WHITE PAPER SERIES / EDITION 1

AUTO-ID LABS

BUSINESS PROCESSES & APPLICATIONS
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AUTOIDLABS-WP-SWNET-011

Standardization Requirements within the RFID Class Structure Framework

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Abstract

We identify those functional elements within a radio frequency identification (RFID) tag that must be standardized to enable functionality to be added to tags in a timely and standardized manner. As RFID systems become ubiquitous and used in a plethora of distinct applications, the functionality that may be contained within an individual tag will be varied. Access to this varied functionality must be performed in a standardized manner. Standardization must occur at all levels of functionality to enable the proliferation of functionality that will be demanded by the marketplace, effectively allowing for a standard approach to vendor specific functionality. The RFID Class Structure defined by the Auto-ID Center provides the framework for discussing and developing RFID protocol standards that cover a broad spectrum of functionality. Standards within this framework provide the base functionality that enables vendors to add market demanded functionality in a timely manner while remaining standards compliant. We review the RFID Class Structure and identify those functional elements that must be standardized within each class of the framework to enable a proliferation of vendor proprietary functionality in a standardized manner.

1. Introduction

Radio frequency identification (RFID) systems must achieve a large degree of standardization in order to achieve ubiquitous, or near ubiquitous, deployment. Only through standardization will economies of scale be realized to enable low-cost RFID tags and readers. With the arrival of these low-cost systems, extreme large scale deployments of RFID systems will be enabled across all industries and all application domains.

As RFID systems find greater acceptance throughout business, military, and other uses, the base functionality provided within the lowest possible cost tags will prove to be insufficient for some applications. Those applications that can afford higher cost RFID tags and have a demonstrated need for some functionality beyond a simple object identifier, will cause a proliferation in the tag functionality available in the marketplace. This functionality must be managed and contained within a standardized framework while simultaneously allowing for innovation and product differentiation.

The Auto-ID Center defined an RFID Class Structure [2] to provide a framework for the discussion and development of RFID tag functionality. This framework reflects the philosophy of the Auto-ID Center that there exists a hierarchy of tag functionalities, and that those hierarchies must build upon one another in a ubiquitous standardized system. This framework forms the foundation for the development of RFID standards within EPCglobal, Inc. providing broad guidelines on how to think about the tag functionality. However, the framework does not provide specific guidance on what features or functional elements need to be standardized within each class in the hierarchy.

In this paper, we identify the minimal set of functional elements that must be standardized in an air-interface protocol within each class of the framework and argue that these are the only elements

that need to be standardized. Our philosophy is one of minimalism in the actual standardized functionality of the protocol while providing the maximum flexibility for vendor specific functionality. This approach does require additional supporting standards such as those that exist for the EPC System and a data standard for how data is stored and what data is stored within the tag's memory. We identify the need for these standards, and recommend what they should specify, at the appropriate points within this document.
We begin our exposition of minimal standardized functionality by reviewing the RFID Class Structure defined by the Auto-ID Center. Then, each class within the framework is examined in detail. Within each class, the minimal set of functional elements that must be standardized are identified and discussed. We finish with the relevant conclusions and summary of the minimal required standardized features.

2. The RFID Class Structure

The RFID Class Structure [2] depicted in Figure 1 provides a framework to classify tags according to their primary functional characteristics. The RFID Class Structure classifies tags as belonging to one of five classes: Class 1 (Identity Tags), Class 2 (Higher Functionality Tags), Class 3 (Semi- Passive Tags), Class 4 (Active Ad Hoc Tags), or Class 5 (Reader Tags). Each successive class within this framework builds upon, i.e., is a superset of the functionality contained within, the previous class, resulting in a layered functional classification structure as depicted in Figure 1.
Class 1 forms the foundation of this framework. The Class 1 Identity Tag is designed to be the lowest cost, minimal usable functionality tag classification. Identity Tags are pure passive RFID tags

