Automatic Identification

Building an Internet of Things

What Is Automatic Identification?

- Automatic Identification (Auto-ID)
  - Broad term given to a host of technologies used to help machines identify objects
  - Generally coupled with automatic data capture
    - Want to identify items, capture information about them, and get that information into a computer system
  - Goals include:
    - Increased efficiency
    - Reduced data entry errors
    - Free up staff to perform more value-added functions

What Is Automatic Identification?

- Auto-ID has been around in various forms for decades
  - Bar Codes (e.g. Uniform Product Codes)
  - Optical Character Recognition (OCR)
  - Voice Recognition
  - Radio Frequency Identification (RFID)
  - Biometrics (e.g. Retinal Scans)

What Is Automatic Identification?

- Today, bar code systems are the most prevalent method for identifying items in commercial settings
- Shortcomings of bar codes include:
  - They require line-of-sight
  - Standard UPC bar codes identify only the manufacturer and product, not the unique item

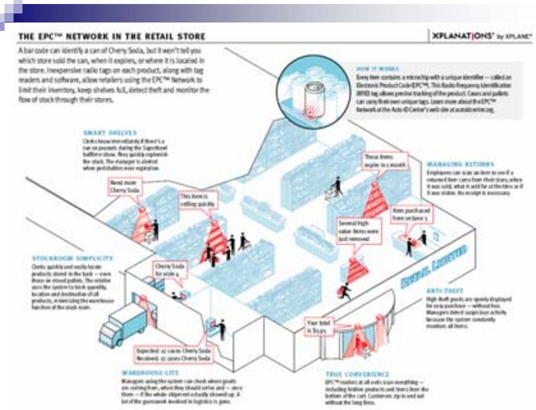
Radio Frequency Identification

- Radio Frequency Identification (RFID) offers the potential to eliminate these shortcomings
  - Identifying objects through RFID does not require line-of-sight
  - A new encoding scheme could be created to allow unique identification of individual objects

The Auto-ID Center

- Founded in 1999 as a unique partnership between ~100 leading global corporations and 5 research universities, led by MIT
  - Formerly the MIT Auto-ID Center
- Purpose: To define the standards and assemble the building blocks needed to create an “Internet of things” – a *open* global network that connects computers to objects

What are some of the potential issues associated with the creation of an “Internet of things”?



The EPC™ Network

- The EPC™ Network is composed of five fundamental elements:
  - Electronic Product Code (EPC™)
  - Identification System (RFID Tags and Readers)
  - Savant™ Middleware
  - Object Name Service (ONS)
  - Physical Mark-Up Language (PML)

Electronic Product Code (EPC™)

- Numerous identification coding standards exist:
  - Universal Product Code (UPC)
  - License Plate Numbers
  - Vehicle Identification Numbers (VIN)
  - Social Security Numbers (SSN)
  - International Standard Book Number (ISBN)
  - IP Addresses
  - MAC Addresses

Electronic Product Code (EPC™)

- In order to uniquely identify physical objects, there must be a sufficient number of codes to accommodate past, present, and future needs

OBJECT	UNIQUE NUMBER	BITS REQUIRED
Automobiles	6.0 x 10^6 per annum	23
Computers	5.6 x 10^8 in use	29
Humans	6.0 x 10^9 total	33
Razor Blades	2.0 x 10^{10} per annum	34
Grains of Rice	1.3 x 10^{16} per annum	54

(Figures as of 2001)

Electronic Product Code (EPC™)

- An EPC™ is comprised of four distinct numbers (partitions):
  - EPC™ Version Number
  - Domain Manager Number
  - Object Class Number
  - Serial Number

Electronic Product Code (EPC™)

- EPC™ Version Number
  - Enables the definition of multiple types (versions) of EPCs™ that differ in total bit length and number of bits in each of the four partitions
  - As of today, seven versions of EPCs™ have been defined

Electronic Product Code (EPC™)

- Domain Manager Number
  - Identifies the domain manager (generally an organization) of a set of EPCs™
    - For example, a particular Domain Manager Number would identify all objects manufactured by *Mary's Cola Company*
  - The domain manager is responsible for the allocation of Object Class Numbers and Serial Numbers for that set of EPCs™

