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SIP-RLTS: An RFID Location Tracking System Based on SIP

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Abstract—**Radio Frequency Identification (RFID) technology has recently being favorably considered as a cost-effective alternative for indoor location tracking. However, most current implementations use active tags and conventional middleware, which are more expensive, complicate to use, and may not work with other pervasive devices such as IP Multimedia systems or cell phones. In this paper, we propose an RFID-enabled location tracking system, SIP-RLTS, based on Session Initiation Protocol (SIP). Our proposed solution can be used for both Push and Pull location tracking modes and can be used with either active or passive tags. The use of SIP infrastructure, coupled with the proposed location-oriented middleware extension, Ontology infrastructure and semantic integration, making SIP-RLTS a more cost-effective solution for the next generation communication services.**

Indexed Terms—**RFID, location tracking, middleware, Ontology, semantic integration**.

I. INTRODUCTION

Radio Frequency Identification (RFID) is an emerging wireless technology that uses tiny IC chips to uniquely identify, capture, and transmit information from tagged objects to enterprise systems via radio waves. RFID was first used over sixty years ago by the British Air Force to identify friend aircrafts in World War II. With recent advances in information and communication technologies, cost reduction in RFID devices (readers and tags) and mandates by industry giants (e.g., Wal-Mart, Target, Tesco and Albertson) and various governmental agencies (e.g., Department of Defense and Department of Homeland Security), RFID has became one of the hottest technologies being deployed in access control/security, mass transit, toll collection, asset tracking, logistics and supply chain management. Compared with optical bar codes, RFID tags have the advantages that they can be read without line of sight and that multiple tags can be detected at once from a longer distance. As such, RFID technology has been widely used to track physical objects in various indoor locations such as hospitals, nursing homes, schools, and cold chains through distributed networks.

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Session Initiation Protocol (SIP) [1] is an application-layer control (signaling) protocol for creating, modifying and terminating sessions between two or more participants. SIP can be used to create two-party, multiparty, or multicast sessions that include Internet telephone calls, multimedia distribution, and multimedia conferences. Currently, SIP has been widely adopted by telecommunication companies to support the next generation communication services, such as VoIP, instant messaging and presence. In addition, SIP is becoming a candidate protocol for mobility management in network systems, through which the information can report to the host when it changes its IP address or in a roamed network. The use of SIP for presence and mobility management has been expanded to location management systems.

Location-Based Services (LBS), which provide personalized services to users based on their real-time location information collected by positioning technologies, are expected to be a fast growing area in the next generation communication networks. Several cutting-edge technologies, such as GPS (Global Positioning Systems), Wi-Fi, Bluetooth, sensors, and RFID, are standing out as the technology of choice for LBS. Each technology has its own advantages and disadvantages and plays specific roles for different usages. For example, GPS has been the main navigation system in outdoor environments, which provide latitude and longitude information as well as moving maps for automobiles and airplanes. However, GPS will not work once inside the building because the path between receiver and satellite will be obstructed. Wi-Fi or Bluetooth positioning system, which can reuse the existing wireless network, has been used as a tool for indoor location tracking; however, they are more expensive and may be inappropriate for some situations such as monitoring patients, young kids or senior citizen. RFID has recently being favorably considered as an alternative tool for indoor LBS, due for its low cost and easy to install.

This paper introduces a location tracking system, named SIP-RLTS, using RFID technology. In order to integrate RFID into location-based communication solutions, we adopt SIP as the main control protocol. We also employ the SIP event notification model [2] to support the PUSH and PULL operations needed by most LBS. Besides, since most RFID tags and readers have limited capability in data computing and SIP communications, we introduce a location-oriented RFID middleware to solve the resource constraint problem.

To cut the cost of deploying RFID tracking system, more and more companies are inclined to use movable RFID readers such as forklift-mounted or handheld readers to scan the tags. Although the use of moveable readers brings in some flexibility, it also carries a computational burden because the continuous movement of these readers forces the location information be dynamically updated. To solve this problem, we provide a cache and stabilization mechanism in the location engine to keep the location information update timely and reliably.

This paper is organized as follows: Section II describes related works. In Section III, apart from describing our study scenario and motivation, we provide details regarding SIP-RLTS framework, components and implementation. Section IV analyzes the scalability, latency, security and privacy performance of our proposed solutions. Section V discusses some feature implementations and contrast SIP-RLTS with SRMS [3], another SIP-based RFID implementation for data management. The last section concludes the study.

II. RELATED WORK

LBS is expected to be a major area of growth in the next generation communication networks. [4] provided an overview of the technologies and standards used in related location-based applications, including positioning technologies, data formats and protocols for communications. The system, Cyberguide, presented in [5] offered instant guided information to users, taking into account their current location.

Since SIP is being adopted as an important control protocol for the next-generation communication networks, the integration of location tracking system with a standards-based SIP communication infrastructure has been discussed in a number of publications. [6] described an 802.11 tracking solution, which was built upon a complete SIP based voice-over-IP (VoIP) system. [7] introduced a SIP based Internet telephony infrastructure, called Columbia InterNet Extensible Multimedia Architecture (CINEMA), to provide integration for LBS. [8] presented ideas on how to use SIP event mechanism to send location-enhanced presence information and user profiles in a location-based architecture. These works not only highlighted some interesting features such as triggering communication actions according to location changes, but also illustrated the strong flexibility for developing new LBS using an SIP supported platform.

