# Overview of RFID Technologies for Ubiquitous Services

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**Abstract**

The terms “ubiquitous”, “Auto-ID,” and “wireless tag” have recently become very popular and they frequently appear in the daily newspapers. Despite their popular use, it is very difficult to express their real functions because the definitions of these terms are not clear. This paper explains promising services that are currently proposed, technical problems common to these services, and the direction in which research should head in the future.

## 1. Introduction

Ubiquitous services are services that enable access from anywhere to anything regardless of time and space. They need every object to be connected to a network in order to communicate. Since objects often move, wireless communications should be used. The communication tool that best suits these conditions is the wireless tag. The functions that a wireless tag requires depend on its role in a usage scenario. For example, if tags are attached to all objects, as in the Auto-ID center [1] described later, cost is a more important issue than the functions provided by the tags. On the other hand, in the sensor networks provided by Dust Inc. [2], functions are much more important than cost. This paper explains the functions that wireless tags require in several proposed ubiquitous service examples.

## 2. From barcode to RFID

Auto-ID discriminates objects automatically, and part of this service is already in use as barcodes or optical character recognition (OCR). The introduction of the barcode was a revolutionary step because it fundamentally changed physical distribution systems. It is now exceptionally rare to find a product that has no barcode. The cost of a barcode is negligible because it is printed and barcode readers are very cheap because they have a simple structure. However, barcodes do have a limited memory capacity: they can identify a product category or manufacturer but cannot distinguish each individual product.

The current readers are connected to networks. The drawbacks to barcodes are that they are easy to copy and must be passed in front of a reader. To address these problems, new trials are being conducted to make the physical distribution system more efficient or to manage customer information by affixing wireless tags to each product and establishing a connection to networks [3].

### 2.1 Passive tag

Wireless tags were originally designed to deter shoplifting and not to manage products. A simple shoplifting protection system cannot discriminate each product as having a specific ID. However, recently developed wireless tags that can not only discriminate each product, but also write data in themselves are available at very economical costs (less than $1 per tag). Such a tag, which has an ID, is called an RFID (radio frequency identification) tag. The tag’s power is supplied by the reader to reduce the cost of the tag. These tags are called passive tags because their power is supplied from a separate source. **Figure 1** shows the working principle behind

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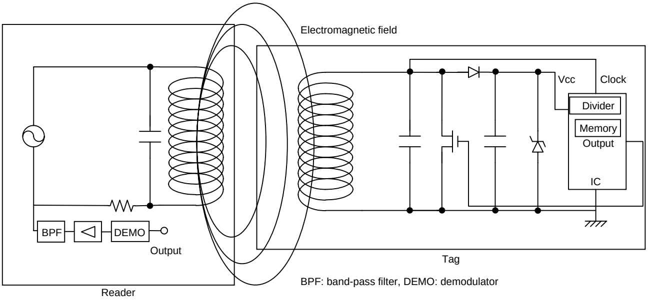


Fig. 1. Basic circuit diagram for passive tag and reader.

passive tags. The power is supplied based on a similar principle to the transformer by electromagnetic inductance between the wireless tag and a reader. The reader transmits high-frequency modulated waves that combine power with commands. The tag receives and simultaneously detects the waves and uses them for power. Depending on the system, a typical tag has a simple microprocessor and a divider. It recognizes received commands and replies with its own assigned ID. The passive tag cannot drive an oscillator because it has no battery. However, it receives powerful carrier waves and utilizes them instead of an oscillator. It replies using frequency transformation through signals divided using the divider. The electromagnetic inductance type tags can only transmit signals over one meter, but they can be used worldwide because the frequencies are standardized from 100 to 135 kHz (LF: low frequency) and 13.56 MHz (HF: high frequency).

Recently, new types of passive tags have debuted. They can receive high-frequency waves using an antenna, detect these waves, and use them as a power supply instead of using electromagnetic inductance. One characteristic of these new passive tags is their small antenna for high frequency use. Based on the antenna pattern, the signals can be transmitted over longer distances, such as 10 m, using the 900-MHz band in the US [4]. However, because they are new, their frequencies have not yet been standardized. The frequency of 2.45 GHz can be used worldwide, but its maximum transmission range is only a few centimeters due to the low power.

Since the passive tags provide simple functions, the manufacturing cost is low once a die chip has been cast. The chip cost is determined by the number produced and its size. Currently, 350-µm × 350-µm chips are being manufactured. However, they do not work as the RFID themselves, as mentioned above, because they require a coil or an antenna to receive high-frequency waves.

