Architecture for High Density RFID Inventory System in Internet of Things

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Abstract. This paper proposes a novel architecture of Internet of Things (IOT) implemented using RFID. Our proposed architecture solves the problem of over-loading as the load on the RFID Tag reader is the total number of changed objects rather than the actual number of objects present. Our architecture is based on EPCglobal Network with some assumptions and modifications. We have discussed in details the components and working of our model. We have also discussed the physical implementation of our model taking the examples of two sample applications one for the retail system and other for smart home applications and their performance results have been tabulated and represented graphically.

Keywords:
Internet of Things, RFID, Smart Home Application, Retail system

1 INTRODUCTION

RFID is the new generation Auto ID technology that uses wireless communication to uniquely identify and track an object. It was invented in 1948 and was first-used during the IInd World War by the US Army for identification of friend or foe (IFF) aircrafts. RFID is widely used across a multitude of industry sectors and applications like airline baggage tracking, automated vehicle identification and toll collection. A RFID system basically consists of a Tag, a Reader and an antenna. The RFID Tag is basically a transponder with a silicon microchip for storing large amounts of data. Tags can be either active or passive. Passive tags are read only, gains its power from that generated by a reader. and reading range is typically shorter up to 30 feet (3 meters) and the data storage capacity is comparatively less (96/128 bits) as compared to active tags. Active tags have both read/write capability and are powered by means of battery. This battery-supplied power enables data to be read and written on to a tag and thus gives it a greater reading range up to 300 feet (100 meters) and large data storage capacity (128 KB). Some popular frequency ranges or RFID and their applications are given in Table1.

Table 1. Ranges and Applications of RFID

Frequency Range	Characteristics	Applications
Low Frequency 125 – 300 kHz	Short range (To 18 inches) Low reading speed	Livestock ID Reusable containers
High Frequency 13.56 MHz	Medium range (3-10 feet) Medium reading speed	Access Control Airline Baggage ID Library automation
Ultra High Frequency 400 MHz–1 GHz	High range (10 – 30 feet) High reading speed Orientation sensitive	Supply chain management & Container Tracking
Microwave Frequency > 1 GHz	Medium range (10+ feet)	Automated Toll Collection Vehicle Identification

There are a number of existing (ISO) and proposed RFID standards (EPC Global) that have different data content, use different protocols and have different applications as shown in Table 2. With the adoption of Gen 2 ePC (UHF) standards, the adoption of RFID systems is now a major tool for supply chain management.

Table 2. RFID Standards

Specification	Description	Frequency
ePC UHF Class O	64-bit factory programmed	900 MHz
ePC UHF Class 1	96/128 bit one-time programmable	860-930 MHz
ePC HF Class 1	96/128 bit one-time programmable	13.56 MHz
ePC UHF Gen 2	96/128 bit one-time-Programmable	860-960 MHz
ISO 18000-3	Item Management	13.56 MHz
ISO 18000-4	Item Management	2.4 GHz
ISO 18000-6	Item Management	860-960 MHz

The RFID reader can be

1. Fixed RFID reader like UHF standard
2. Multi antenna RFID reader for supporting several appliances
3. Handheld mobile RFID (MRFID) readers

The internet of Things (IOT) is a networked interconnection of objects. It is global expansion wireless Electronic Product Code (EPC) network implemented through RFID tags [3] or QR Codes. An EPC number essentially contains:

1. Header, which identifies the length, type, structure, version and generation of EPC
2. Manager Number, which identifies the company or company entity
3. Object Class, refers to a stock keeping unit or product SKU
4. Serial Number, which identifies a specific item of the Object Class being tagged.

