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STANDARDS FOR PASSIVE UHF RFID

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Passive ultra-high frequency (UHF) radio frequency identification (RFID) technology has been widely adopted by retail and other industries for serialized item-level identification and data sharing.

This article introduces the standards that support and define all procedures in various passive UHF RFID applications. Electronic Product Code (EPC) Radio-Frequency Identity Protocols Generation-2 UHF RFID Standard, or C1G2, is a foundational standard that defines the format, encoding, and procedures within the air interfaces of RFID systems. Low Level Reader Protocol provides a standard and portable interface between different applications and RFID readers from different vendors. The format and encoding of the EPC information are defined by the EPC Tag Data Standard, which enables each tag to be uniquely identified (e.g., item-level identity of many goods in a warehouse). Additional protocols, such as Discovery, Configuration and Initialization and Reader Management, specify and clarify more processes (e.g., the management of many readers) that can be deployed in various business applications. We provide a general introduction of passive UHF RFID technology standards and review each protocol's features and procedures.

Over the last decade, radio-frequency identification (RFID) technology, especially passive ultra-high frequency (UHF) RFID, has been widely deployed by retailers to provide serialized, item-level identification (ID) and data sharing in their supply chain [1]. Due to RFID technology's ability to dramatically cut costs and increase data capabilities, it has been adopted beyond retail into other industries. For example, RFID is suitable for precise indoor localization and tracking applications [2], and it shows promise as a pervasive sensor and data carrier. Despite its increasing attention in the industrial world and in academic communities, a foundational and systematic overview of the underlying protocols of passive UHF RFID technology is lacking. To overcome this gap, this article introduces all important protocols,

from the very bottom physic layer to the application layer, which enable the passive UHF RFID technology. Hereafter, the terms passive UHF RFID and RFID will be used interchangeably. Note, however, that RFID technology includes low frequency, high frequency, and ultra-high frequency systems, and an RFID system can be classified as a passive, semi-passive, or an active system.

A typical RFID application includes (a) one or more readers, (b) RFID tags affixed to items, (c) a host computer, and (d) one or more software programs. Essentially, an RFID reader frequently sends continuous waves (CW) to interrogate and energize tags. Then, tags send back their unique identifier, such as an Electronic Product Code (EPC), through backscattering and modulating the incident CW. The reader provides an interface for applications to report unique

IDs and other observations from tags, such as received signal strength indicator, phase, timestamp, and others. Dedicated protocols need to be established to enable and regulate this large data stream. Figure 1 illustrates a high-level overview of these protocols (green boxes) in typical RFID-based business support systems and similar applications. First, the EPC Radio-Frequency Identity Protocols Generation-2 UHF (C1G2) RFID standard defines the physical and logical requirements for an RFID system (including readers and tags) and operates in the 860–960 MHz UHF range. Second, Low-Level Reader Protocol (LLRP) provides an interface between the RFID reader and host computer. Additionally, Discovery Configuration and Initialization (DCI) and Reader Management (RM) protocols, discussed later, provide standards for control and data exchange among a variety of business applications. Furthermore, the Tag Data Standard (TDS) provides unique IDs for each item, the most critical feature of RFID technology. These standards can be categorized into three groups: RFID air interfaces, RFID software interface, and identification standard.

RFID AIR INTERFACES

EPC Radio-Frequency Identity Protocols Generation-2 UHF RFID Standard [3], also known as Class-1 Generation-2 (or C1G2) RFID standards, is the cornerstone for all RFID systems. It was first published in 2004 by EPCglobal, and the latest version, Release 2.1, was published in July 2018. In 2006, the C1G2 standard was approved by the International Standards Organization (ISO) and published as ISO 18000-6C standard, which defines physical and logical requirements for a passive-backscatter, interrogator-talks-first (ITF) RFID system operating in the 860–960 MHz frequency range.

The C1G2 standard comprises two layers: a physical layer that defines signaling interactions between reader and tag, and a tag identification layer that defines the logical operating commands and procedures between reader and tag.

