

ACTIVE TAG ZOO

- Deva Seetharam and Richard Fletcher

INTRODUCTION

Active RFID has been gaining popularity over the last few years due to its performance benefits. Although active RFID is a relatively old technology (Mario W. Cardullo claims to have received the first U.S. patent for an active RFID tag in 1973 [1]), it has been overshadowed by its popular cousin – passive RFID. Passive RFID technology has been the primary candidate for tagging of cases and items, where the cost of tags is critical. However, for tagging containers or valuable assets, active RFID tags are better suited. For many such applications, the population of tags is usually constant and the cost of the reader infrastructure represents the lion's portion of the deployment cost. In this case, the active tag system may be less expensive than the passive tag system since the cost of an active RFID reader can be 10X – 20X less than a comparable passive tag reader.

Active RFID technology offers several performance benefits as well. Unlike passive tags or semi-passive tags, active RFID tags do not employ backscatter mechanism for communication to the reader, and are thus less susceptible to environmental factors and poor electromagnetic propagation. The increased sophistication of the active RFID tag IC also provides for greatly increased reading range, increased security, increased resistance to interference, and increased functionality, such as sensors or radio-location. Due to these powerful characteristics, active RFID can be used in a wide variety of applications such as sensor networks, mobile payment, prisoner tracking and asset tracking [2].

Active tags are generally defined as radio transponders with an onboard power source and transmitter. Given this loose definition, several wireless technologies have emerged to serve the need for medium range identification, tracking and sensing. In addition to various proprietary protocols, several international standards now exist, including IEEE 802.11 Wi-Fi, ISO 18000-7, IEEE 802.15.4 and UWB. In this article, we explore several emerging wireless standards that are candidates for active RFID tagging. We also present an active RFID platform we have developed and a sample application implemented on that platform.

COMPARISON OF SHORT-RANGE WIRELESS TECHNOLOGIES

Due to the recent advances in CMOS fabrication technologies, it has become possible to manufacture advanced microcontrollers and RF communication ICs at very low cost. More significantly, the availability of low-cost devices has led to the development of several short-range (< 100m) wireless communication standards. In particular, the following international standards are suitable for building active RFID systems:

1. ISO 18000-7
2. IEEE 802.15.3 (or UWB)
3. IEEE 802.11 (or WLAN)
4. IEEE 802.15.4 (or WPAN)

One might observe that Bluetooth, arguably the most popular short-range wireless networking, is not included in this list. We didn't include Bluetooth because we believe its network structure may not be suitable for building active RFID systems. That is, as per the Bluetooth specification [3], communicating devices are organized in master-slave networks called "Piconets". Each Piconet can have at most one master and seven slaves. Consider two possible Bluetooth active RFID architectures:

1. Reader is the master – this would mean only maximum of seven slaves (tags) can communicate with a reader at any time. Although parked-slave mode would allow

more than seven tags, this mode would induce unwarranted complexity and latency in the system.

2. Tag is the master – depending on the application, there would be undesirably large number of masters (tags) talking to a small number of slaves (readers). Many masters in close proximity could lead to severe network collisions and poor network performance.

Since neither of these architectures is attractive, we don't consider Bluetooth as a viable technology for active RFID.

In the following sections, we present the relative merits and de-merits of the above-mentioned four standards¹.

ISO 18000-7

The ISO 18000-7 standard [4] is based on the Savi active RFID protocol, which was the first commercial active RFID system employed by the US military in the early 1990's. The 18000-7 standard operates primarily in the 433 MHz frequency band.

Advantages

- This standard was specifically designed for RFID systems.
- Since the operating frequency is 433 MHz, this technology has no problems in co-existing with any of the popular wireless technologies such as Bluetooth, WLAN, cordless phones and microwave ovens.
- Based on international frequency regulations, 433 MHz offers the broadest acceptance for Active RFID [8].
- Good propagation characteristics in crowded environments as signals can move around obstructions by means of diffraction.
- Long communication range – approximately 100 m [9].
- Low power operation – approximately 20 mW [9].