Some publications have already dealt with the applications of RFID technology for location tracking. One well-known RFID location tracking system, SpotON [10], investigated flexible location sensor deployments in small-scale environments. In the SpotON system, objects are located by homogenous and distributed sensor nodes and an aggregation algorithm is used to compute their three-dimensional location based on radio signal strength analysis (RSSI). [11] presented LANDMARC, a prototype system that used RFID technology for locating objects inside buildings. LANDMARC improved the overall accuracy of locating objects by utilizing reference tags. The paper also demonstrated that active RFID is a viable and cost-effective candidate for indoor location sensing based on experimental analysis. In [12], the authors proposed an assisted navigation system where an RFID reader is embedded into a blind navigator's shoe and passive RFID sensors are placed in the floor. Other notable developments include, but do not limit to, LEAPS [13], FLEXOR [14], and Ferret [15].

There have been fewer attempts to use SIP as a control protocol for RFID management. In [3], a SIP-based RFID management system, named SRMS, is presented. It introduced RFID tags as surrogate user agents and used SRMS name server to perform location registration and mapping between EPCs (Electronic Product Code) and SIP URIs (Uniform Resource Identifiers).

There are more middleware being developed for RFID applications (e.g., as in [9, 16]). Middleware can be used to filter noisy or missing data and aggregate redundant data based on the specifications defined by the EPCglobal RFID community. Our solutions expand the existing RFID middleware by adding an RFID ontology infrastructure, a semantic location computational scheme and an SIP event-notification component for pull and push LBS.

III. SIP-RLTS: A LOCATION TRACKING SYSTEM

A. Scenario

Considering the following scenario: Bob is working at an intensive care unit (ICU) of a major teaching, research and service hospital. Bob is an attending physician whose patients need constantly monitoring to ensure that they are not leaving the unit without attention and in some emergent cases, Bob and his nurses can be alerted and response on a timely basis.

Several alternatives can be used to achieve the same purpose. For instance, the ICU can be wired with a digital surveillance video cam system and is constantly monitored by a full-time guard on a 24 hours 7 days basis or installing a Wi-Fi wireless tracking system. After some exploration and pilot test, the hospital has decided to integrate the RFID location technology into its existing SIP-VoIP infrastructure.

The deployment of such an RFID solution will be like the followings: Each patient is stuck with an RFID tag and Bob and his two assistants are assigned a PDA in which a SIP-RLTS client is installed. Bob added the patients and assistants into his buddy list. By doing this, bob can see the location of his patients and assistants. This day, Bob's PDA is suddenly ringing and receives a notification message that patient Alice is leaving her designated area. Bob transfers the message to the assistants and asks them to deal with the problem. One hour later, Bob starts to visit and observe his appointed patients in the hospital. His PDA receives notification of patient name, where does the patient stay, and the patient illness condition.

B. Motivation

The IP Multimedia Sub-system (IMS) is an architectural framework based on SIP, which aids the formation of Fixed Mobile Convergence (FMC). IMS/SIP supports the access of multimedia services across wireless and wired terminals including the mobile phones and fixed telephones as well as serves as the client software for IM and VoIP. However, in recent years, researchers and practitioners have started to integrate some interesting and useful forms of devices such as Wi-Fi handsets and PDAs into the telecommunication networks. Therefore, it is reasonable and natural for us to predict that after connecting people anytime and anywhere by these facilities, the next step is to connect other devices that are currently mainly used to identify inanimate objects into communication networks so as to develop other kinds of services. Furthermore, according to Metcalfe's law [17] which claims that the value of a telecommunications network is proportional to the square of the number of nodes of the system, it is a possible tendency to introducing RFID access technology into the next generation communication networks based on SIP because there are a large number of RFID tags and sensors in the field.

In the area of Internet and telecommunication networks, more and more communication services are developed using location information, not only for tracking network agents, but also for helping people or devices make communication decisions and trigger communication actions. For example, the communication preference model of a doctor's cellular phone will be changed depending on whether he is at office or outdoors. This kind of information is often referred to as location contents and the services based on location contents are commonly referred to as LBS. Considering the various advantage of RFID such as non-line-of-sight, contact-less, penetrability and low cost, and the fact that RFID has been viewed as a promising technology to determine the location of physical objects labeled by tags in indoor environments, the commercial and research potential and value for integrating RFID into communication services will be considerable.

In addition, the cost of installing backbone network for transferring a large volume of data and develop and configure network elements such as registrar, proxies, and database as well as data presentation server is certainly much higher than that if we design an RFID location system as an expanded service to integrate with existing telecommunication platform such as VoIP or IMS. The cost of developing and deploying an RFID-enabled location tracking system, obviously, will be much lower than other competing solutions such as Wi-Fi or Bluetooth devices.

C. System Architecture

In order to seamlessly integrate RFID with the location service facility and other communication applications, our solution is to develop an RFID-enabled location tracking system, SIP-RLTS, based on an open SIP VoIP infrastructure. The standard consists two major components: 1) user agent clients and 2) SIP servers, which include proxy, redirect server and registrar server. Typically, a SIP user agent (UA) is referred to as an Internet endpoint such as IM clients and SIP phones. In the case of SIP-RLTS, we introduce RFID readers and tags into this SIP communication system and treat them as user agents. Toward this end, each RFID reader or tag is assigned a unique SIP URI that is registered in the location database.