### 2.2 ePC tag

The Auto-ID center thinks that an important factor in tag popularity is low cost. It proposes using the 96-bit electronic product code (ePC) inherited from the current barcode system and adding a serial number to the tags. It will keep product history or detailed information on the network instead of storing it in the tag's memory to avoid having to expand the memory capacity. Object name service (ONS) is a service that makes detailed information accessible through networks based on the ID and offers the information to locations that require it after rapid certification via the network. Servers called Savants respond to inquiries from various applications and tag ID. By standardizing this information flow, Auto-ID achieves lower operational costs and enables data distribution (**Fig. 2**). It is focused on standardized items such as tag ID, ONS, and the physical makeup language (PML), a language on Savants, in addition to developing other features for various applications.

The ubiquitous ID center, the standardization orga-

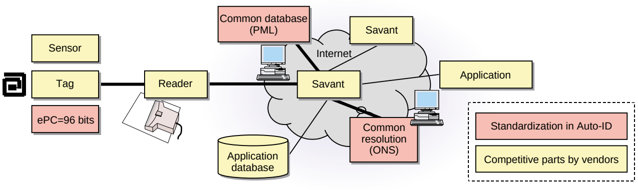


Fig. 2. Standardization strategy of Auto-ID center.

nization for RFID in Japan, also has plans to simplify tag functions to decrease cost. It proposes its own 128-bit ID, and its plans for data distribution are along the same lines as those of the Auto-ID center.

## 3. Problems holding up widespread use

Stores that sell small expensive goods that are easy to shoplift such as CDs, videos, and DVDs already use wireless tags to deter shoplifting. However, the tag functions are disabled or the tags are removed from the goods when the goods are purchased. Below we explain the two main reasons for disabling the tag functions upon purchase.

### 3.1 Maintenance for shoplifting protection

If the tag function continues to work after the goods have been purchased, an alarm will sound when the customer enters another shop equipped with the same anti-shoplifting system. There are several ways to avoid this scenario. The most promising way is to read and store the tag IDs of all goods in a database when stocking goods, and to write the ID and status as purchased in the database when the goods are sold. This can discriminate the reentry of goods into a store from shoplifting. Furthermore, when people enter the store with goods purchased in other stores, the store system can recognize that the goods were not sold in that particular store. However, if the current equipment is not upgraded and the ID is not stored when stocking goods, alarms will continue to occur when the customers enter a store with goods purchased at other stores. In other words, coexistence among existing equipment is a problem that must be addressed.

### 3.2 Problem of privacy

As powerful sponsors of the Auto-ID center, Wal-Mart and Benetton responded quickly to concerns about privacy. If the tags are affixed to all goods and their functions continue to work outside the store, then anyone with a reader can obtain information about those goods. The retailers had to treat this not as a simple technical issue, but as a social issue with significant ramifications regarding customer satisfaction. Currently, the focus of introducing RFID is on increasing the efficiency for retailers or manufacturers. The main obstacle to this system is expected to be the issue of the invasion of customers’ privacy. If this system does not readily provide significant advantages to the customers, they are unlikely to accept it.

There are several proposals for privacy protection. One of them is to use the Kill command feature proposed by the Auto-ID Center. Each tag has a unique password, and when it receives the password, the tag erases itself. This function is useful in protecting the customer’s privacy, but it raises some further problems. On the other hand, the encryption described previously will give tags and readers a certain degree of security. While there are several proposed encryption schemes, none is a complete solution. Some of them allow tag output to include relatively constant information, need to rewrite data to the tag memory to avoid tracking, or require a conscious decision by the user.

For active tags, these restrictions are not as strict as for passive tags. For example, the active tag in car keys used for wirelessly locking and unlocking the doors from a short distance uses the code hopping technique. Anyhow, the privacy issue is not simply technical but has a human side. Solving it completely will take a considerable amount of time.

## 4. High-functionality tag

Because passive tags must be put on all products, they must have a short radio range and simple functions to keep the cost low. The cost of a passive tag is currently under $1. Now, let us assume that a tag is affixed to each carton delivered or stocked, rather than each individual product. A tag cost of several hundred dollars would be acceptable if one carton holds a hundred items and the tag is reused ten times. Of course, in this case, it is not possible to trace each product and detect it being shoplifted. However, a tag cost of several hundred dollars allows a battery-powered tag to be used. Then the tag can contain a sensor, function as a reader, or record data to itself. Moreover, the radio range can be extended to approximately one kilometer if a radio license is obtained. This does not involve privacy problems because the tags never come into the hands of customers.