Electronic Product Code (EPC™)

- Object Class Number
  - Identifies the class (category, type, etc.) of object identified by the EPC™
    - For example, a particular combination of Domain Manager Number and Object Class Number will identify all objects manufactured by *Mary's Cola Company* that are *Cherry Cola*
  - Current UPCs consist of a Domain Manager Number and an Object Class Number

Electronic Product Code (EPC™)

- Serial Number
  - Identifies a particular instance of an object
    - For example, a particular combination of Domain Manager Number, Object Class Number, and Serial Number will identify an object that is a *specific* can of *Cherry Cola* made by *Mary's Cola Company*
  - The addition of a Serial Number is what differentiates EPCs™ from UPCs

Electronic Product Code (EPC™)

BIT ALLOCATIONS OF THE SEVEN DEFINED EPC™ VERSIONS

		VERSION NUMBER	DOMAIN MANAGER	OBJECT CLASS	SERIAL NUMBER
EPC-64	TYPE I	2	21	17	24
	TYPE II	2	15	13	34
	TYPE III	2	26	13	23
EPC-96	TYPE I	8	28	24	36
EPC-256	TYPE I	8	32	56	192
	TYPE II	8	64	56	128
	TYPE III	8	128	56	64

Electronic Product Code (EPC™)

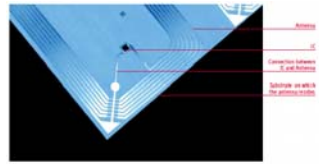
- The 96-bit version (the original EPC™ designed), allows for approximately:
  - 268 million Domain Managers (as compared with 100,000 with UPC)
  - 16 million Object Classes per Domain Manager (as compared with 100,000 with UPC)
  - 68 billion Serial Numbers per Object Class (this yields up to 1.15 x 10^{19} uniquely identified items *per* Domain Manager!)

RFID: The EPC™ Identification System

- EPC™ Networks use RFID tags (transponders) and readers (interrogators) to store and read EPCs™
- In addition to eliminating the shortcomings of bar code identification, radio frequency identification enables a number of novel applications

RFID: The EPC™ Identification System

- Basic RFID tags consist of four components:



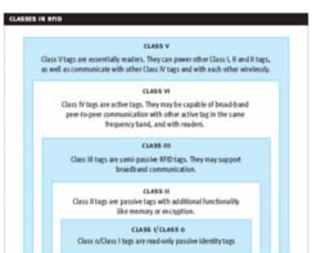
RFID: The EPC™ Identification System

- There are three categories of RFID tags:
  - Active Tags
    - Use a battery to power the circuitry and broadcast a signal
  - Passive Tags
    - Draw power entirely from the reader, which sends out electromagnetic waves that induce a current in the tag's antenna
  - Semi-Active Tags
    - Use a battery to power the circuitry, but communicate by drawing power from the reader

RFID: The EPC™ Identification System

- The primary trade-off between active and passive tags is one of range vs. cost
  - Active RFID tags can broadcast 100 ft. or more, but cost well in excess of $1 each (making them impractical for identifying low-cost items)
  - The range of passive RFID tags is generally < 10 ft., but they are far less expensive than active tags and require no maintenance (i.e. changing battery)
    - Thus, passive tags will be used for most consumer goods, while active/semi-active tags will likely be found further up in the supply chain

RFID: The EPC™ Identification System



RFID: The EPC™ Identification System

- Tags will operate in Class 0 or Class I mode by default
  - This will allow readers to perform identification of all RFID tags without having to search for the correct class
- Tags will be failsafe, in that they will fail to a lower class upon failure of added functionality
  - This ensures that identification can always occur
  - This implies that active tags will fail to semi-passive, while semi-passive tags will fail to passive

RFID: The EPC™ Identification System

- As an example, a Class I tag will contain the following:
  - EPC™
  - Error detection/correction code (specifically, a Cyclic Redundancy Check)
  - Password (used by the `Kill` command)

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RFID: The EPC™ Identification System

- RFID readers generally use inductive coupling to communicate with passive tags
  - The coiled antenna of the reader creates a magnetic field with the coiled antenna of the tag
  - The tag draws energy from this field, which is uses to send back radio waves to the reader containing its message