Each user agent in an SIP communication network is required to have the capability of sending a request message or replying suitable messages according to a request. Some RFID readers may satisfy this requirement by installing an SIP stack in the firmware. However, comparing with IM and VoIP terminals, the RFID tags have very limited computational capabilities, which cannot complete the SIP message operations by themselves. Thus, in our solution, we propose to expand the RFID middleware to support the SIP operations such as message wrap/parse and transaction maintenance for RFID tags. As Fig. 1 depicts, the middleware serves as a proxy or surrogate agent between the SIP communication and the RFID networks.

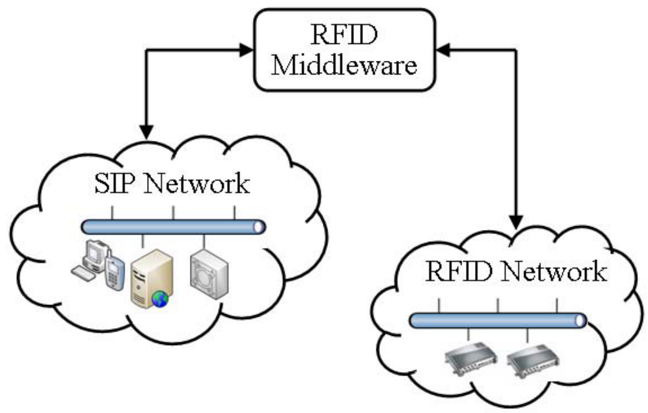

Fig. 1. The role of middleware

SIP-RLTS is designed to be scalable for various location-based applications. As we can see from Fig. 2, the core architecture was divided into four layers [18] -- sensor, abstraction, fusion and application layers from the bottom to the top:

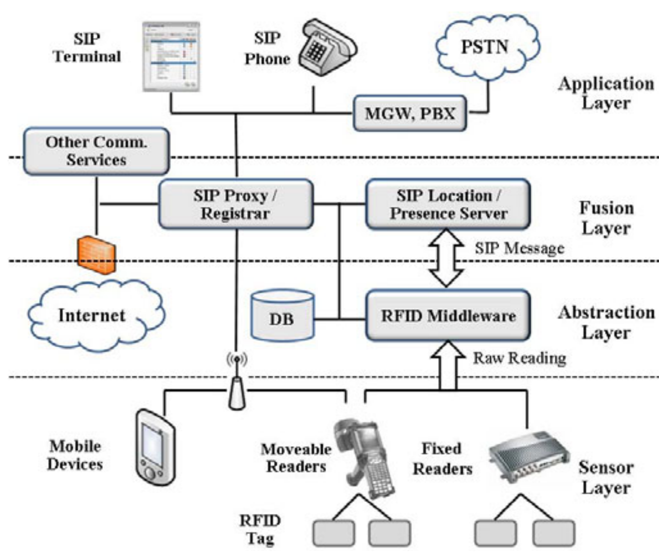

Fig. 2. SIP-RLTS system architecture

1) *Sensor layer:* In this layer, the raw data, which will be

identified and captured by various types of sensor agents forms the basis for the location. In our case, RFID readers (movable and fixed readers) are the main sensors of this layer. However, the layer can also contain other physical sensors, such as 802.11 scanners and even the virtual readers such as GUI for data entry.

2) *Abstraction layer:* The abstraction layer was designed to perform three major functions: a) smoothing, and aggregating raw data to produce quality data, b) abstracting the filtered and aggregated data into semantic location information; and c) providing a standardized format for reporting the location information to a higher layer. In our implementation, the location data is formatted into SIP PUBLISH message [19]. Besides, this layer is designed to be open and scalable; for example, it is designed to be compatible with EPCglobal's Application Level Events (ALE) specification.

3) *Fusion layer:* The fusion layer provides linkages for all the communication entities to interact with each other via a standard SIP interface. The processing done at this layer includes: a) receiving publish messages such as status and location changes from the middleware and other SIP clients; b) providing SIP interface for subscription and notification, and c) providing query interface for higher layer applications.

4) *Application layer:* SIP clients and some communication components such as PSTN-VoIP gateway are located in this layer. SIP clients can also be an SIP software installed in PCs, PDAs or mobile phones. They can easily get location based communication services through the SIP interface.

We are currently building an SIP-RLTS prototype by integrating the location-oriented RFID middleware with an expanded OpenSER SIP Server [20]. We expand the OpenSER by adding the location service component, thus making it the SIP proxy, registrar and location server.

D. SIP-RLTS Middleware

Location-oriented middleware is the most important component of the system. Fig. 3 depicts the structure of our middleware extension, which consists six modules:

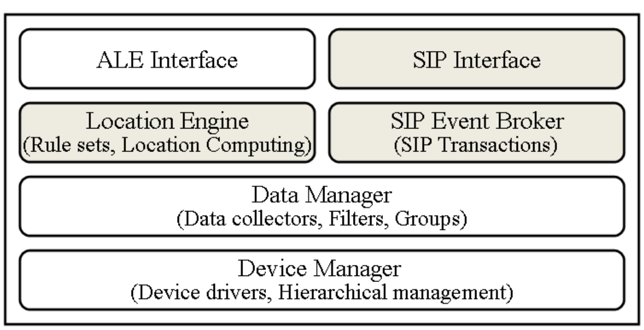

Fig. 3. The conceptual model of SIP-RLTS middleware

1) *Device manager:* This component incorporates several RFID reader interfaces so that the RFID applications can be built independently from specific RFID devices. An interface to manage readers is provided in this module.