Disadvantages

- Compliance with this standard involves the use of four related patents. Although the patent holders are willing to negotiate licensing, the terms are not readily available.
- No specific support for dense reader mode (multiple readers operating in close vicinity).
- No built-in support for reader-to-reader communications.
- Susceptible to interference since narrowband signals are used.
- No built-in support for security mechanisms such as encryption or authentication.
- Relatively low data rate – approximately 28 Kbps.

IEEE 802.11

IEEE 802.11 [5] is a set of Wireless Local Area Network (WLAN) standards developed by the IEEE LAN/MAN Standards Committee. (PanGo Networks [12] has developed 802.11 based active RFID systems.)

Advantages

- The cost of chipsets is falling since there is intense competition among vendors due to the popularity of this technology.
- Since the standards committee is active, the technology is continuously improved.
- Existing routers and access points can be easily modified to act as RFID readers.
- Provides robust security mechanisms.

¹ It is important to understand that power consumption and communication range values can vary with design and operating conditions. The presented values are only approximate indications.

- Highly resilient to noise and interference since the technology employs spread spectrum signals.
- Long communication range – approximately 100 m.

Disadvantages

- High power consumption – approximately 300 mW for 802.11 b [10]. This is an important issue for battery-powered tags.
- Can interfere with the existing 802.11 networks. This can be a major issue if the number of tags is large. It will be an issue even if the amount of information transmitted by tags is small because even a small packet (unit of transmission) can affect large WLAN packets.
- Designed as wireless Ethernet technology and is meant for high data rate applications.
- Operating frequency is crowded with many other wireless technologies such as Bluetooth, microwave oven, 2.4 GHz cordless phones, etc.

IEEE 802.15.3

Most commonly known as Ultra-Wide Band, IEEE 802.15.3 [6] is a set of high-data-rate Wireless Personal Area Network (WPAN) standards proposed by the IEEE LAN/MAN Standards Committee. Parco (Merged Media [13] is one of the leading providers of UWB RFID technology.)

Advantages

- Good resistance to interference due to the nature (narrow pulses spread over a wide spectrum) of signals.
- Positions of tags can be precisely measured using the time of arrival of signals.
- Relatively low power operation – approximately 150 mW [10]. This feature makes it highly suitable for battery-powered tags.

Disadvantages

- The standard has not been ratified yet².
- Very new technology. UWB RFICs are not yet available.
- Not accepted by frequency regulations in most parts of the world.
- Designed primarily to support extremely high-data-rate WIMEDIA applications.
- Relatively short communication range – approximately 30 m.

IEEE 802.15.4

The IEEE 802.15.4 [7] standard is a low-power low data-rate protocol that forms the MAC and Physical layers of Zigbee protocol stack [14]. (TagSense [15] has developed IEEE 802.15.4 based active RFID systems.)

Advantages

- Very low power consumption – approximately 15 mW. Makes it ideal for battery-powered tags.
- Defined in three different frequency bands – 868 MHz, 902 MHz and 2400 MHz. It can be deployed in most parts of the world.
- Appropriate data rate – 250 Kbps. Designed specifically for low data-rate embedded networks.
- Ratified and active standard.
- Built-in support for security mechanisms.
- Support for reader-to-reader communications can be easily added using Zigbee.
- Highly resilient to interference and noise since it employs spread spectrum signals.

Disadvantages

² In fact, IEEE 802.15.3 group has been dissolved since differences between members of the committee couldn't be resolved [11].

- Operating frequency bands are crowded with many wireless technologies such as Bluetooth, microwave oven, WLAN, cordless phones, etc.
- Tag positioning cannot be precise since the computation is based on received signal strength.

Based on this comparative analysis, we found that IEEE 802.15.4 could be the most suitable platform for building an active RFID platform for a wide variety of applications since it provides an appropriate data rate (250 Kbps) and communication range (> 50 m) at right cost (~ \$3 per RFIC) and power consumption (~ 15 mW).