2 BACKGROUND

EPCglobal has developed the Object Name Service (ONS) [4], a mechanism which makes use of the Domain Name System (DNS) protocol [5] to discover information about a product and related services from the Electronic Product Code (EPC) and is used for the resource addressing of Internet of Things. The EPC is first encoded to a Fully Qualified Domain Name (FQDN), then existing DNS infrastructure is used to query for additional information. This procedure makes use of the Name Authority Pointer (NAPTR) DNS record [6], which is also used by E.164 NUmber Mapping (ENUM) [7]. Ubiquitous ID Center (uID Center) brings forward similar resource addressing service named uCode Resolution Protocol (uCodeRP) [8], which also utilizes the protocol similar to DNS.

We are proposing ONS based a novel architecture of Internet of Things (IOT) implemented using RFID network. Our proposed architecture solves the problem of over-loading as the load on the RFID Tag reader is the total number of changed objects rather than the actual number of objects present as described in Section-2.

3 RFID NETWORK ARCHITECTURE

EPCglobal is a joint venture between GS1 (formerly EAN International) and GS1 US (formerly Uniform Code Council). The organization has created worldwide standard for EPC, RFID and the use of the Internet to share data via the EPCglobal Network.

Fig 1 shows the EPCglobal Network Standards given by EPCglobal. EPCglobal Network has following components

3.1 Tags (Transponder) with EPC

Tags follow coding standard of EPC tag information. The EPC coding scheme provides differentiating codes [1] for each object of RFID network. Air interface protocol (GEN 2 AIP) regulates communication between the reader and the tag). Tag data translation protocols converts EPC information to Internet compatible format

3.2 EPC enabled Reader (Interrogator/Scanner)

Reader follows standard reader protocol to exchange data between EPC-capable middleware Reader management specifications are used to configuration readers.

3.3 Object Naming Service (ONS)

ONS is the network service system, similar to the DNS. This server will contain all EPC numbers and their associated IP addresses. ONS points out the specific EPC-IS server where the information being queried. It has standard security specifications and API.

3.4 EPC Information Service (EPC-IS)

EPC-IS is a software component to communicate with the EPCglobal Network and the ONS server. It stores the information processed by EPC middleware and query related information. EPCIS protocols manage storing and accessing of EPC information via the EPCglobal Network)

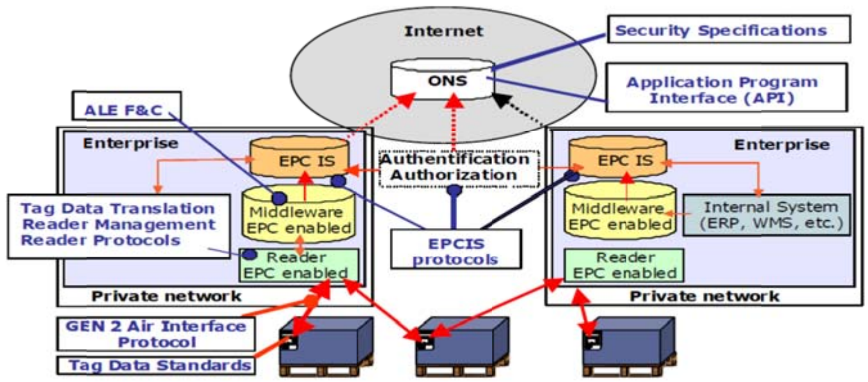

Fig 1: EPCglobal Network Standards (Source: GS1 Germany/EPCglobal)

3.5 EPC middleware (Savant)

Program module or service with a series of specific attributes, which is integrated by users to meet their specific needs. The most important part of EPC middleware is Filter and collection Application Level Events (F&C ALE).
Our proposed RFID based Internet of Things network architecture is based on the original EPCglobal Network architecture and has some specializations as explained below:

1. RFID Tags

The RFID tags are attached to each object that is to be identified as shown in Fig 3 (a). The RFID tags used for our purpose are passive and are in inactive state and need to be woken up by a wake-up call when in radio range of an active Tag Reader.