### 4.1 Simple active tag

The transmission range of the RFID tags can be increased by equipping the tag with a battery. This type of tag is known as an active tag. The simplest active tags only transmit the ID periodically and do not have a receiver. Active tags normally have minimal functions to extend the battery life as long as possible. For example, the ID is only transmitted for asset management or for pallet recognition. Therefore, inexpensive sensors that consume very little power can be integrated into a simple active tag. A vibration sensor or a thermal sensor consumes very little power and transmits only one bit of information. The effect on battery life is very slight if they are integrated into simple active tags. **Figure 3** shows an example of a simple active tag whose only function is to transmit its ID [5]. The battery will last approximately five years if it transmits its ID once every seven seconds based on the regulations for low-power radio (500 μV/m at 3 m). Examples of asset tracking using simple active tags will be introduced in the other papers in this issue.

### 4.2 Semi-passive tag

There are many semi-passive tag methods. Simple active tags do not have a receiver function. To compensate for this, one proposal is a tag that has an unpowered receiver and waits until it receives a signal, in the same way that a passive tag does, and then uses onboard battery power to transmit its ID and data. This type of tag could be used to track containers or monitor the air pressure of car tires.

**Figure 4** shows an example of a tag used to track containers. Because the object bearing the tag is a container, the tag does not need to be especially small, so it can have a large battery, which can have a long life. The battery life depends on the transmission duty cycle and the battery size, and this type can last almost five years.

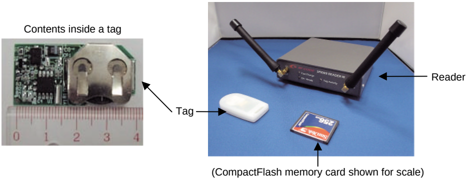


Fig. 3. Simple active tag and reader.

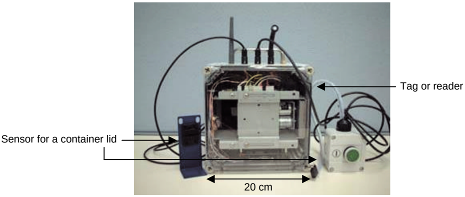


Fig. 4. RFID tag and reader for tracking containers.

### 4.3 Sensor-equipped tag

American car manufacturers may be required to monitor the air pressure in car tires for safety reasons. An analog-to-digital (AD) converter is required to measure the physical value and transmit it. The tag for monitoring air pressure can be constructed using a simple active tag implemented only with an AD converter and a small memory. This configuration decreases the battery life, but the influence on the cost is slight. There is significant demand for such a tag, because it could measure quality during the transportation of foods or valuables and record simple measurements.

### 4.4 Multihop*1 tag

The most widely used wireless communications standard is IEEE 802.11 for wireless LANs, which can communicate over a few hundred meters when there are no obstacles between the terminals. However, this standard has some drawbacks if it is used for RFID.

① High power consumption caused mainly by using high frequencies and aiming for a high data rate rather than a long range.
② High probability of interference because many users already use such frequencies.
③ High cost, which will be hard to decrease, because an expensive microprocessor is required for complex communication methods.
④ Long link connection establishment time necessitated by the advanced OS used.

It is of course possible to use a wireless LAN for RFID tags for applications that require the functions despite the short life or expense. For these reasons, some ideas were proposed to simplify IEEE 802.11 standards. Bluetooth [6] was initially planned to be a very simple protocol. However, as it was changed to accommodate general-purpose use, many functions were added. Its power consumption is becoming much higher than originally planned because of its complex signal processing. Since the number of simultaneously connected terminals is limited, it is not suitable for use with RFID. ZigBee [7] is designed taking these criteria into consideration. It has a less sophisticated operating system, a lower bit rate, and simpler processing. These specifications can accommodate the use of RFID. The Dust system is similarly designed, but its specifications are unique and are not slated for standardization. These techniques are developed based on the use of the 915-MHz band of the ISM (Industry Science Medical) band in the US (ZigBee plans to use 2.45 GHz too). Therefore, these systems cannot be used outside the US. These highly functional tags can establish multihop connections as tags communicate with each other. Because multihop connections can expand the service area, the investment in readers can be decreased compared with simple active tags or passive tags. Naturally, the tag cost is higher, but it is suitable for applications that must work over a large area using a few tags. The Dust system and ZigBee are intended for use as sensor networks.

*1 Multihop: Multiple hopping. Hopping means data transmission from a node to other node.

### 4.5 Infrared tag

The tag function must be “wireless”, but need not use a “radio frequency”. Infrared tags, are inexpensive and free of wires, although they have high power consumption. These tags are effective for applications that require directional transmission and reception. Some examples of promising applications using infrared tags are introduced in the following papers.

## 5. Common techniques among ubiquitous services

As mentioned above, the appropriate function must be selected for each application, and the perfect wireless tag has yet to be developed. **Figure 5** and **Table 1** show functions of RFID. It is necessary for all services to know “when”, “what”, “where”, and “result”. The equipment should consume low power. Since a reader is connected to a network, it can determine “when” by checking the time when it reads a tag. We can easily handle “what” by using a unique ID to each tag. The difficult issues pertain to “where” and “result”.