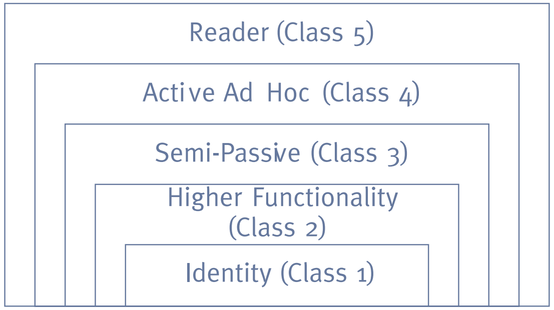

Fig. 1: Auto-ID Center RFID Class Structure – Layered Hierarchy

that are expected to implement a resource discovery mechanism and store a unique object identifier only. The signaling and modulation defined for Class 1 tags is the foundation for all passive communication within this hierarchy. Class 2 Higher Functionality Tags build upon the Identity Tag by providing more functionality, such as a tag identifier and read/write memory, while still maintaining a pure passive power and communication scheme. Class 3 Semi-Passive Tags add an on-tag power source, such as a battery, to their Higher Functionality foundation. Semi-Passive Tags combine passive communication with an on-tag power source that enables a tag to operate without the presence of a passive tag reader (i.e., a Class 5 Reader Tag). Class 4 Active Ad-Hoc Tags encompass the Class 3 Semi-Passive Tags and, in addition, are ad-hoc networking devices that are capable of communicating with other Class 4 tags using active communication and with Class 5 Reader Tags using both passive and active communication. Class 5 Reader Tags encompass the functionality of a Class 4 Active Ad-Hoc Tag and, in addition, are able to power and communicate with pure passive Class 1 and Class 2 tags and communicate with Class 3 tags via passive communication.

The RFID Class Structure, in addition to providing a classification for the tag functionalities, requires that tags compliant with the Structure implement at least the functionality of a Class 1 Identity Tag. This requires that Class 3, Class 4, and Class 5 tags be able to harvest energy and communicate as if they were pure passive Class 1 or Class 2 tags (although potentially at lower operating range). Energy harvesting is required even when an on-tag power source is present for three primary reasons:

- energy harvesting does not drain the power storage device
- tags may operate, potentially with limited functionality, even when the tag's powered functionality is in a "deep sleep" or "hibernation" mode, and
- the tag will communicate within normal pure passive communication range thereby limiting the long range communication pollution that might otherwise occur.

By requiring that tags be able to communicate in at least a pure passive Identity tag fashion, battery powered tags may be identified without utilizing any battery power. And, when a battery is exhausted, the tag is still able to be identified, and possibly function, albeit at lower functional and performance capabilities.

Ultimately, standards will define what functionality is actually required to be compliant with a specific class of tags. For Class 1 tags, the standard defines all of the tags functionality. For Class 2 and higher tags, the standards can only specify a subset of the possible on-tag functionality since the range of possible functionality is limited only by the designer's imagination and the customer's ability to pay for it. Therefore, the standards, in addition to inheriting functionality from lower class standards, must be flexible to enable new functionality to be added in a timely, market driven fashion.

In the following sections, we examine each class in more detail, and we identify the minimal set of those features that must be standardized within each class of the RFID Class Structure to enable a minimal amount of standardized functionality that simultaneously enables maximum implemented functionality flexibility.

3. Class 1: The Identity Tag Functionality

The Class 1 Identity Tag protocol forms the foundation of the RFID Class Structure. As the foundation, the Identity Tag protocol is designed to provide the minimum functionality required to be usable for the lowest-cost item-level identification applications. Taking a network oriented view of this functionality [1], the standard(s) that specifies(y) the Class 1 functionality define(s) the physical layer and a portion of the data link layer, and it/they must further define the minimum data content, memory layout, and resource discovery mechanisms. The standardized commands to access all of this functionality must be mandatory.

Optional functionality does not exist in a Class 1 standard, since optional functionality, by definition, is not required to be usable for the lowest cost item level identification applications. Therefore, optional functionality properly belongs in a Class 2 standard specification. In addition, since Class 1 forms the foundation of all functionality, readers and systems rely upon the Class 1 capabilities implemented by all tags. Many applications simply do not have sufficient time to determine from each tag what functionality is implemented and what is not. This is particularly true if the optional functionality affects a reader's ability to discover, or read the object identifier, from each tag or the communication rates that the tags may optionally implement. The reader is limited in its discovery rate, or tag identification rate, by the slowest mandatory discovery and communication functionality.

A Class 1 standard contains a bare minimum of functionality beyond the discovery functionality since all additional functionality adds cost and complexity to the tag.