2) *Data manager:* Data Manager deals with transforming raw data into clean data for further processing. RFID raw data often contains false readings and duplicate readings. Data smoothing is introduced to remove noisy readings and gather missing readings so as to provide reliable readings for aggregation. Besides, it can reduce the burden on the network and data storage systems. In terms of data aggregation, there are two levels: basic and higher levels. Undoubtedly, readings with the same EPC, location and timestamp should be considered as duplicated readings and be merged at the basic level. However, for those readings which have the same EPC and location but with different timestamps (i.e., those items have not been moved during this time period), they will only be merged at the higher level because they did not change location.

There are two major events processed by this module: a) TAG_ENTER event, which was triggered when the objects move into the detection field of a responsible reader and b) TAG_LEAVE event, which was generated when objects leave the detection field of the responsible reader.

3) *Location engine:* The location engine takes the events received from data manager and calculates the device's approximate location. The system will provide semantic location information like "SIP:alice@dl.com's location is Room306". Furthermore, based on active RFID tags and two or more readers, we can use advanced positioning computing module in the location engine to get more precise information such as 2D or 3D coordinates for a given SIP entity.

4) *SIP event broker:* This component implements SIP event notification model described in RFC3265 [2]. The system supports receiving semantic location packages asynchronously from the Location Engine as well as accepting SIP requests from other systems. Besides, this component provides transaction mechanism, message queues and state machine changes to support asynchronous message passing.

5) *SIP and ALE interface*: The SIP interface is an API designed to provide interface between SIP event broker and Internet. The ALE (Application Level Events) interface is an API type interface through which clients may obtain filtered, consolidated EPC data from a variety of sources.

E. SIP-RLTS Location Engine

RFID is used to identify and capture existing physical objects to the virtual world, known as computer network. Stick with an RFID tag, a physical object can be recognized as a unique entity of the virtual world. Thus, in a sense that the RFID system can be viewed as the bridge between the physical spaces and the virtual world through RFID readers. However, in order to use these data in specific applications, a processing component, called Location Engine, is designed to semantically transform digital message into logic information such as location events. Consider the problem of determining the location of an object stick with a RFID tag, we may get the data from a reader like "the RFID tagged object is now in my detection field" and the location information of the reader like "the reader is now in Room306" through other positioning technologies such as Wi-Fi or IP address location. Then the data was entered into the processing component and was outputted with the information like “the object is now in Room306”.

1) RFID Ontology

Business world has became increasing mobile and pervasive today; these changes imply that location tracking services must be aware of and adapt to their changing contexts in highly dynamic environments. Ontology provides a mechanism to encapsulate the changing contexts. Fig. 4 depicts a graphical representation of the Ontology for our RFID solutions. As shown, the Ontology contains seven entities – User, device, zone, tag, reader, PDA and device management.

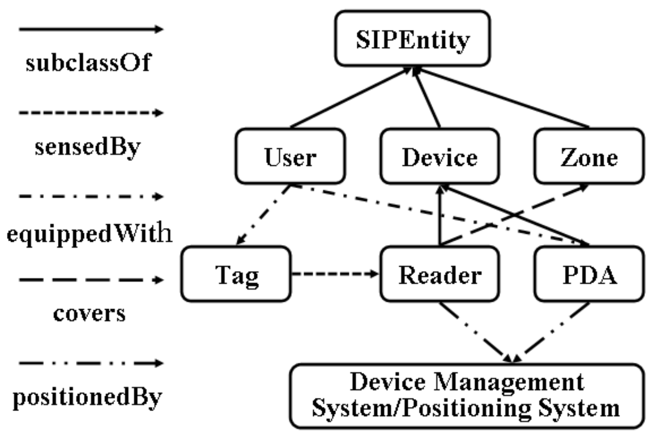

Fig. 4. Ontology for RFID entities

Five methods were deployed to associate with and provide supports among RFID entities:

a) *SubclassOf*: User, device, and zone are the subclass of the root entity. In addition, reader or PDA is a subclass of the device entity.

b) *SenseBy*: A tag may be sensed by a reader.

c) *equippedWith:* A user is equipped with a tag or an PDA.

d) *covers*: A reader covers a specific zone.

e) *positionedBy*: A reader or a PDA's position can be entered into the system manually or detected automatically by a positioning system such as Wi-Fi, Bluetooth, or GPS.

The root represents the generic entity in the RFID context, from which the user location information can be determined. To indentify the location of a user, we should first refer to the User-Device relationship and then search the location information from the Device-Zone relationship (see Fig. 5). The user-device relationship can be formed either the user with an RFID tag was detected by a reader or the user logins to a PDA. Using a device management system or other positioning system, we can established the device-zone relationship.