### 5.1 Position estimation

The global positioning system (GPS) is widely used outdoors as a position estimation tool. It estimates the position from the arrival times of radio signals transmitted from satellites. Its accuracy decreases significantly indoors in principle because the radio signals from satellites are attenuated and reflections from walls or floors have a detrimental effect. To solve this problem, some applications have been developed. MIT’s Cricket [8], [9] and UCLA’s I-badge [10], [11] estimate the position indoors by using the difference in the transmission rate of ultrasonic waves compared with radio waves. These systems are designed for human navigation indoors and

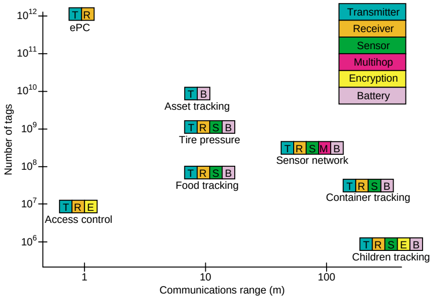


Fig. 5. Wireless tag function for various applications.

Table 1. Features of wireless tags.

| Type of tag | Range | Worldwide use | Encryption | Anti-collision | Multi-hop | Battery life | Receiver | Sensor | Memory | Maker |
|---|---|---|---|---|---|---|---|---|---|---|
| ePC Class 0 (13.56 MHz) | <1 m | Yes | × | △ | × | ∞ | Yes | None | None | Phillips |
| ePC Class 0 (915 MHz) | <10 m | No | △ | ○ | × | ∞ | Yes | None | Yes | Matrics |
| ePC Class 1 (915 MHz) | <10 m | No | × | △ | × | ∞ | Yes | None | None | Alien |
| ePC Class 2 (2.45 GHz) | <1 m | Yes | ○ | ○ | × | ∞ | Yes | None | None | Alien |
| ePC Class 3 | <30 m | No | ○ | ○ | × | <3 years | Yes | Yes | Yes | Unknown |
| ePC Class 4 | <30 m | No | ○ | ○ | × | <few months | Yes | Yes | Yes | Unknown |
| ePC Class 5 | <30 m | No | ○ | ○ | ○ | <few months | Yes | Tag reader | Yes | Unknown |
| Smart Dust | <300 m | No | △ | ○ | ○ | <2 years | Yes | Temp/light | Yes | Dust |
| Zig Bee | <75 m | Yes*/no | △ | ○ | △ | <2 years | Yes | None | Yes | Many |
| Bluetooth | <100 m | Yes | △ | △ | ○ | <half year | Yes | none | Yes | Many |
| IC card | <10 cm | Yes | ◎ | NA | NA | ∞ | Yes | None | Yes | Many |
| µ-Chip | <10 cm | Yes | × | × | × | ∞ | Yes | None | None | Hitachi |
| Simple active tag | <30 m | No | × | × | × | <10 years | None | Motion | None | Many |
| Tire pressure monitor | <30 m | No | × | × | × | <3 years | Yes | Pressure/temp | None | Many |
| Food Tracking | <30 m | No | × | × | × | <few months | Yes | Temp/motion | Yes | Many |
| Infrared | <10 m | Yes | × | △ | × | <few months | Yes | None | None | Many |
| Bar code | <10 cm | Yes | × | × | × | ∞ | None | None | None | Many |

* ZigBee defines three frequency bands: 2.45-GHz band is worldwide, 800-and 900-MHz bands are for Europe and the USA, respectively.

Green rows are our predictions.

Bluetooth usually is used for embedded devices. There are few cases of use for active tags.

have a high data rate connection between a terminal and a network. It is difficult to obtain information on goods by using their tags because the battery life is very short. We have developed an indoor position estimation system for objects that incorporate long-life tags. Details are given in the following papers.

## 5.2 Incorporating sensors

It is necessary to incorporate a sensor in the tag or reader to learn the “result”. It is very effective, especially for physical distribution management, to incorporate a sensor and a memory in a tag so that it can know the history of the object. In this case the sensor power consumption is strongly limited, just as with radio components. Currently, temperature sensors, light sensors, and vibration sensors run on relatively little power, and they can be integrated into a wireless tag.

## 6. Future work

We are focusing development on an active RFID that incorporates high functionality. Currently, we are developing a system using commercial active RFID, but we plan to construct a single-chip tag to achieve low cost and long battery life. We also plan to develop a tag that enables position estimation with an error of only a few centimeters using ultrasound and has a battery life of over five years.

## 7. Conclusion

There are various types of RFID and it is necessary to select a type of tag that is best suited for a particular purpose. We have developed some applications using active tags that have high functionality and the value of these functions may increase in the future. These applications are introduced in the following papers.

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