2. Tag readers (Master and Slave)

Fig 2: Placement of Master and Slave Tag Readers at Floor 0 of a Building having 6 Blocks (A-F)

Our system has two types of Tag Readers –Master reader and Slave reader [2]. The master reader is a conventional powerful fixed active reader with a direct fixed or wireless connection. It initiates a read process in the slave reader and wakes up any passive tags for power-up or any other service initiation. In addition, it collects the item-level information and forwards it to the back-end for further processing. Fig 2 shows the placement of Master and Slave Tag Readers. The Master Tag readers are placed at entry/exit points while Slave Tag Readers are in Blocks.

3. The Master reader

It communicates with both ONS and Inventory database in two different states as shown in Fig 3 (b). The proposed database is used for inventory management in the system with many records. It is responsible for maintaining information as cache for reading purposes.

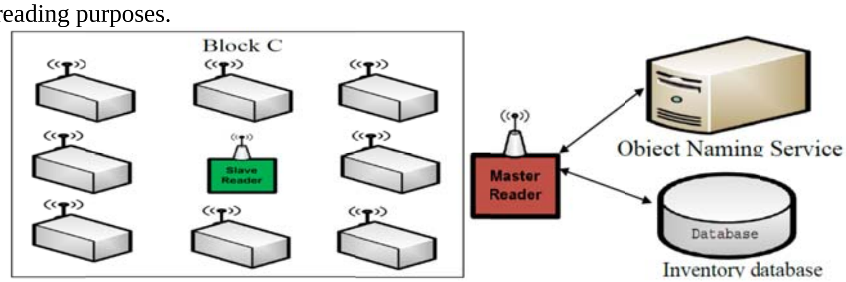

Fig 3 (a) Block Structure (b) Communication of Master reader with ONS and Inventory database

We have made following assumption in proposing our system architecture:

1. The number of RFID objects in the block is very large
2. The objects are stationary within a region except for when they are brought in and out of the region
3. The movement of objects within a region is not present once the object is made stationary
4. There are a fixed number of entry/exit points within the region. The movement of objects are only to get in and out of the region
5. Each object has a unique RFID that can be interpreted at the Object Name Server (ONS).

4 NETWORK WORKING

The objects labeled with the RFID tags will be located within the closed region divided into blocks each of which having a slave reader to identify the items whose RFID tags can be activated by the slave reader. This slave reader will in normal working situation be in inactive state. The slave readers will be connected to a master reader which would act like an aggregation server for the slave reader readings and will pass the information the ONS and used the inventory database for caching. The connection of the slave to the master reader can be wireless, direct wired or switched with redundant cabling based on the use case. The slave readers located at the entry/exit point will remain active and function as the primary readers for data update.

4.1 Case I Initial Setup / Refresh

The initial setup will consist of the master reader instructing the slave readers to active state (by sending wake-up call) one by one which in return will force the RFID tags of all the objects in the state space (region) into the active state (by their wake-up calls). The slave readers will transmit the read RFID tags to the master reader which will, with the help of the ONS cache the location of the objects in the inventory server. The field will include the RFID, the object description, the user identification number (in case it is different from the RFID) as in the case of a local repository of the ONS. Alongside this, the location as well as the block number of the objects will be saved.

4.2 Case II Reading

The reading of a tag involves getting the data from the inventory database and returning the information.

4.3 Case III Removal of Object

In case of removal of object, the active readers the exit points will activate the RFID tags. These RFID tags will send the information to the readers which will match it inside the inventory database. The deletion of information can occur directly from the inventory database for the object. In case of an object absent, it indicates that the data inside the database needs refresh.

4.4 Case IV Addition of Object

The addition of object to the system through the entry points will involve the wakeup of the RFID tag by the entry points. The entry point reader will inform the master to wake up the corresponding slave to a reading state where it reads active tags but does not transmit the Wake-up Calls. The newly entered object will be in the active state and will be transmitting the RFID information. This can be used to track its new location by the slave readers without activating the other objects and thus preventing energy wastage or clatter.