Each network layer for the Class 1 Identity Tag will have specific functionality that must be standardized. The physical (PHY) layer standard functionality defines how the reader communicates to the tag and how the tag communicates to the reader using passive communication. The physical layer features include the signaling, modulation, and encoding of symbols. The physical layer must be amenable to long range passive communications since the Class 3 tags will be able to communicate at an order of magnitude longer range than can the Class 1 tags. And, the Class 3 tags will communicate using the same physical layer as do the Class 2 and Class 1 tags. The Class 1 standard protocol need not define all of the physical layer functionality that may exist for all classes utilizing passive communication; however, it must be designed such that physical layer extensions that are added within higher class standards work seamlessly with the physical layer functionality defined in the Class 1 Identity Tag protocol.

The data link (DATA) layer forms the base logic layer of the class structure. The data link layer standard defines how communications are logically grouped, or packetized, the commands that the reader may issue to the tag, the tag's response to any commands, when and how a tag may initiate communication or functionality without being commanded by the reader, and the resource discovery, i.e., tag identification, algorithm. In packetized communication, framing symbols, or punctuation, exist to delineate the beginning, the end, and the important features within the communication. The punctuation must be amenable to communication across a broad range of noise environments, reader densities, and communication ranges including long range Class 3 passive communications.

The information content and commands contained within the packetized communication are standardized within the data link layer. The actual commands defined in the Class 1 standard should provide the minimum functionality required to achieve high performance identification rates but provide no more functionality than is absolutely required. The commands and packetized communication must be forward compatible with the higher class commands. The resource discovery functionality is the only functionality that should be standardized in the data link layer of a Class 1 protocol standard.

The PHY and base DATA layers form the foundation for passive communication with all higher functionality and higher class tags.

As the lowest cost tag, the Class 1 tag has a minimum amount of memory. The lowest cost Class 1 tag logically utilizes two distinct memory banks: System memory and Object Identifier (OID) memory. System memory is the location where system operating parameters and controlled parameters, such as passwords, are stored. System memory cannot be accessed by memory addressed commands, such as *Read* and *Write*. Instead, System memory is accessed either by the tag directly during its operations or commanded to access specific parameters by a specific command, e.g., *WritePassword*. The minimum size of the System memory is determined by the number and storage requirements of required parameters, such as passwords, stored in System memory. The actual size of System memory is dependent upon the implementation of the tag.

The Object Identifier (OID) memory stores the identifier for the object to which the tag is affixed, plus additional data that may be used during resource discovery. A practical implementation would have the Object Identifier memory storing three distinct values:

Protocol Control Parameter (PCP) bits, Cyclic Redundancy Check (CRC), and Object Identifier, e.g., Electronic Product Code (EPC). The PCP bits are designed to store information on the characteristics of and/or the use of the tagged object. The PCP bits will be able to store at least the ISO Application Family Identifiers (AFIs). The CRC is an error detection code designed to protect the communication of the Object Identifier.

The CRC is calculated over the Object Identifier. A minimum of a 16-bit CRC should be used to minimize the number of errors that may go undetected by the reader when it receives the object identifier and CRC communication from the tag. A 16-bit CRC detects 99.998% of all possible errors that may be experienced in the communication of the Object Identifier [3].

Table I summarizes the minimum required standard functionality for a Class 1 protocol.

	Class 1 Maximum Functionality
Physical Layer	Base Passive Communication Signaling Coding Modulation Symbol Waveforms and Timings
Data Link Layer	Base Communication Packet Commands and Responses Reader-Talk-First or Tag-Talk-First Identity Discovery Algorithm
Memory Required	System Memory Object Identifier Memory (PCP, CRC, OID)

Table 1: The functionality that must be standardized within class 1 protocols

2.1.4 Class 2: Higher Functionality Tag Functionality

The Class 2 Higher Functionality Tag protocol builds upon the functionality defined in the Class 1 Standard. Additional physical layer standards should not be necessary since a properly designed Class 1 standard will define a physical layer that is usable for all Class 2 tags. Thus, all additional functionality for Class 2 tags is added in the data link layer and above.

There exists a large array of possible functionality that may be implemented within a pure passive RFID tag. Advances in silicon design and manufacturing will increase the possible implementable functionality, and new problems will demand that previously overlooked or never before imagined functionality be implemented within a pure passive RFID tag. It is impractical to standardize each of these possible functions individually.

Additional functionality must be added in a manner that enables product differentiation and innovation without having to go through a standards process. Standards processes are always overly long in duration, and they limit a companies ability to meet market demands or create new functionality that increases demand for their products. Therefore, a small set of functionality must be added such that this functionality enables innovation and product differentiation in a standardized manner. In this way, the standardized functionality in a Class 2 Higher Functionality Tag is minimized, yet vendor specific functionality may be added in a manner that precludes interference or confusion between tags from different vendors.