SYSTEM IMPLEMENTATION

Figures 1 through 4 present IEEE 802.15.4 based active RFID tags and readers developed by TagSense Inc. Here is a brief description of these figures:

- Figure 1 - ZT-100 active tag designed for large pallets and containers. It can transmit 300,000 messages using 2 low-cost AA alkaline batteries.
- Figure 2 - ZT-10 miniature active tag. It can transmit 35,000 messages using one low-cost CR-2032 lithium battery.
- Figure 3 - ZR-HUB Wi-Fi enabled reader. It can act as a data hub and a link to Wi-Fi networks. It also includes a programmable integrated processor that can perform RFID filtering and data processing.
- Figure 4 - ZR-USB compact RFID reader. It can transfer tag data over USB interface to any computing device. A single USB cable is used for data transmission and power.

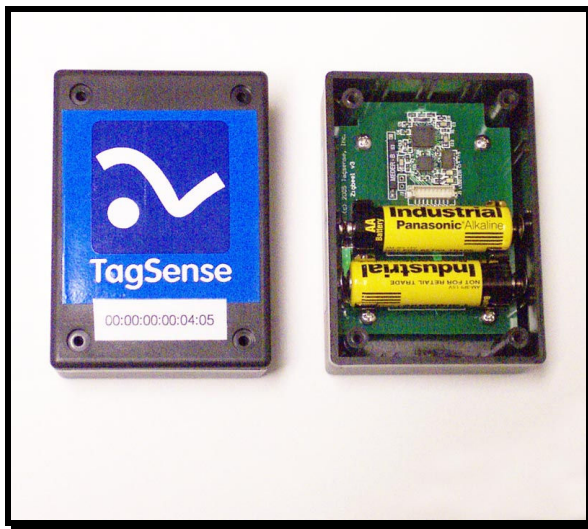


Figure 1 – ZT-100

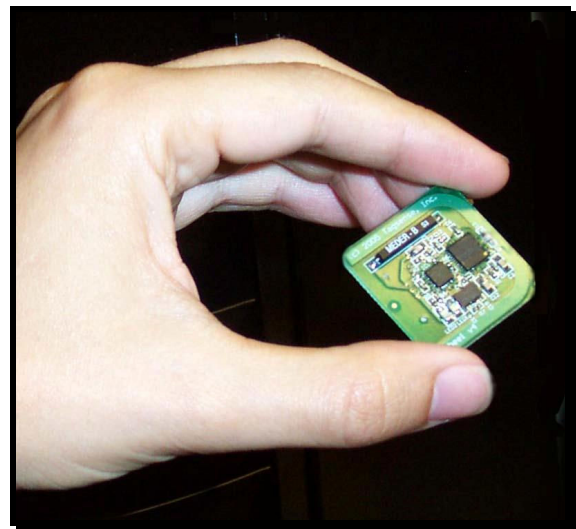


Figure 2 – ZT-10



Figure 3 – ZR-HUB

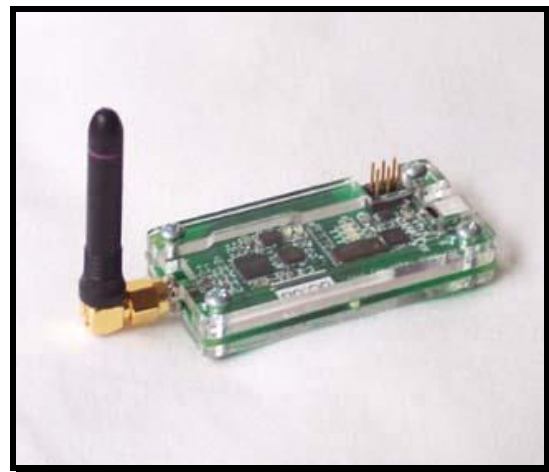


Figure 4 – ZR-USB

SAMPLE APPLICATION

To explore real-life usage scenarios of this active RFID platform, we developed a Pallet Locating and Tracking System (PLATS) and deployed it to analyze a magazine supply chain³. Active RFID systems are suitable for pallet tracking applications for the following reasons:

1. Huge facilities can be covered using a few relatively inexpensive active readers.
2. Many businesses require large pallets (with contents that absorb RF waves) to be tracked. Moreover, these pallets are usually stacked one over the other. Given these harsh operating conditions, passive tags may not work.

The PLATS system identifies supply chain inefficiencies by measuring the following parameters:

³ It is important to note that PLATS can be used with all types of supply chain applications, not only magazine pallets.