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RFID: The EPC™ Identification System

- There are two collision-related issues that must be addressed in RFID systems:
  - Reader Collision – Interference caused by an overlap in reader signals
    - Addressed by using time division multiple access (TDMA) to “schedule” readers
  - Tag Collision – Interference caused when more than one tag responds to a signal at the same time
    - One method involves “polling” tags based on their EPC™
    - Others are based on well-known networking anti-collision algorithms such as slotted Aloha

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RFID: The EPC™ Identification System

- Performance metrics traded-off by these algorithms include:
  - Speed at which tags can be read
  - Outgoing bandwidth of reader signal
  - Bandwidth of return (tag) signal
  - Amount of state required to be stored on a tag
  - Tolerance of algorithm to noise
  - Tag cost
  - Reader cost
  - Ability to tolerate tags entering/leaving the field during the inventory-taking process

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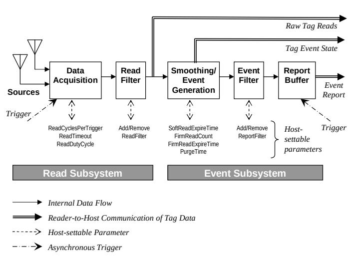
RFID: The EPC™ Identification System



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Savant™ Middleware

- If each object currently using a barcode were to use an EPC™, the infrastructure would have to handle millions of events every second
  - RFID readers will be picking up a continual stream of EPCs™
- In order to reduce network traffic, modular components known as Savants™ will be used to process, filter, and digest events

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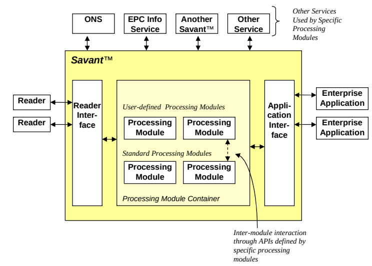
Savant™ Middleware

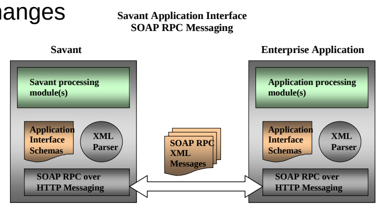
- Since EPC™ is barely in its infancy, as it matures there will be significant innovation and change in what applications do
- To address this, the emphasis in the specification of Savant™ is on extensibility
  - Thus, the Savant™ is defined in terms of *Processing Modules* or *Services*, each of which provides a specific feature and which may be combined in order to meet the needs of a specific application

Savant™ Middleware



Savant™ Middleware

- Interfaces between Savant™ and enterprise applications will be implemented as SOAP RPC exchanges



Savant™ Middleware

- Version 1.0 of the Savant™ Specification defines only two "standard" processing modules:
  - autoid.core (provides identity information)
  - autoid.readerproxy (provides reader information)
- Future versions will define additional processing modules, as well as how processing modules access external services (such as ONS, EPC™ Information Services, and other Savants™)

Object Name Service (ONS)

- Since only the EPC™ is stored on an item's tag, computer systems need a way of matching the EPC™ to information about the item
- ONS is an automated networking service similar to Domain Name Service (DNS) and built over top of the DNS framework
- It is a framework for locating EPC™ Information Services for objects tagged with EPCs™

Object Name Service (ONS)

- Given an EPC™, the ONS framework will return the location of a EPC™ Information Service storing information related to the identified item
- More specifically, it will return either:
  - The IP address of the EPC™ Information Service, at the manufacturer, storing information for the EPC™
  - The IP address of an internal EPC™ Information Service to which information about the EPC™ can be written

Object Name Service (ONS)

- As an example, consider the resolution of the following 96-bit EPC™ using ONS:

01.203D2A.916E8B.8719BAE03C

<Version>.<Domain Manager>.<Object>.<Serial>

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Object Name Service (ONS)

- First, an ONS Pre-Resolver translates the EPC™ into a domain name:

8719BAE03C.916E8B.203D2A.01.epc.objid.net

<Serial>.<Object>.<Domain Manager>.<Version>.<Root Domain>

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Object Name Service (ONS)