SIP-RLTS determines the user position based on the presence of the user's tag in the area (zone) covered by a responsible RFID reader. When a user stick with an RFID tag enters a detection field of a reader, the system indicates the new position of that user by referring to the reader's current location. We use the SWRL (Semantic Web Rule Language) [21] to describe and reasoning the location of the tagged users or objects. For instance, the rule used to identify the location of a user can be expressed as:

$$equippedWith(User,Tag) \wedge sensedBy(Tag,Reader) \wedge covers(Reader,Zone) \Rightarrow Location(User,Zone) \qquad (1)$$

2) Semantic integration

One of the major challenges faced in RFID implementation is to transform the captured raw data into a format that is understandable and can be used directly by the back-end enterprise applications. Semantic integration plays a key role in such transformations. Let us use an example (see Fig. 5) to illustrate the location search and semantic integration processes. As shown, the location server contains three relationships (tables) -- Tag-Reader, Reader-Zone and Tag-Zone -- forming from the three entities: tag, reader, and zone.

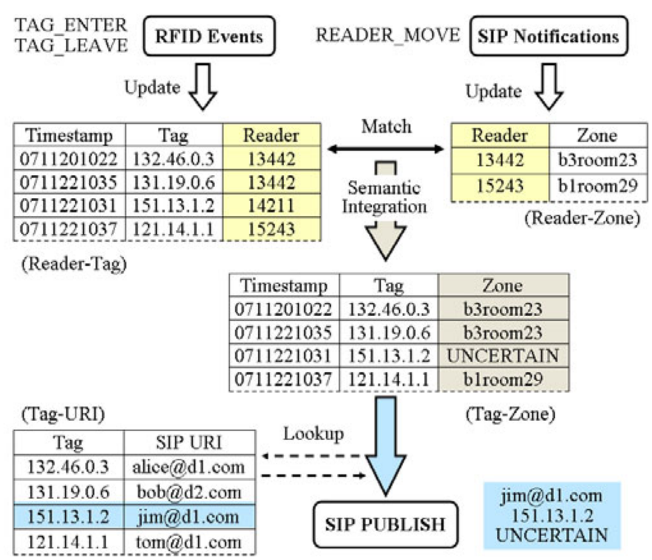

Fig. 5. Location engine

a) *The Tag-Reader relationship*: This table records the tag events from readers, including tag’s EPC, reader and the reading timestamp. When a tagged object enters or leaves a zone, the Data Manager of the middleware receives the information from the responsible reader and generates the event TAG_ENTER or TAG_LEAVE. This aggregated event is then used to update the Reader-Tag table via the location engine.

b) *The Reader-Zone* relationship: This database records the location (zone) of each reader. When a reader moved, a READER_MOVE event will be triggered for an instant update on the Reader-Zone table. READER_MOVE event can be generated by various methods. For example, the event can be triggered automatically when the SIP notification messages reporting the movement of the reader (if the reader was registered as an SIP entity). Another method is to enter the current location of the readers manually using the device management interface provided by the middleware.

c) *The Tag-Zone relationship*: We can establish this relationship by joining the Tag-Reader and Reader-Zone tables. For example, as shown in Fig. 5, if a user with the 132.46.0.3 tag enters the field of reader 13442, a record of (132.46.0.3, 13442) will be produced and recorded in the Reader-Tag table. We can then find the record in the Reader-Zone table, telling that reader 13442 is now in 'b3room23'. As a result, we can generate a record in the Tag-Zone table, telling that 132.46.0.3 is now in 'b3room23'. For those readers the system does not keep (sense) its current location (e.g., 14211), the tags detected by it will be marked as 'UNCERTAIN'.

3) *Location engine execution*

We can use a standard query language such as TSQL2 to complete this join operation. However, if the readers are in constantly moving (e.g., the reader was mounted in a forklift or is a handheld reader) it may cause unavoidable delay. In order to improve the integration efficiency, two dictionaries associated with Reader-Tag and Reader-Zone are built into the cache. We can then match the records in these dictionaries with the same reader value and update the dictionary of Tag-Zone on the fly. This implementation is feasible as the number of tags whose locations subscribed by other communication entities is often not very large. However, in some situations such as: a) a considerable number of tagged objects moving fast and b) the moving of readers happen frequently, the dictionary of Reader-Tag may be updated dramatically and quickly. For reliability and efficiency purpose, we propose a stabilization algorithm (see Fig. 6) to periodically refresh the full dictionary of the Tag-Zone relationship.

Algorithm1: Stabilization (d_ReaderZone, d_TagReader)

```
keyrz = d_ReaderZone.firstIndex
keytr = d_tagReader.firstIndex
while keyrz<>d_ReaderZone.lastIndex and keytr <>
  _TagReader.lastIndex
if d_ReaderZone[keyrz].Reader =
  d_TagReader[keytr].Reader
Update d_TagZone with (d_TagReader[keytr].Tag,
  d_ReaderZone[keyrz].Zone)
keytr++
else if d_ReaderZone[keyrz].Reader >
  d_TagReader[keytr].Reader
Update d_TagZone with (d_TagReader[keytr].Tag,
  UNCERTAIN)
keytr++
else
keyrz++
return d_TagZone
```

Fig. 6. Stabilization algorithm

The time complexity of this in-memory algorithm is O (M+N), where M and N are the length of the dictionary of Reader-Tag and Reader-Zone, respectively. Comparing with the join query of database tables, it is obvious that the cache-based integration is faster.