The physical layer of C1G2 protocol defines the interface between a reader and tag and is the “signaling layer” in a layered network communication system. It regulates frequencies, modulation, data coding, RF envelope, data rates, and other parameters required for RF communications. Briefly, there are three foundational characteristics of RF communication: signal/information encoding, modulation, and anti-collision protocols. Communication between reader and tag is half-duplex, meaning the reader “talks” while the tag “listens” (downlink), or vice versa (uplink). During downlink, a reader sends data to one or more tags through modulating RF signal. Additionally, C1G2 protocol regulates if a reader modulates the signal by double-sideband amplitude shift keying (DSB-ASK), single-sideband amplitude shift keying (SSB-ASK),

or phase-reversal amplitude shift keying (PR-ASK) using a pulse-interval encoding (PIE) format, as illustrated in Figure 2a. PIE determines the way a message is encoded during downlink: a short, high-level pulse followed by a short, low-level pulse (length of which is noted with PW in Fig. 2a indicates a binary ‘0’. A binary ‘1’ is coded as a long high pulse followed by a short, low pulse of length PW.

During communication via uplink, tags transmit information by backscatter-modulating the CW transmitted by a reader. Here, C1G2 defines the encoding format that can be either FM0 or the Miller-modulated subcarrier for tags [4], and use the same modulation methods in downlink communication, such as DSB-ASK, SSB-ASK, or PR-ASK.

Another critical consideration at the physical layer is an anti-collision protocol. Usually, there are multiple tags, often thousands, within the detectable range of a reader. If two or more tags respond simultaneously, the reader cannot communicate with either of them due to signal collision. Therefore, an effective protocol that prevents tag collisions during inventory counts is necessary in many operations. C1G2 protocol deploys a derivative of slotted ALOHA, also known as Q-protocol, Q algorithm, or adaptive Q algorithm, that modifies the behavior of tag accessing. Different from the standard allotted ALOHA where a node can access the channel in any upcoming time slot and possibly cause signal collision, a CIG2

node’s channel access is controlled by magic number, Q , to prevent collision; hence, “Q-protocol.” The basic scheme of Q-protocol is as follows [5]:

- a reader selects a number, Q , that specifies the number of slots in an inventory round;
- the reader initiates the inventory by sending a *Query* command that contains several parameters, including Q , to control tag populations that will participate in the subsequent inventory;
- each tag creates a random number between 0 to $(2^Q - 1)$ that specifies a time slot at which each tag will respond to the reader;
- the tag sends its EPC if the reader can decipher the number and acknowledges it; and,
- the reader may read from or write to the tag’s memory and perform other operations unique to the tag.

Therefore, a complete set of 2^Q slots constitute one inventory round, and the Q-protocol timing of channel access is illustrated in Figure 3.

Tag-identification layer defines tag memory, flags, states, and three basic ways for a reader to manage tag populations:

- Select:** The process of a reader selecting one or more tags for subsequent operation, such as inventorying and accessing selected tag(s). The reader can select tags based on a value or values in its memory.

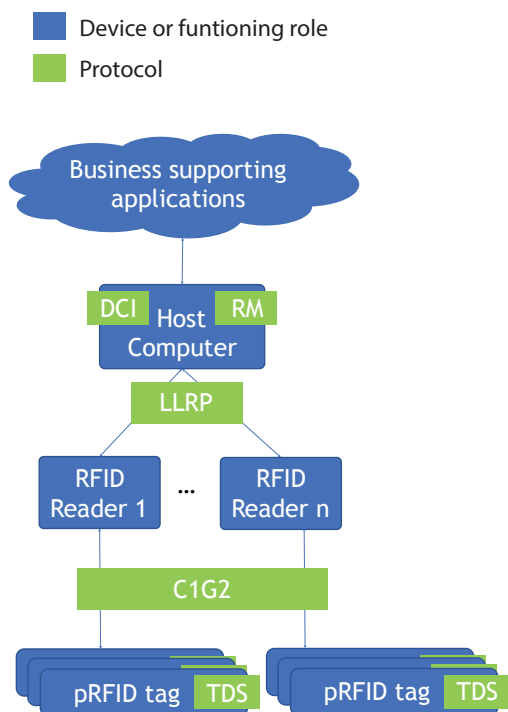


FIGURE 1. High-level overview of various protocols in the data stream of a passive UHF RFID-based system.