- Next, an ONS Resolver performs a DNS lookup based on the specified EPC™ domain name to obtain the server's IP address:

203D2A.01.epc.objid.net → Object ID Root Server

916E8B.203D2A.01.epc.objid.net → Manufacturer Server

8719BAE03C.916E8B.203D2A.01.epc.objid.net → Product Server

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Object Name Service (ONS)

- Finally, the resulting IP address can be used to obtain information about the object from the specified EPC™ Information Service
- With this description in mind, another way of thinking about EPCs™ is as *pointers* to information

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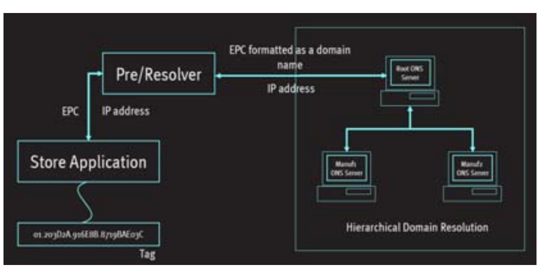
Object Name Service (ONS)



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Object Name Service (ONS)

- ONS will handle vastly many more requests than the current DNS system
- In order to avoid flooding the Internet with unnecessary lookups, organizations will be required to maintain local ONS servers, which will store information for quick retrieval
  - For example, a retailer might store (cache) ONS data from its suppliers locally, rather than performing external lookups for every transaction

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Physical Mark-Up Language (PML)

- Main goal is to provide a common, standardized vocabulary to represent and distribute information related to objects identified by EPCs™
- PML-encoded information will be retrieved from EPC™ Information Services (which are located through the ONS infrastructure)
- PML is based on XML

Physical Mark-Up Language (PML)

- Information described in PML will include:
  - Information directly captured from the EPC™ network, such as:
    - Location information (e.g. tag *X* was detected by reader *Y*, which is located at position *Z*)
    - Telemetry information (e.g. object mass, ambient temperature)
    - Composition information (e.g. the composition of a pallet containing multiple objects)

Physical Mark-Up Language (PML)

  - Information originating outside of the EPC™ Network, such as:
    - Product-related information (e.g. links to instruction manuals or suggested recipes)
    - Process-related information (e.g. a link to a shipping record)
    - Manufacturer-related information (e.g. technical support phone number)

Physical Mark-Up Language (PML)

- The main use of PML is to act as a common interface between the various components of an EPC™ network, including:
  - A Savant™/EPC™ Information Service and an external application
  - Savants™ attached to individual sensors and Savants™ that aggregate information
  - A sensor (such as an RFID reader) and a Savant™

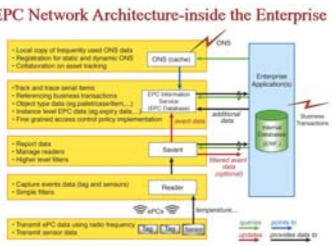
EPC™ Information Services

- EPC™ Information Services (formerly referred to as PML Servers) make EPC™ Network related data available in PML format to requesting services
- EPC™ Information Services will provide both internal and external data

EPC™ Information Services

- Data made available by EPC™ Information Services may include:
  - Tag-read data collected from Savant (for example, to assist with instance-tracking)
  - Instance-level data (for example, date of manufacture, expiry date, etc.)
  - Object class-level data (for example, product catalog information)

The EPC™ Network Architecture



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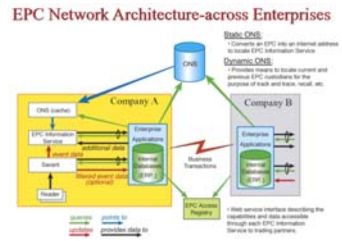
The EPC™ Network Architecture



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The Benefits of Auto-Identification

- Why are organizations rushing to invest in the development of the EPC™ Network?
  - Sponsors of the Auto-ID Center include:
    - Best Buy Corporation
    - Department of Defense
    - Home Depot
    - Kellogg's Corporation
    - Pepsi
    - UPS
    - Wal-Mart Stores Inc.
    - Coca-Cola
    - Gillette
    - Johnson & Johnson
    - Kraft
    - Proctor and Gamble
    - US Postal Service