5 APPLICATION IN SHOPPING MALL OR RETAIL SHOP

Market studies indicate that companies with current RFID deployments are pursuing and achieving significant business benefits. For RFID deployment according to our architecture, we need to separate different products in different blocks each with different Slave Reader. We can use different rooms for different blocks as discussed in Smart Home Application. We put active master readers at billing desk, entry and exits points. The slave readers are placed in different blocks and elsewhere for location identification. We should use different Tag read orientations for minimum interference and optimizing performance. The commonly used read orientations in retail are horizontal, vertical and End-on inlay orientations as shown in Fig 4. There is wide variation on percentage of read accuracy depending on inlay type.

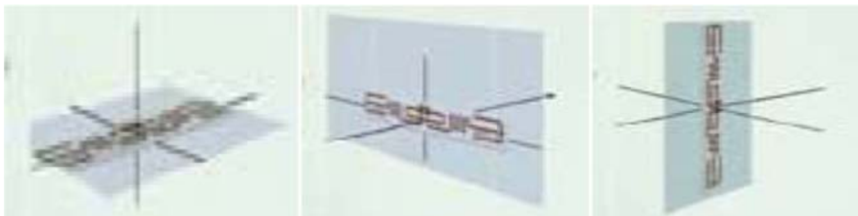

Fig 4: Orientation of Tags (a) End-on (b) Horizontal (c) Vertical

Fig 5 shows an example of clothing shop with clothing rack wit hanging clothes (top) with vertical tag orientation, jeans (bottom left) with end-on inlay orientation and shoeboxes (bottom right) with horizontal inlay orientation. For our architecture to function correctly the location of all objects within the shopping mart must be fixed. The objects of one block are not permitted to be shifted or placed in other block. The relative movement of objects within a mart should be negligible.

Fig 5: Retail shop with different products placed different blocks and monitored by their Slave Readers

For a retail shop, a major concern is to detect theft and inventory pile. We can easily avoid such situations by providing customers a PII (personally identifiable information) number and that can be associated with tag identification (EPC) numbers.

For Checking Out, as mentioned above, we have placed Master Tag Reader at billing desk and Entry and Exit points of each block. All checkouts are done by Master Tag reader by scanning EPC numbers of object Tags. The master Tag reader scans the first item and then its quantity, instead to scanning each item individually. After checkout, the Tags are usually deactivated to avoid their further interference. The theft is detected by continuously scanning EPC numbers at entry or exit points.

6 PERFORMANCE RESULTS

For the retail shop application, the performance curves (Inlay read percentage) as function of read distance for different orientations of Tags are shown in Table 3 and corresponding Fig 6.

Table 3. Inlay Read Performance (%)

Reading Distance (in ft)	Inlay Read Performance %		
	Shoebox	Hanging	Jeans
1	100%	100%	100%
2	100%	100%	95%
3	100%	95%	80%
4	100%	90%	70%
5	100%	80%	60%
6	100%	75%	50%

The curves show that the read performance horizontal tags (in Shoebox) is better than the performance of Vertical tags (hanging clothes) when distance is more than 3 feet. The end-on orientation (for jeans) performance is least, even at distance of 2 feet from the reader. A hundred percent read rate is possible in a variety of situations as shown in Fig 7.

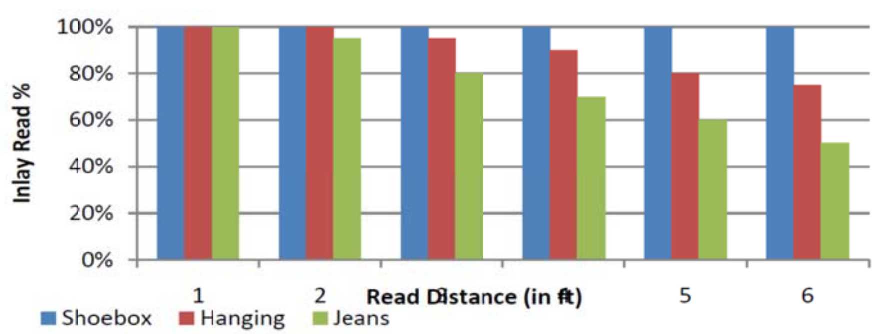

Fig 6: Configuration Variation Effects: Inlay read performance for varying arrangements

