Technology and Applications in Transportation

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The only two cars in Van Wert County, Ohio (population 784) in 1891 made transportation history …
Do You RFID?

- Automated Tolls
- Bus Pass
- Contactless Payment
- Automotive Security
- Access Control
Outline of Talk

• Introduction
• Market
• Applications
• History
• Taxonomy (place in the wireless landscape)
• How it works (illustrative)
• Conclude

Key Takeaways
• Transportation and logistics have strong ties to RFID
• RFID has transformative potential if used correctly; disastrous if not
• RFID is simple in concept but there are many ‘surprises’ in practice
Transportation & Logistics Share Dominates

Total RFID Market = $6B (2011)

Source: ABI Research
Passive Tag Minimum Cost Trends

The Passive Smart Label

- Antenna: 15%
- Chip: 50%
- Die Attach: 15%
- Packaging: 20%

<table>
<thead>
<tr>
<th>Year</th>
<th>Price (Cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>60</td>
</tr>
<tr>
<td>2010</td>
<td>30</td>
</tr>
<tr>
<td>2015</td>
<td>15</td>
</tr>
<tr>
<td>2020</td>
<td>10</td>
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</table>

Legend:
- Margin
- Package
- Attach
- Antenna
- Chip
A Typical Supply Chain

- Efficiency and reliability depends on ...
  - Transportation system performance and facility condition
  - Supplier performance
  - Regulatory and institutional barriers

Need
Real-Time Information & Asset Visibility

Largest Ports: 1. Shanghai (2010: 650 metric tons, 29M TEUs), 2. Singapore (was largest in 2005)
The supply chain ‘loses’ $37B/year\(^1\) (worsens as GDP grows)
- Goods damaged, spoiled, wrong delivery, diversion (theft) …

Some indirect costs from an unreliable transportation system
- $10 billion in goods “lost” during delivery process (U. of FL study)
- 20% of perishables expire before they are sold (FDA study)
- 15% of shoppers leave without finding an item (The GAP)

\(^1\)The National Retail Security Survey, University of Florida, 2011
Indoor Real-time Location Tracking Systems

RTLS saves 50% of labor spent looking for items (Bernstein Research Statistics)
### Emerging Applications for Every Mode

#### Roadways
- **Roadside asset** and inventory monitoring
- **Bridge** structural health monitoring
- **Tunnel** structural health monitoring

#### Railways
- Railcar and engine configuration
- Automatic control and signaling systems
- Rail condition monitor and inventory
- Tunnel safety checks

#### Airways
- Runway asset monitoring
- Vehicle access control
- Cargo safety and security
- Baggage tagging and tracking

#### Pipelines
- Condition monitoring
- Stress and breakage monitoring
- Corrosion monitoring

#### Intermodal
- Crane safety systems
- Traffic signaling systems

#### Waterways
- Cargo tracking and security
- Traffic and signaling controls
- Tunnel safety
Asset Visibility and Security

**HAZMAT**
- Asset safety monitoring
- Asset identification and inspection

**Productivity**
- Load efficiency
- Truck Identification

**Cold Chain**
- Product Temperature Monitoring
- Asset identification and authentication

**Construction Materials Tracking**
- Quality control
- Asset location tracking
- Inventory management

**Harvest Distribution**
- Quality management and lot tracking
- Weigh scales and distribution points
- Packaging and distribution points

**Asset Tracking**
- Tamper and condition monitoring
- RTLS
# Brief History of RFID Development

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>RADAR Perfected in WWII</td>
</tr>
<tr>
<td>1948</td>
<td>Harry Stockman “Communication By Means of Reflected Power”</td>
</tr>
<tr>
<td>1959</td>
<td>Friend or Foe Military Long Range Transponder</td>
</tr>
<tr>
<td>1960</td>
<td>Checkpoint &amp; Sensormatic EAS Commercialization 1-bit Electronic Article Surveillance</td>
</tr>
<tr>
<td>1966</td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>Los Alamos Scientific Labs Declassified “Short-range Radio-telemetry for Electronic Identification using Modulated Backscatter”</td>
</tr>
<tr>
<td>1979</td>
<td>First Implantable RFID for Livestock</td>
</tr>
<tr>
<td>1990</td>
<td>LA Adopts Pet Tagging</td>
</tr>
<tr>
<td>1992</td>
<td>First RFID Toll Collection System in U.S.</td>
</tr>
<tr>
<td>1996</td>
<td>Wal-Mart Mandate</td>
</tr>
<tr>
<td>2003</td>
<td>Military Mandate</td>
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<tr>
<td>2003</td>
<td></td>
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</table>
Taxonomy – Wireless Landscape

Satellite
(ex. GPS, L-V Bands, DirectTV)