For those cases that it is necessary to push the location changes of a RFID tag to location server as soon as possible, we implement an RFID event handle algorithm as shown in Fig. 7. The algorithm is invoked when a tagged object is moving into or out of the detection field of a reader. When the event TAG_ENTER is received, the location engine computes and publishes the location information immediately. When receiving TAG_LEAVE, the location engine send the PUBLISH message with the location field marked by 'UNCERTAIN'.

Algorithm 2: Handle_RFIDEvent (event)

```
if (event.type = TAG_ENTER)
sortInsert (d_TagReader, event)
go through d_ReaderZone to look for the current location
  rzone for the event.reader
generate SIP PUBLISH message with (event.tag, rzone)
updateDatabase;   // record the location history
if (event.type = TAG_LEAVE)
delete(d_TagReader, event)
generate SIP PUBLISH message with (event.tag,
  UNCERTAIN)
updateDatabase;   // record the location history
```

Fig. 7: Algorithm for event handling

F. SIP-RLTS Location Server

Location server plays a key role for interfacing with the RFID middleware and other SIP clients such as the SIP IM tools, SIP enabled PDA, as well as SIP phones. Similar to the presence service of conventional SIP provided, the location service provides an interface to retrieve user location information, thus providing the means of making information available to other SIP application servers. The location server was designed as an add-on to the existed SIP application server. In our solution, both the location information from the location server and the presence information from the presence server are processed by SIP stack and distributed by SIP event notification model.

Fig. 8 illustrates the flow of message exchanges among the SIP servers and devices. The PUBLISH message is used when a tracked object is moving. In this solution, when a tagged object moves to a new location detected by a reader, the middleware will send a PUBLISH message on behalf of the tag to location server with the new location information. A SUBSCRIBE message is used by a so-called watcher (monitor) to subscribe to the location information of another entity, which can be a tagged object or a mobile user. The watcher can subscribe to one or more entities. For example, a doctor can subscribe to all his tagged patients and his nurses who carried PDAs or cell phones. A NOTIFY message is sent to the watcher carrying the XML-based location information in the body of the SIP message. More details of the XML specification for the location information between SIP entities are given in [22].

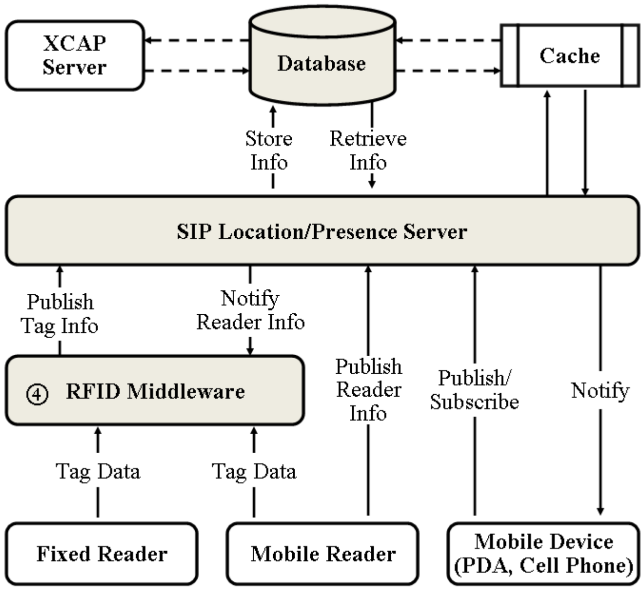

Fig. 8. Message exchange among components

G. How Does SIP-RLTS Work

Fig. 9 shows the detailed message flow of how SIP-RLTS work. The process is as follows:

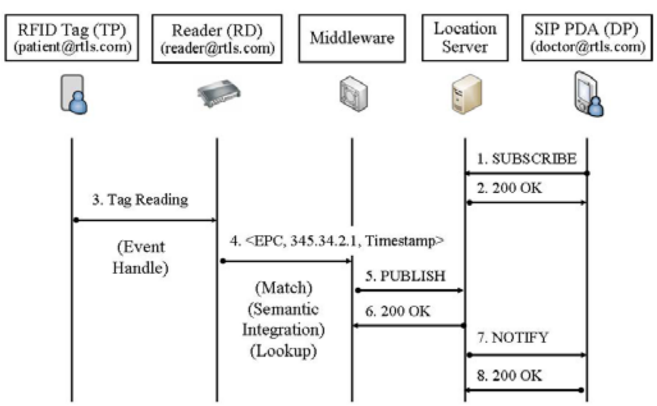

Fig. 9. Message flow

1) The doctor's PDA (DP) initiates a subscription to the Location Server for *patient@rlts.com*.

2) The Location Server processes the subscription request and adds *the doctor@rlts.com* into the subscription list of *patient@lts.com*. Then sends a response message, 200 OK, back to DP.

3) The TP is detected by the Reader RD, which receives the raw data including the TP's EPC code and detection time.

4) The reader RD transforms the received data into read event and forwards it to the middleware.

5) The middleware processes (filters, groups) the read event and generate a TAG_ENTER event. Receiving the event, the location engine updates the Reader-Tag dictionary and computes the location of TP. Such location information is formatted into a PUBLISH message by the SIP stack and then send to the location server.

6) The location server receives the PUBLISH message and sends back a 200 OK message.

7) The location server incorporates the published data into the *patient@rlts.com*'s location document and then sends a notification to those who are interested in the location information of TP.