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The Benefits of Auto-Identification

- The potential benefits to manufacturing companies of Auto-ID are significant:

SUPPLY CHAIN AGILITY	REVENUE GENERATION	COST REDUCTION
– Complete visibility and traceability of products – More responsive production – Reduced order cycle times – Delivery in mixed pallets – Improving forecast accuracy	– Improved On-Shelf Availability – Mass Customization – Frequent new product introductions	– Automated proof of delivery – Improved security of products – Eliminating stock verification – Incorporating shelf life of products – Reducing inventory levels (& warehousing requirements)

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The Benefits of Auto-Identification

- As an example, the following table shows current out-of-stock (OOS) levels as measured in three studies:

STUDY DETAILS	AVERAGE LEVEL	PEAK LEVEL
ANDERSEN CONSULTING, 1996	8.2%	15.0%
ROLAND BERGER, 1999	5.0%	17.5%
ECR FRANCE, 2000	10.9%	15.0%

  - Clearly, improving on-shelf availability of products has clear financial benefits

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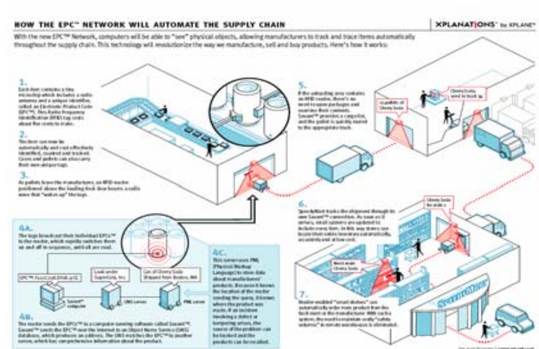

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The Benefits of Auto-Identification

- Kitchens Inc. is a specialty retailer in the U.S. home improvement industry, with annual revenues of $2 billion (US)
  - The company operates 500 stores through 3 distribution centers
- In 2002, Kitchens Inc. implemented *case*-level auto-id at its distribution centers using RFID tags already attached to incoming cases of products by its vendors

The Benefits of Auto-Identification

- Implementation costs were approximately $7.8 million (US) per distribution center
  - This covered hardware, software, and integration costs
- Annual maintenance costs are expected to be approx. $100,000 (US) per year per facility

The Benefits of Auto-Identification

- Kitchens Inc. experienced a 35% improvement in labor productivity and an 88% reduction in vendor and paperwork shrink
  - Vendor and paperwork shrink = loss due to vendor fraud and administrative and paperwork errors
- This translated into annual savings of $16.7 million (US) in labor and $6.9 million (US) in shrink reduction

The Benefits of Auto-Identification

FUNCTION	CURRENT BUDGET	% IMPROVEMENT	NEW BUDGET	SAVINGS
Receiving	$2,599,721	0%	$2,599,721	–
Check-in	$17,017,341	80%	$3,403,468	$13,613,873
Putaway & Replenishment	$15,760,272	15%	$13,396,231	$2,364,041
Order Filling	$10,663,587	7%	$9,920,856	$746,731
Shipping	$1,955,080	0%	$1,955,080	–
TOTAL	$48,000,000	35%	$31,275,356	$16,724,644

AREA	CURRENT EXPENSE	% REDUCTION	NEW EXPENSE	SAVINGS
Administrative & Paperwork	$5,763,000	85%	$864,450	$4,898,550
Vendor	$2,034,000	100%	–	$2,034,000
Employee Theft	$15,255,000	0%	$15,255,000	–
Shoplifting	$10,848,000	0%	$10,848,000	–
TOTAL	$33,900,000	–	$26,967,450	$6,932,550

Case Study: Auto-ID and Retail Theft

- Some characteristics of an EPC™ Network:
  1. Identification does not require line-of-sight
  2. Individual instances of objects can be identified
  3. EPC™ Tags (and the objects they identify) can be monitored in real-time
  4. 2 + 3 allows for instances of objects to be tracked (control maintained on an instance across time)
  5. 2 + 3 also allows for tracing (building a supply chain history for an instance)