For the implementation of our architecture the performance characteristics of master and slave RDIF tag readers should be shown in Table 4 and corresponding Fig 7. As shown in figure, the number of tags read by slave reader should decrease steeply with increase in reading distance so that two slave tag reader cannot interfere with each other. On the other hand, the master tag reader should have long range so that it can make connection with all the slave readers.

Table 4. Reading Performance (%) of Master and Slave Tag Readers

Reading Distance (in ft)	Tags Read by Master Reader	Tags Read by Slave Reader
1	100%	100%
2	100%	80%
3	95%	55%
4	90%	45%
5	85%	35%
6	80%	20%

The higher range of master readers as illustrated in the figure is a prime requirement for the system to be effective. No object entering the system should be able to skip the master reader. Ideal placement for the master reader would be overhead or along the sides of the entry/exit points. The sphere of 100% reading performance should cover the entire area of these points. Additional readers networked as one can be used to boost performance. The performance curve indicates that the slave reader should also be placed to make blocks (Fig 3a) keeping them at 2-3 feet from each other. This range largely depends on the tag density (here 20 tags/feet) for higher density increases clutter and disturbance. Also for slave readers, the density refers to the number of active tags within range rather than all tags, in case of which, there could be 1-2 tags in a slow moving system within the range of a tag reader.

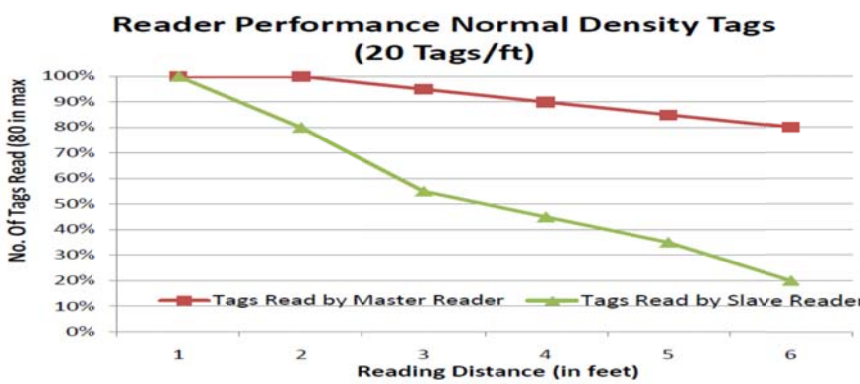

Fig 7: Reading Performance comparison of master and Slave Tag Readers

7 CONCLUSION

RFID offers new levels of visibility for companies that want to track physical items between locations. In the retail supply chain, the goods tagged at the point of manufacture can now be traced from the factory to the shop floor, providing a real time view of inventory for all supply chain partners. Internet of Things (IOT) is future network of all objects and it can be implemented using RFID. Its standards are given by EPCglobal. Our proposed architecture is based on EPCglobal Network with some assumptions and modifications. It solves the problem of over-loading as the load on the RFID Tag reader is the total number of changed objects rather than the actual number of objects present. We have also discussed the way to implement our architecture for sample applications like retail system and smart home. Future work in this system could be to incorporate a means for tracking movement of objects within the system. Another extension could be to provide a placement criterion for the slave readers, which in the current architecture use the overlapping structure similar to the placement of wireless access point for internet access. The major difference in the systems is the size of the slave readers which is much smaller, with smaller ranges as compared to access points. Also, slave readers can be arranged without wired connections to contact and share information wirelessly over the network. Awareness of RFID technology and Internet of Things concept can benefit industry and home automation globally.

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