- **Pallet processing delay** – This parameter signifies the amount of time a pallet is kept waiting at the consigner’s loading docks after that pallet has been prepared. It can be computed as follows: *actual pallet dispatch time – pallet creation time*.
- **Pallet dispatch delay** – This parameter signifies the shipping delay caused by the consigner and/or the delay induced by trucking companies in picking up the pallets from consigner site. It can be computed as follows: *actual pallet dispatch time – estimated dispatch time*.
- **Pallet transportation delay** – This parameter signifies the delay caused by the trucking companies due to road conditions and/or sub-optimal delivery schedules. It can be computed as follows: *(actual arrival time – actual dispatch time) – (estimated arrival time – estimated dispatch time)*.

The terms used in the above equations are defined as follows:

- Pallet creation time – the time at which a pallet is shrink-wrapped and made ready for shipping at the consigner site.
- Estimated pallet dispatch time – the time at which a pallet is expected to leave the consigner site.
- Actual pallet dispatch time - the time at which a pallet actually leaves the consigner site.
- Estimated pallet arrival time – the time at which a pallet is expected to reach the consignee site.
- Actual pallet arrival time – the time at which a pallet actually reaches the consignee site.

These parameters can be observed and presented using three subsystems that form PLATS:

1. Consigner site subsystem
2. Consignee site subsystem
3. Central server

These subsystems are explained below.

For this illustration, it is assumed that estimated pallet dispatch and arrival times can be computed from historical data. On the other hand, the creation, actual dispatch and arrival times must be determined for every pallet, and are measured using active RFID devices.

CONSIGNER SITE SUBSYSTEM

The consigner site subsystem has the following three components:

1. Tag programming station - As shown in **Error! Reference source not found.**, the programming station is a PC with a touch screen and a special RFID reader. It is used to associate tags and pallets in the system.

The tag ID (read by the reader) and the pallet number (must be entered using the touch screen) are transmitted to a central server to create the association between that tag and the pallet. Once a tag and a pallet are associated, the pallet can be tracked by reading the associated tag. The time at which a tag is associated with a pallet is considered as the *Pallet Creation Time*.

The process of associating a tag and a pallet is called ‘programming’ the tag. Programmed tags must be attached to the corresponding pallets.



Figure 5 - Tag programming station

2. Loading dock readers - The tagged pallets are kept in the loading docks and the readers in the docks read them until the pallets are loaded onto trucks. The latest time at which all readers stop reading a specific tag is considered to be the *Actual Dispatch Time* of the associated pallet.

When the trucks are ready, the pallets are loaded onto trucks to be transported to different consignee sites.

3. Hub - The hub aggregates data from multiple readers and propagates it to the central server over Internet.

The architecture of consigner-site subsystem is shown in Figure 6.