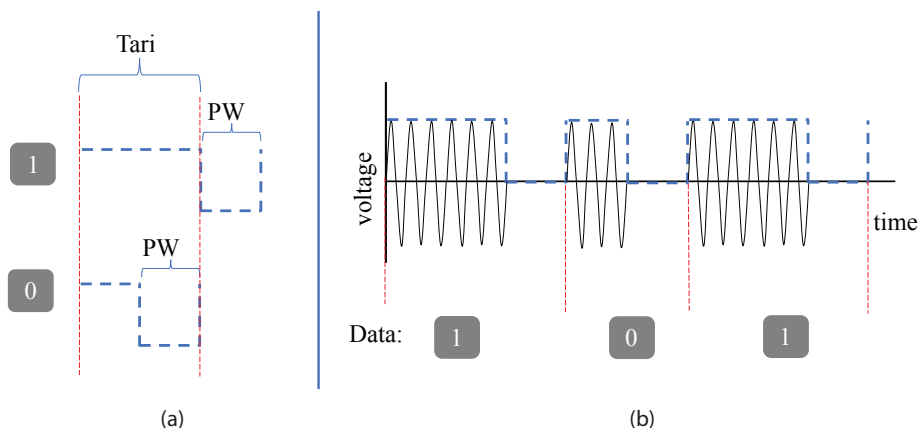


FIGURE 2. (a) PIE binary encoding format using high- and low-level pulses (blue dotted line), a pre-specified low pulse width (PW), and a Type A Reference Interval (Tari); (b) PIE binary encoding with amplitude shift keying modulation of a carrier wave.

b. Inventory: In most application scenarios, RFID tags are treated as unique identities of physical objects, as is the case with serialized item-level identification in supply chain management. In those scenarios, the reader identifies (or queries EPC data from) tags in a process called inventory operation. An inventory operation comprises multiple commands, and the reader starts the process by sending a Query command. Then, one or more tags may reply. When the reader detects a single tag's reply, it interrogates that tag for EPC and other related data.

c. Access: In some applications, the reader needs to read, write, authenticate, or otherwise engage with an individual tag. For example, tags may store extra information (e.g., expired date) in their user memory that the reader needs to collect. The access operation enables the reader to communicate with individual tags and perform operations, such as reading, authenticating, writing, locking, or killing a tag.

RFID SOFTWARE INTERFACES

The primary goal of the development and implementation of RFID technology is to improve the efficiency of business operations, especially for supply chain management. To this end, GS1 [6] developed and published several standards, outlined below, to define the interfaces that enable data exchange between various business applications and services.

A: Low-Level Reader Protocol (LLRP)

LLRP [7] provides interfaces between application software (client) and readers. It composes about 100 standard commands that enable full control over low-level functionality across multiple readers that may have been obtained from different vendors, thus greatly improving the portability of RFID systems. LLRP also supports vendor-specific commands, meaning different vendors can offer services beyond the standard commands that function within the existing architecture of an RFID system. LLRP controls the operation time and access parameters within an RFID air protocol, like C1G2. LLRP works within the application layer and defines the format and procedure of communication between a client and one or more readers that contain. It usually contains a fail-safe

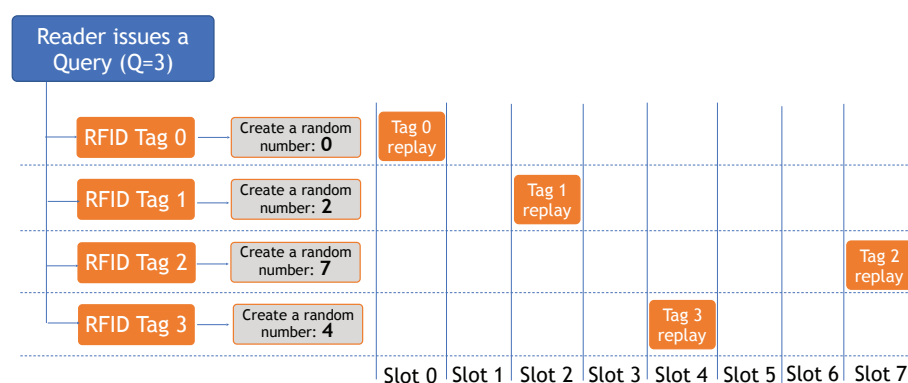


FIGURE 3. The timing of channel access by RFID tags in the Q-protocol.

mechanism to cope with network error situations. The main features of LLRP include:

- Enables application software to command readers to inventory tags, read data from tags, write data to tags, and execute other operations (e.g., “kill” or “lock” tags).
- Offers a robust method for readers to report status and coordinate with application software when handling errors occur during tag access operations.
- Provides a means for clients to manage downlink and uplink operations by controlling RF power levels and spectrum utilization.
- Supports the retrieval capabilities of various readers, and, subsequently helps clients operate all readers with the correct parameters.
- Helps clients coordinate multiple readers to work together; for example, it mitigates RF interference when multiple readers are deployed.
- Facilitates the management of readers to mitigate Reader-to-Tag and Reader-to-Reader interference and maximize operations efficiency over the entire tag population.
- Supports new RFID air protocols in the future.