Case Study: Auto-ID and Retail Theft

RELEVANT CHARACTERISTICS FOR AN ANTI-THEFT SOLUTION

	RFID	EPC™	ONS	SAVANT™	PML	EPC™ Information Service
No Line-of-Sight Identification	✓					
Identification of Instances		✓				
Real-Time Visibility	✓			✓		
Tracking		✓	✓	✓	✓	✓
Tracing		✓	✓			✓

Case Study: Auto-ID and Retail Theft

- Stage 1: Prediction (Before Theft)
  - RFID combined with Savant™ can recognize patterns in real-time and trigger deterrence measures (when EPCs™ unexpectedly disappear from the network)
  - Effective in combating three significant types of theft:
    - Open pack theft
    - Sweep theft
    - Disabling anti-theft tags

Case Study: Auto-ID and Retail Theft

- Stage 2: Detection (During Theft)
  - Detection requires all components of the EPC™ Network and can combat the following types of theft:
    - Concealment
    - Barcode switch
    - Collusion with employees
    - Intentional undercount during inventory

Case Study: Auto-ID and Retail Theft

- Stage 3: Proof (After Theft)
  - If tags remain active, they can be tracked to their point of origin
  - If tags are deactivated, they lose their "legal identity", and will be considered as counterfeit from then on
    - This hampers both resale of stolen items as well as preventing fraudulent returns/refunds

Where Do Things Stand?

- August, 2003
  - Gillette begins tagging its Mach 3 razors and refill packs with RFID tags
  - Several U.K. retailers begin testing networks to use the technology to combat theft
    - The refill packages, which retail for ~$12 US, are the highest theft item in the U.K.

Where Do Things Stand?

- September, 2003
  - Auto-ID Center publicly releases Version 1.0 Specifications at various stages of completion (ranging from recommendations to working drafts)
    - EPC™
    - RFID Reader Protocol
    - Several RFID Tag Specifications
    - Savant™
    - ONS

Where Do Things Stand?

- October 24, 2003
  - U.S. Department of Defense announces a new policy requiring all of its suppliers to use RFID tags by January 2005
    - If possible, each individual product should be identified by an EPC™, though tagging at the case/pallet level will be a minimum

Where Do Things Stand?

- November 1, 2003
  - Auto-ID Center disbands its current form to be replaced with a joint venture of the Uniform Code Council and EAN International called EPCglobal Inc.
  - MIT to continue independent RFID research through a new organization called Auto-ID Labs

Where Do Things Stand?

- November 7, 2003
  - Wal-Mart announces plans to spend $3 billion over the next several years to upgrade its inventory tracking system to utilize EPC™ Network technology
    - The U.S. launch is set to begin in 2005
  - Analysts have estimated that once complete, the savings due to reduced logistical errors and reduced labor costs could exceed **$8.4 billion** (U.S.) *annually*

RFID: Towards the 5¢ Tag

- The Auto-ID Center's specifications only require that RFID tags carry an EPC™, communicate using an open standard, and meet certain minimum performance requirements - they do not specify *how* those tags should be built
- However, a target cost of 5¢ per tag has been recognized as a requirement for mass-adoption

RFID: Towards the 5¢ Tag

- Today, the cost of a passive RFID tag (~50¢) can be approximately broken down as follows:
  - 20¢ - IC
  - 5¢ - antenna
  - 5¢ - assembly of IC to antenna
  - 5¢ - pre-conversion
  - 10+ ¢ - conversion to substrate and then to a package
    - Clearly, new techniques are required in order to meet the goal of 5¢ per tag

RFID: Towards the 5¢ Tag

- Reducing the size of the IC
  - Requires minimizing the required functionality
  - A tag will store only the EPC™ in memory
    - This reduces the minimum requirement to read-only tags
    - Mapping to additional information is accomplished through ONS
  - The logic need only deal with the problem of reading multiple tags

RFID: Towards the 5¢ Tag

- New manufacturing processes
  - While smaller microchips are cheaper, working with them is far more difficult
    - Numerous processes are being developed to reduce both the cost of ICs and the related conversion costs
  - Other companies are experimenting with ways of reducing the cost of RFID antennas

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