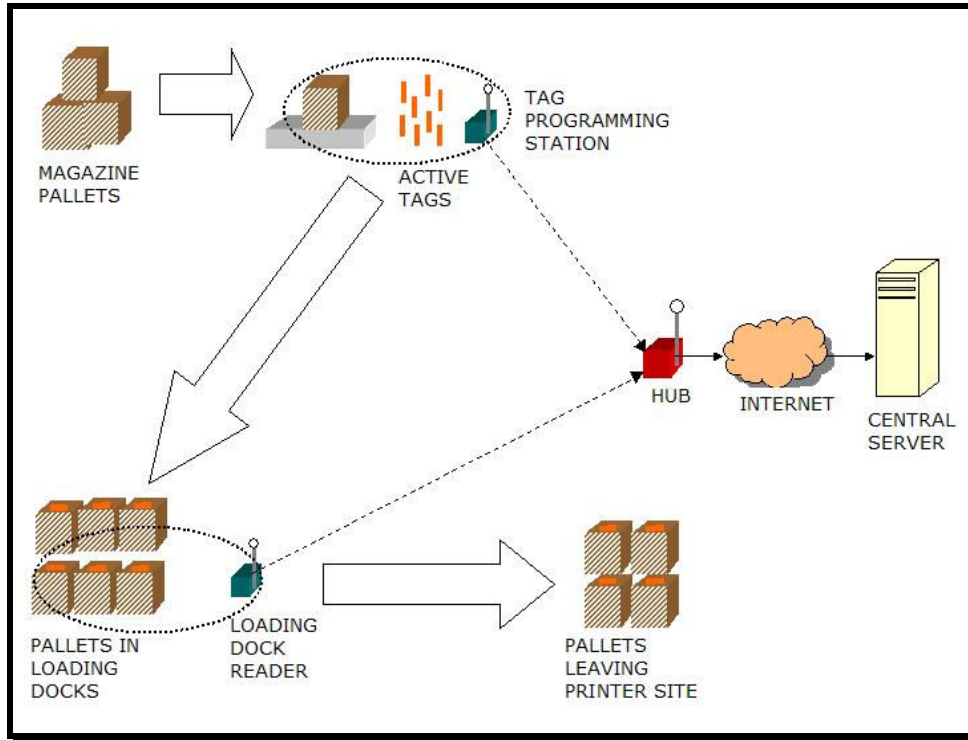


Figure 6 - Consigner site system architecture

CONSIGNEE SITE SUBSYSTEM

The consignee site contains the following two components:

1. **Receiving area readers** - As shown in Figure 7, tagged pallets arrive at the receiving area of consignee's facilities. The RFID readers in these areas can read tagged pallets when they arrive. The earliest time at which any reader (at the consignee site) reads a tag is considered to be the *Actual Arrival Time* of the associated pallet.
2. **Hub** - Similar to the hub in consigner sites, the hub at the consignee sites aggregates data from readers and propagates it to the central server.

The system architecture of consignee site subsystem is shown in Figure 7.

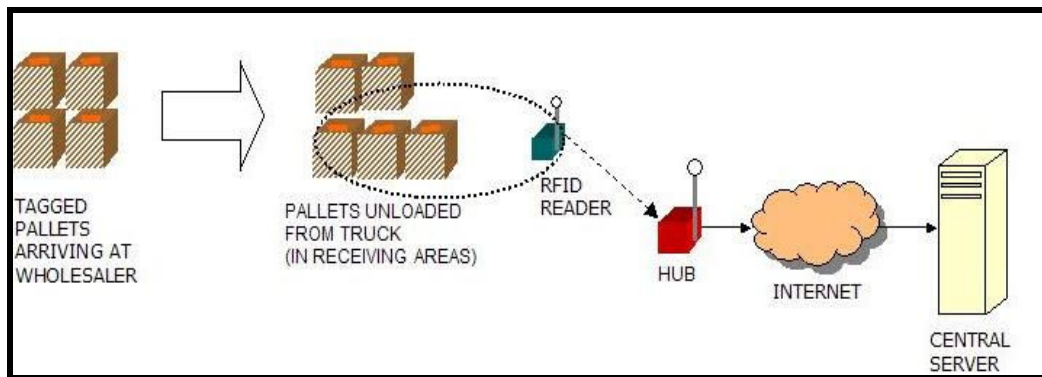


Figure 7 - Consignee site system architecture

CENTRAL SERVER

The central server contains the following two components:

1. **Application server** – it performs data collection and analysis.
2. **Web server** – it presents a web interface to pallet tracking and location information. In addition it presents sophisticated statistical data and tools.

SYSTEM PERFORMANCE

This PLATS system has been running for the past 5 months at 3 sites. The system has performed well – 99.5% read rate and excellent battery life. Figure 8 presents a plot of trip duration versus number of trips (a trip is defined as one shipment transportation from a consigner to a consignee). Obviously, the number of trips decreases as the duration of trips increases.