B: Discovery, Configuration and Initialization (DCI)

Usually, there are multiple readers and clients in a typical RFID system; thus, it is highly demanding for readers and clients to discover and authenticate each other. To this end, EPCglobal developed and published the DCI standard [8] to define the procedures for a reader discovering one or more clients,

WE PROVIDE AN INTRODUCTION OF PASSIVE UHF RFID TECHNOLOGY STANDARDS AND REVIEW EACH PROTOCOL'S FEATURES AND PROCEDURES

for the client discovering one or more readers, and for a reader downloading firmware. DCI protocol also specifies the required and optional operations of a reader and client that allow them to exchange configuration information and initialize operations. The client can control the reader by operations protocols, like LLRP. During implementation, a virtual device called an *Access Controller* is deployed in the RFID system to perform DCI functions. Figure 4 illustrates the relationships among the reader, client, access controller, and other network services in an RFID system.

C: Reader Management (RM)

The RM standard [9] provides interfaces used by management software to monitor the operating status and health of EPCglobal-compliant readers. RM standards define two separate but related management protocol specifications, the EPCglobal Simple Network Management Protocol Management Information Base and the EPCglobal Reader Management Protocol.

IDENTIFICATION STANDARD

Almost every RFID application depends on a tag's unique ID as represented by the stored EPC. An EPC is a universal identifier for physical objects and is intended for use in business applications for tracking various items. In most applications, RFID tags serve as the data carriers of EPCs. Hence, TDS [10] defines EPC and the way they are encoded. EPC TDS also specifies the data carried on a C1G2 RFID tag, including the EPC, user memory data, control information, and tag manufacture information. There are two forms of EPC data as defined by the TDS:

- One as a Internet Uniform Resource Identifier (URI) for user-friendly applications, such as electronic documents, databases, and messages, that can be easily understood by a human user. For example, a URI-based EPC would look like “urn:epc:id:sgt in:0614141.112345.400”.
- The second is a compact binary representation, or EPC Binary Encoding, which is designed to facilitate EPC data storage in a memory-limited RFID tag.

TDS standards specify which way to transfer EPC data, given the two forms, and define the correspondences between EPC and other GS1 keys, as defined in GS1 General Specifications (e.g., GTIN, SGTIN, GIAI, GRAI, etc.) [11]. Figure 5 illustrates the main components of TDS and how they fit together.

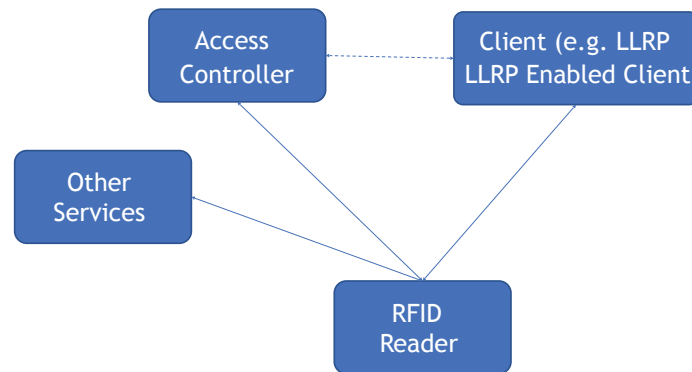
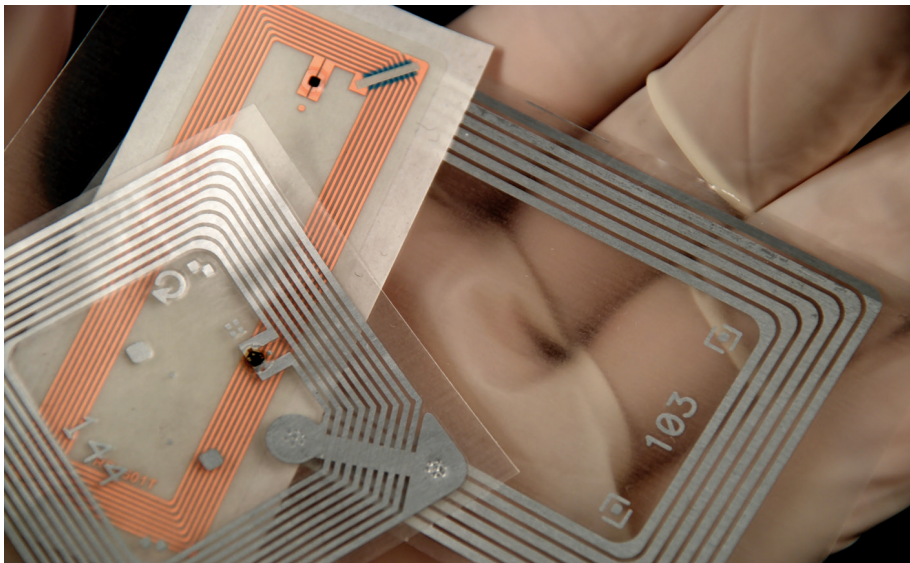