Since nearly all of the possible functionality will be optional in a Class 2 tag, there must be a mechanism to determine what functionality is actually implemented on a specific tag.

	Class 2 Functionality Beyond Class 1
Physical Layer	None
Data Link Layer	General Packet for Communication Read and Write Commands
Memory Required	Tag Identifier Memory (PCP, CRC, OID)

Table 2: The Functionality beyond Class 1 that must be standardized within class 2 protocols.

To this end, utilizing the EPC concept, a Tag Identifier, e.g., an EPC, stored in a Tag Identifier (TID) memory, will be used to identify the tag. The Tag Identifier should be used as a pointer to information about that tag including what functionality is currently implemented on that tag. To simplify the search for Class 2 and higher class tags, the resource discovery mechanisms used to retrieve the Object Identifier should also be usable to retrieve the TID memory contents. Similar to the OID memory, the TID memory contents should consist of PCP bits, a CRC calculated over the Tag Identifier, and the Tag Identifier.

The Tag Identifier identifies the tag and is used to determine what functionality is implemented on the tag. Accessing proprietary functionality in a standardized manner may be performed in one of two ways: either memory mapped functionality or packetized communication. Memory mapped functionality maps specific memory locations in User Memory to specific functions, either retrieving data or executing those functions. The standard commands required to access memory are *Read* and *Write*. No other commands need to be standardized or implemented to access memory mapped functionality.

Packetized communication utilizes a network oriented approach to accessing on-tag functionality [1]. A communication packet encapsulates a message in a standardized *wrapper*. This wrapper typically contains the identity of the packet source, the identity of the packet destination, the message being communicated, error detection codes, and any additional information that must be included to enable that packet to reach its destination. In [1] a series of packet formats are suggested for packetized communication from a reader to a tag. For RFID systems, the packet commands encapsulate the vendor specific commands accessing on-tag functionality. Thus, functionality is accessed in a standardized fashion similar to how data is communicated over the Internet using TCP/IP communication packets. Table 2 summarizes the required standard functionality for a Class 2 protocol that goes beyond that required for a Class 1 protocol.

5. Class 3: Semi-Passive Tag Functionality

The Class 3 Semi-Passive Tag builds upon the functionality defined in the Class 2 Standard. The primary additional system component found on a Class 3 tag but not a Class 2 tag is an on-tag power source, such as a battery. The two primary purposes for this power source are the increase in passive communication range as compared to a pure passive Class 1 or Class 2 tag and to enable on-tag functionality, such as a temperature sensor, while the tag is not being powered by a reader.

	Class 3 Functionality Beyond Class 2
Physical Layer	Wake-Up Signaling
Data Link Layer	None
Memory Required	None

Table 3: The Functionality beyond Class 2 that must be standardized within Class 3 protocols

To maximize the life span of this power source, an ultra low power "deep sleep" mode must be implemented. A new command, most likely in the form of a special signal emitted by the reader (a new physical layer function), must be standardized to tell the tag to begin using its battery for communication. Conversely, a new command to put Class 3 tags in their ultra low power mode should be standardized, but is not required to be standardized.

The Class 3 Semi-Passive Tag builds upon the functionality defined in the Class 2 Standard for all additional functionality. By building upon the Class 1 and Class 2 foundation, a Class 3 tag, when its battery fails, will be able to harvest energy and communicate with readers as if it were simply a pure passive Class 2 tag. This graceful failure enables a common reader to retrieve information from the tag without the need for special equipment. And, when in a "deep sleep" mode, the tag may be identified and communicate with a reader without using, and possibly recharging, its battery.

Table 3 summarizes the required standard functionality for a Class 3 protocol that goes beyond that required for a Class 2 protocol.

6. Class 4: Active Ad Hoc Tag Functionality

The Class 4 Active Ad hoc Tag protocol builds upon the Class 3 Standard for its passive communication capabilities, but the Class 4 Active Ad hoc Tag standard defines a new active communication standard. The active communication standard is expected to be a relatively low-bandwidth ad hoc wireless communication standard. Higher bandwidth wireless connections are possible, but these are typically used for high speed high bandwidth computer-to-computer communications.