8) DP receives the notification since it is in the subscription list of *patient@rlts.com*, and sends back a 200 OK response.

IV. PERFORMANCE ANALYSIS

A. Scalability.

Scalability is a very important aspect for RFID system because we usually have a large number of RFID tags in the field. Scalability of the SIP-RLTS is highly dependent on the capacity of the location server such as bandwidth, CPU, and memory.

Suppose there are N_t tagged objects in the system and the number of moving events are Poisson distributed with mean τ per object, the average number of watchers subscribed to one tagged object is V_t, the number of watchers is N_w, the average number of tagged objects to whom the watcher has subscribed to is V_w, and the SUBSCRIBE refresh rate for every watcher is r_s.

If we ignore the message exchange between the location server and other positioning server, we can use the average request rate, denoted by M, as a metric to estimate the scalability of the location server because the number of SIP requests processed per second roughly represents the load of the server.

Thereby, the request rates of PUBLISH message is τNt, the request rates of NOTIFY message generated by the location server is $\tau N_t V_t$, and the request rates of SUBSCRIBE message is $N_w V_w\ r_s$. The average SIP request rate, M, is the sum of them, which can be given as:

$$M = \tau\ N_t + \tau N_t V_t + N_w V_w\ r_s \qquad (2)$$

In general, the amount of SUBSCRIBE requests is relatively small, as comparing to other two request types, especially when we use a certain mechanism such as RLS [23] (subscribing for a group's URI which represents a list of tagged objects) to reduce the amount of SUBSCRIBE messages. Thus, If the location server can handle T requests per second (where, $T = M$), then we can get the maximum possible number of tagged objects, N_{max}, as:

$$N_{max} \approx T\ /\ (\tau + \tau V_t) \qquad (3)$$

Suppose the location server can support 600 requests per second, minimum τ is 1/1200 and V_t is 20, then the maximum number of RFID tagged objects the system can support is about 36000, which is a reasonable size for most corporations.

B. Latency

Since the location server and middleware rely on asynchronous message-passing model to process multiple events triggered by the movement of a large number of RFID tags, the time from a RFID reads, which will trigger a TAG_ENTER or TAG_LEAVE event, to middleware until the semantic movement event is received by a watcher's device is also an important performance measure to the end users. The location reflecting latency T_s can be described as:

$$T_s = T_p + T_m + T_l \quad (4)$$

Where T_p stands for the propagation delay and *Tm* and *Tl* are the processing time at the middleware and the location server. In our consideration, the propagation delay is independent to the traffic and can be viewed as a constant *c*. The processing delay can be estimated by using a queuing model [24].

As Fig. 10 depicts, we model the RFID location-oriented middleware and the location server as a *M/M/1* queuing system. Suppose the RFID readings arrive middleware according to a Poisson process with rate λ_m, and the probability distribution of the processing time is exponential with mean $1/\mu_m$. (Here, we assume that there is no relation between the message service rate of middleware and the message arrival rate of the location server since the location server also receives PUBLISH messages from other positioning systems). Based on the Queuing theory and Little's theorem [25], the processing latency in the *M/M/1* queuing system can be computed as

$$T_m = 1 / (\mu_m - \lambda_m) \quad (5)$$

Similarly,

$$T_l = 1 / (\mu_l - \lambda_l) \quad (6)$$

Thus,

$$T_s = c + 1 / (\mu_m - \lambda_m) + 1 / (\mu_l - \lambda_l) \quad (7)$$

Suppose the average arrival rate λ_m of the middleware is 80 tags per second, the average service rate μ_m is 160 tags per second, and the processing time at the middleware T_m is 0.0125 sec. For the location server, suppose the average arrival rate λ_l for PUBLISH message through the location server is 30 messages per second and the average service rate μ_m is 120 messages per second, then the processing time at the location server T_l is 0.0111 sec. If the average propagation delay *c* is 0.0300 sec, then the location reflecting latency T_s is 0.0569 sec. This delay is within an acceptable range for most applications.

C. Security

Security is another important issue for the location tracking systems because people are unlikely to use the tracking services unless service accessibility is limited to authorized users. In addition, the access is based on certain privacy rules and a process is in place to keep out strangers. In order to protect location information, three security aspects need to be addressed [26]: security of location information exchange, access rights to location information, and privacy rules for location information.

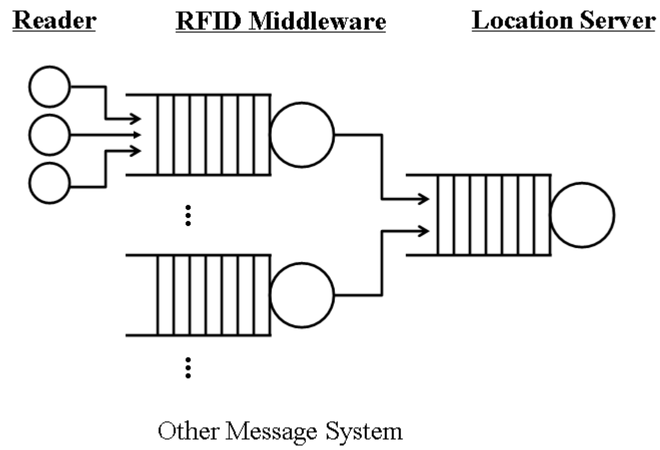

Fig. 10. The queuing network model of the system

Like other SIP information exchanges, Transport Secure Layer (TLS) and IP Security (IPSec) can be used to secure the SIP-RLTS transmissions. In our solution, since the middleware is on behalf of a number of RFID tags, the SIP message exchange only happens between the middleware and SIP location server rather than between all the tags and the location server. In most cases, SIP-RLTS will be integrated with a trusted network such as SIP VoIP systems. Thus, securing SIP message exchange is certified.