FIGURE 4. The relationship of an Access Controller (DCI services), the client, and a reader in an RFID system. Here, other services include, but are not limited to, the services defined in Reader Management (RM) protocol.

As shown in Figure 5, TDS defines the method that converts EPC data in URI form to binary encoding form, and vice versa. First, TDS determines the format and presentation of EPC in business software, known as pure identity EPC URI, which focuses on providing a preferred way to denote a physical object in a business context. Second, TDS specifies the means to translate the pure identity EPC URI into the EPC Tag URI format and encodes the pure identity with additional RFID control information that can guide subsequent tag data capture events. Then, EPC Tag URI information is encoded into a compressed binary form and stored into the EPC memory bank of a C1G2 RFID tag. The

process of reading EPC from a tag and converting it to URI format follows the above procedure, but in reverse order.

FUTURE TRENDS

RFID technology has been the foremost method for low-cost and ubiquitous tag sensing over the last decade. Early explorations of this technology have included integrating a passive UHF RFID tag with an extra sensor, with the tag serving as the power and communication channel for the sensor. Recently, increasingly more studies have focused on deploying a commodity tag that provides various types of ambient environment information. For example, these tags can provide precise positioning information and track slowly moving objects in an indoor environment [12], or can sense the ambient temperature [13].

With the growing interest in this technology, RFID sensing systems will continue to be developed for various applications, and it is imperative that standards be developed to regulate the format and procedures of RFID-based sensors. Interfaces between the client, sensor tags, and readers need to be standardized so that RFID sensing can maintain compatibility within a variety of applications. Additionally, standard interfaces between tags and extra sensors are needed to regulate the process of data exchange, power supply, etc., and, thus, enable different sensors to integrate with RFID tags.

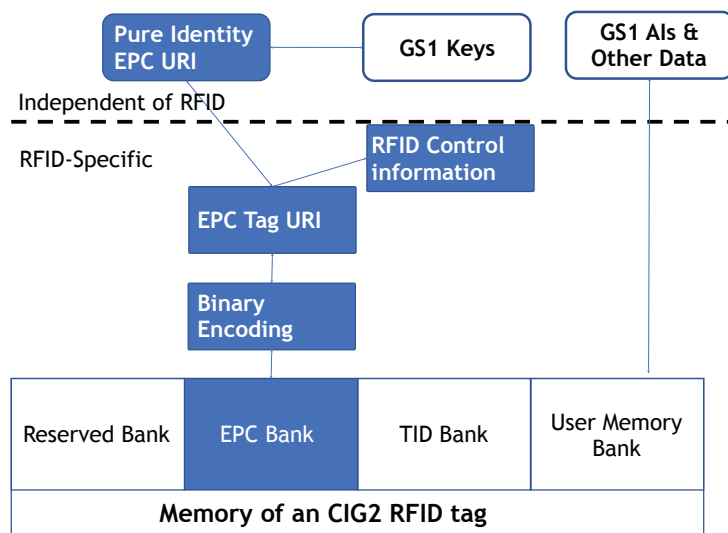


FIGURE 5. Components of the TDS standard. Here, GS1 AIs stands for GS1 Application Identifiers (AIs), which are prefixes used in RFID tags and barcodes to define the method and format of data attributes.

CONCLUSION

This article presents an overview of the existing standards that have enabled passive UHF RFID technology's acceptance and deployment in various industries. Standards, such as TDS, CIG2, and LLRP, support the entire data stream within a typical business application. RFID technology applications are rapidly evolving, especially regarding its use as a low-cost sensor, and that growth will drive a series of new standards that can inform related procedures and boost novel applications. More research is needed to develop effective and portable standards that meet new demands and are robust in reporting sensor data and combining unique tag IDs. ■

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