, JSON is commonly favored over XML and has rapidly supplanted it, prompting us to incorporate the choice of utilizing the JSON format. Our architecture offers the advantage of giving the customer the option to select between XML or JSON based on the requirements of the organization's IS.

Furthermore, our proposed architecture provides support for additional services that are unique to the more recent domains of RFID technology application. For instance, this category of application is distinguished by a substantial amount of data. In certain industries, it is not only critical to handle enormous amounts of data but also data of exceptionally large dimensions; however, relational DBMS are inadequate for handling such high data fluxes. Integration of the NoSQL MongoDB database system facilitates the storage of massive amounts of data within our database management module. Additionally, a real-time analysis service is available, which utilizes the CEP module to extract information from the substantial quantity of raw RFID data streams in real time.

With the intention of encompassing a wide range of pertinent scholarly articles that address the middleware component, we performed literature searches using a collection of references. In order to guarantee a comprehensive and accurate evaluation, we conducted a thorough examination of the chosen documents. Thus, the information presented in Table 3 was supplied by the middleware architectures' developers.

5. CONCLUSION

The proposed middleware distinguishes itself from current middleware systems by its capacity to store vast quantities of RFID data, its incorporation of a CEP algorithm for processing data streams to enable real-time data analysis, its ability to handle immense volumes of data, and its utilization of JSON format for enhanced interoperability. Each airline has its own method of handling baggage. The loss of baggage at airports is a global problem that costs airlines billions of dollars each year. The adoption of RFID technology by airlines can optimize the baggage handling process, and can not only solve the problem of lost luggage but also reduce baggage handling times and passenger anxiety.

The proposed middleware, BTMiddleware, is different from current middleware systems by its capacity to store huge amounts of RFID data, includes a CEP algorithm for processing data streams to enable real-time data analysis, its ability to handle massive data, and its RFID data storage in JSON format for enhanced interoperability. We have also presented a luggage traceability system called BagTrac and its architecture. This system allows for automated and real-time luggage tracking, and reduces baggage handling times, lost baggage costs, and workforce costs.

However, at this stage of development of our middleware, the system may be subject to intrusive manipulation, raising potential security concerns. To address this, we plan to enhance the middleware by adding two levels of security. The first will be integrated into the lower layer, where RFID data will be encrypted as soon as it is captured, preventing unauthorized access at the source. The second will be applied at the upper layer, incorporating a role-based access control system to regulate access by backend applications. These security enhancements will ensure the protection of sensitive data while maintaining the efficiency and functionality of the system.

ACKNOWLEDGEMENTS

This work was supported by the MESRSFC and the CNRST.

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