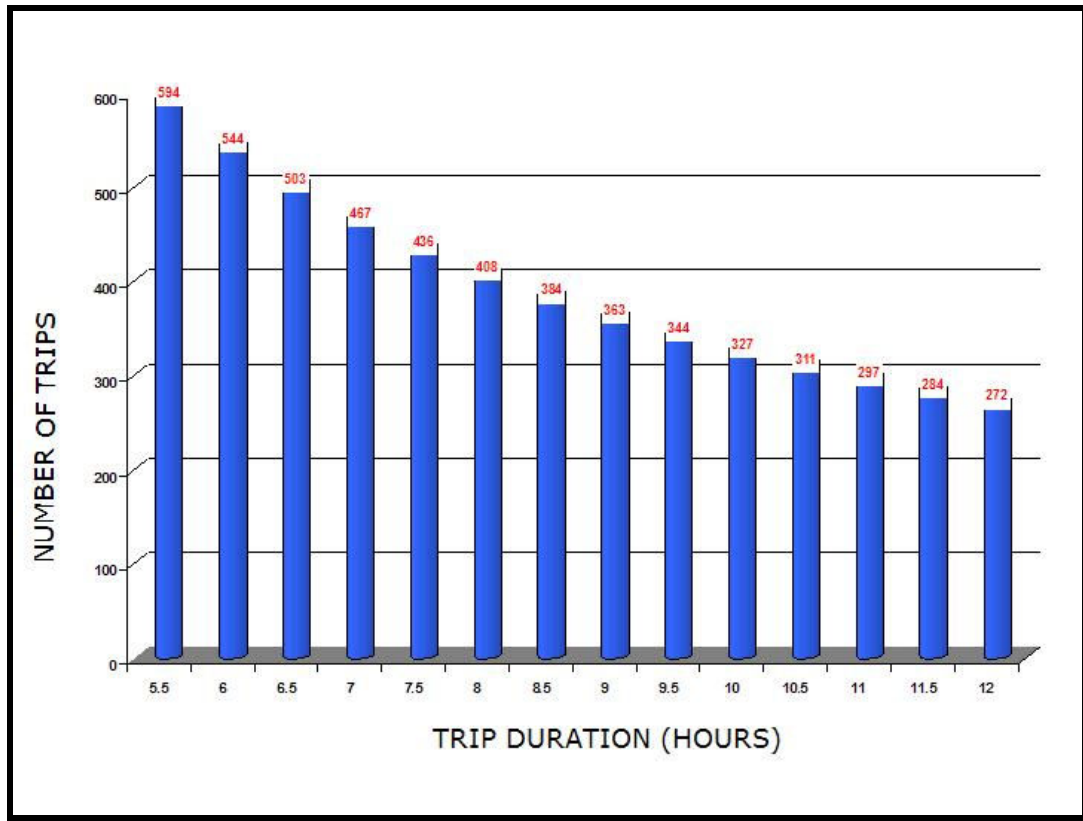


Figure 8 - Trip Duration vs. Number of Trips

The deployed PLATS system has collected extensive data⁴ about the operation and performance of the magazine supply chain. This data has given useful in understanding our customer's magazine supply chain. For instance, we could collect the following useful information:

- Location of pallets - the facility at which each pallet is currently stored and the number of pallets at each facility.
- Processing delay statistics – delays induced at the consigner site and at the consignee site, transportation delays, average delays, seasonal variations etc.
- Processing delay predictions – based on the above statistics, we could predict the delay that could be caused by weather conditions, transportation companies, number of scheduled issues and so forth.

⁴ Due to the confidential nature of data, it cannot be published.

CONCLUSIONS

As demonstrated in the magazine supply chain application, IEEE 802.15.4 based RFID platform could be efficient, economical and reliable. We also find that this platform could be used for a wide variety of applications because of the following features offered by IEEE 802.15.4 protocol:

- Can support both response and beacon types of active RFID systems
- Bi-directional communication between readers and tags
- Potential for tag-to-tag communications
- Eight transmission power levels from 0 dbm to –25 dbm
- Built-in security suite
- Tag controlled anti-collision scheme
- Zigbee ready for interconnecting readers into mesh networks
- Dense reader mode can be easily implemented using CSMA
- Appropriate data rate (250 Kbps)
- Low cost devices
- Low power consumption
- Long communication range

In fact, we are currently designing a prisoner tracking and a construction supply chain management using our IEEE 802.15.4 based active RFID platform.

About TagSense

TagSense Inc. is a RFID research and development firm that works with the gamut of RFID technologies – chipless, passive, semi passive and active RFID. Using these technologies, we have developed solutions for a number of organizations including NASA, USPS, Motorola, MasterCard, and Atmel.

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