In addition, authentication and authorization are built in with our solution. For instance, for a certain patient, only her/his responsible doctor and nurse can subscribe to the patient's location information. In our case, the location server authenticates subscribers using SIP digest authentication over TLS. In addition, we use the existing XCAP (XML Configuration Access Protocol) [24] server to operate the authorization documents, which describes the authorization policies and governs the subscription. Moreover, all requests to access the location server and the middleware are based on access control policies.

D. Privacy Protection

Privacy protection is another critical issue for location systems, which may disclose the position information of a person in a manner contrary to the user's preferences. For example, nurses are not willing to release their location information after work hours to their colleagues. Thus, a mechanism is needed to facilitate the privacy protection according to privacy rules. The authorization document is used by user to set her/his privacy policy value, thus providing a means to decide who will get which level of her/his location information and when to access.

In our proposed solution, the authorization documents are stored in XCAP server (see Figure 8), which is used by users to manipulate privacy policy and buddy lists. Privacy policies including conditions and actions are often created and maintained by the tagged users or managers. Whenever a watcher requests location information of a tagged object, the location server would get the object's authorization document and check the conditions part of privacy rules such as the time and the identity of the watcher. If the current conditions match these rules, the location server would send the location information to the watcher; otherwise, the request will be declined, making the privacy protection more robust.

V. DISCUSSION

Several unique features have built into our proposed system, SIP-RLTS, which distinguish our proposed solutions from other similar implementation.

First, SIP-RLTS has the interoperability advantages over other similar implementations because in our implementation RFID, as well as other positioning systems such as Wi-Fi, Bluetooth, were fully integrated into the SIP communication network and transfer the location information with the same SIP format. That is, when the location server or a watcher receives a SIP message, it only cares about who the user URI represents and where the user is, rather than how the user is sensed and by what kinds of positioning systems. In addition, the system can work over the broad network. This is made possible by the distributed nature of VoIP and by adopting the open standards. Since the RFID middleware here can be treated as a SIP agent who publishes RFID location information, we deploy the system in a distributed way similar to SIP based VoIP infrastructure; That is, in some cases we may deploy the SIP servers and middleware separately into service providers and small companies.

Second, SRMS encapsulates the current location information in the 'contact' header that the amount of information it can convey may be limited. On the other hand, we use the text-based XML encoding document to describe the location information in the SIP body, which allows us expand the system with new value-add services without causing incompatibility problem.

Third, SIP-RLTS is designed to be able to track the tags under movable readers. Actually, all the readers are viewed as tracked objects, whose location information is stored and updated by location server. By doing this, for instance, the RFID middleware can subscribe and obtain the location of a Wi-Fi enabled handheld reader, which is then used to update the Reader-Zone relationship.

Fourth, our proposed system can offer both PUSH and PULL LBS while SRMS only realized the PULL operations. In PUSH model, the user does not need to send query for location information every time but only required to subscribe it. Pub/Sub model obviously can be used to push location information to subscribers with the NOTIFY method. However, sometimes, user may not want to know every location updates of the tracked objects. The PULL model is used in this situation, which allows the user to get location information whenever he/she wants by initiating an active query. In SIP based location system, a PULL operation can be completed by sending a SIP SUBSCRIBE request with setting the "Expires" headers to zero.

Fifth, the SIP-RLTS can use with either active or passive RFID tags as the positioning technology. Passive tags receive energy from readers when being scanned, whereas active tags use batteries to transmit data. Comparing with passive tags, active tags are more expensive and in larger size but have the advantage of being able to transmit longer distance. The selection of active or passive tags is dependent on the applications.

Finally, Wi-Fi is another common alternative positioning technology in indoor environments, based on radio propagation characteristics. Wi-Fi uses existing wireless network and can provide a data channel to transfer location information. However, to use Wi-Fi location system, one needs to visit indoor environment beforehand, thus making it is not good for frequently changing environments. Besides, apart from installing access points in an area, the more expensive Wi-Fi radio chip is needed to stick in the tracked object.

VI. CONCLUSION

In this paper, we presented a RFID-enabled location tracking system based on SIP protocol. We used a four-layer model to describe the system architecture. We then focused on introducing and analyzing the two main components of the system: location-oriented middleware and location server. The middleware provides a set of services: 1) filtering and aggregating the RFID raw data and 2) computing the location information. Ontology and semantic integration are the two cornerstones of the RFID location engine. Location server is designed to collect and distribute the location information based on subscribe description and authorization polices.

To realize the location information service, we analyzed the ontology entities in the system and used the integration technology to design the location engine, which provides the SIP event broker to manage the message exchange. A cache and stabilization mechanism is also introduced in location engine to increase the computational efficiency for frequently moving readers. SIP event notification model is implemented in our solution to support both the PUSH and PULL mechanism of location information conveyance.

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