The hierarchical nature of the Auto-ID Class Structure requires that a Class 4 compliant tag, in addition to implementing the active communication standard, implements the Class 3 and lower class passive communication standards. In this way, a Class 4 tag is able to harvest energy from and communicate with a pure passive reader, and, thereby, maintains a graceful failure path for the loss of its on-tag power.

	Class 4 Functionality Beyond Class 3
Physical Layer	Active ad hoc Communication
Data Link Layer	Active ad hoc Communication Algorithm
Memory Required	None

Table 4: The functionality beyound class 3 that must be standardized within Class 4 protocols

Table 4 summarizes the required standard functionality for a Class 4 protocol that goes beyond that required for a Class 3 protocol.

7. Class 5: Reader Functionality

The Class 5 Reader Tag is a tag capable of initiating passive communication and powering passive RFID tags with its communication signal, i.e., a passive tag reader. A Class 5 Reader standard, since it builds upon the Class 4 tag standards, is able to communicate with Class 4 and other Class 5 tags using active ad hoc communication as well as all other tags using passive tag communication—either initiating the "reader" communication or passively responding to another Class 5 tag. The only additional functionality that a Class 5 tag has over a Class 4 tag is the ability to initiate passive communication with all classes of tags.

A Class 5 Reader, unlike all other tags, may have a connection to a back-end network. In essence, a Class 5 Reader may act like a wireless access point for lower class tags.

Table 5 summarizes the required standard functionality for a Class 5 protocol that goes beyond that required for a Class 4 protocol.

	Class 5 Functionality Beyond Class 4
Physical Layer	High Power Reader Portion of the Communication
Data Link Layer	Reader Portion of the Communication
Memory Required	None

Table 5: The functionality beyond class 4 that must be standardized within class 5 protocols.

8. Summary

The Auto-ID Center's RFID Class Structure that we defined previously provides a framework for the standardization of RFID tag functionality. The original Structure did not prescribe what functionality should be contained within the protocol standard for each Class. In this document, we have exposed our thinking and designs for the protocol standards that we envision existing for each class of tag. The general design philosophy is one of minimal standardized functionality with maximum flexibility for vendor specific functionality. By standardizing how functionality is accessed, vendors may add product differentiating and market demanded functionality without adversely affecting the performance of tags from other vendors.

The standard for a Class 1 Identity Tag forms the foundation for all of the higher functionality tags. The physical layer communication defined in this standard is the basis for all passive communication used in all of the standards for all of the classes. The Class 1 tag contains two key features an Object Identifier (OID) memory block and a resource discovery protocol (an anti-collision algorithm) that returns the contents of the OID. The standard for a Class 2 Higher Functionality Tag builds upon the Class 1 standard by creating a standardized approach to adding vendor specific functionality. In addition to containing all of the required features of a Class 1 tag, a Class 2 compliant tag contains a Tag Identifier (TID) memory block and optional User (USER) memory block. Communication with a Class 2 tag that accesses proprietary commands occurs either through *Read* and *Write* commands or through a packetized communication mechanism. A Class 3 Semi-Passive Tag standard builds upon the Class 2 standard by adding a *Power On* command to enable long-range communication. At close range, a Class 3 compliant tag will operate as a pure passive Class 2 tag drawing all of its communication and base operating power from the reader's communication signal. A Class 4 Active Ad hoc Tag standard encompasses the Class 3 standard and exceeds it by standardizing active ad-hoc networking functionality. A Class 5 Reader standard encompasses the Class 4 standard and adds the ability to initiate passive communication. Combined, the Structure's Classes provide a framework for thinking about standards within a range of functionalities and prescribe a series of standards that build upon one another for the complete range of tag functionalities. Table VI summarizes the base functionality that must be standardized within each class of the framework.

	Physical Layer (new functionality)
Class 1	Base Passive Communication
Class 2	None
Class 3	Wake Up Signaling
Class 4	Active Ad hoc Communication
Class 5	Initiate Passive Communication
	Data Link Layer+ (new functionality)
Class 1	Identity Discovery Algorithm
Class 2	Memory Access Packetized Communication
Class 3	None
Class 4	Active Ad hoc Communication Algorithms
Class 5	Reader Communication
	Memory Required (new functionality)
Class 1	System Memory Object Identifier Memory
Class 2	Tag Identifier Memory
Class 3	None
Class 4	None
Class 5	None

Table 6: The base functionality that must be standardized within each class

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