Cell Size
10 km
1 km
100 m
10 m

Data Rate
1 kb/s 10 kb/s 100 kb/s 1 Mb/s 10 Mb/s 100 Mb/s

Wide Area Networks
(ex. GPRS, CDMA, Wi-Max)

Local Area Network
(ex. Wi-Fi, Bluetooth, DSRC)

RFID
RFID Performance Envelope

Credit Card Size Tags and 1-ft Diameter Reader Antennas

“Unobstructed” Range
- Not real-world
- Ignores impact of materials
- Ignores non-line of sight
- Ignores orientation sensitivity
- Ignores multi-path attenuation
- Ignores interference and noise

Throughput (Tags/Sec)

Range (Meters)

LF = Low-Frequency (~125 kHz), HF = High-Frequency (13.56 MHz), UHF = Ultra-High Frequency (~900 MHz)
# RFID Power Classification

<table>
<thead>
<tr>
<th>No Batteries</th>
<th>Batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passive</strong></td>
<td><strong>Semi-Passive</strong></td>
</tr>
<tr>
<td>Reflected Energy</td>
<td>Passive Compatible Sensor Tags</td>
</tr>
<tr>
<td><strong>Energy Harvesting</strong></td>
<td><strong>Active</strong></td>
</tr>
<tr>
<td>Transmitted Energy</td>
<td>Status &amp; Alerts</td>
</tr>
</tbody>
</table>

- **Passive**: No batteries, reflected energy, passive tags.
- **Semi-Passive**: Batteries, passive compatible sensor tags.
- **Energy Harvesting**: Transmitted energy, energy harvesting for active tags.
- **Active**: Active tags with status and alerts.
Why so many types of RFID?
## Radio Frequency Technology Classification

<table>
<thead>
<tr>
<th>Near-Field</th>
<th>Far-Field</th>
</tr>
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<tbody>
<tr>
<td><strong>Benefit</strong></td>
<td><strong>Deficiencies</strong></td>
</tr>
<tr>
<td>e.g. RuBee (IEEE P1902.1), NFC (ISO 18092)</td>
<td>• Robust link around dense RF media</td>
</tr>
<tr>
<td>• Magnetic field zone control</td>
<td>• Range limited to antenna loop diameter</td>
</tr>
<tr>
<td>• Simple narrow-band protocols maximize battery life</td>
<td>• Multi-tag arbitration speed limited by data rate</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
<td><strong>Deficiencies</strong></td>
</tr>
<tr>
<td>e.g. HF RFID (ISO 14443), LF RFID (ISO 14223-1)</td>
<td>• Excellent zone control</td>
</tr>
<tr>
<td>• Robust near-field energy harvesting for passive HF/LF RFID</td>
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<tr>
<td>• Robust media penetration</td>
<td>• Multi-tag arbitration limited by bandwidth and data rate</td>
</tr>
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### Internal Power Source (e.g. Batteries)

### External Power Source (e.g. RF, Vibration, Light)

A one size fits all solution is illusive.
Application and Technology Mapping

- **Throughput (Tags/Sec)**
  - Passive (< $1)
  - Active (< $20)
  - Throughput (Tags/Sec)

- **Range (Meters)**
  - 5
  - 10
  - 15
  - 20
  - 25
  - 30
  - 35
  - 40

- **High Value Asset & Wireless Sensors**
  - RTLS
  - Personnel & Vehicle Tracking
  - Logistical Units & Metal Containers

- **Transport Devices**
  - Consumer Units & Shelved Items
  - Traded Units & Crates
  - Apparel Racks
  - Pharmaceuticals

- **Item Level**
  - 1
  - 4
  - 8

- **Palm Size Tags**
  - Reader Antenna
  - Dime Size Tags

- **Application Examples**
  - Personnel & Vehicle Tracking
  - Logistical Units & Metal Containers
  - Traded Units & Crates
  - Consumer Units & Shelved Items
  - Apparel Racks
  - Pharmaceuticals
How does Passive RFID work (without a battery)?
How Does Passive RFID Work?

Single Tag Communications
How Does Passive RFID Work?

Multiple Tag Communications

TDMA

Tag 1  Tag 2  Tag 3  Tag 4  Tag 5

Tag n
Maximum Range for Passive Tags

Forward Link Limited: Power Transfer
What are the real-world challenges?
Passive Tag Power Source is Unreliable

Power Distribution at 868 MHz

Palomar, Anu-Leena Annala, et.al.

Peaks (-3 dBm)  Nulls (-14.3 dBm)
Energy Sinks and Shifts

Liquids

H_2O Dipole Energy Absorption

UHF Reader Antenna

Tag Antenna

Metals

Free-Space Tag

Power Transfer

Operating Frequency

Detuned Tag

\[ H(\omega, Q) \]

\[ V_b \]

\[ C_{parasitic} \]

\[ \text{Eddy Losses} \]

\[ I_{\text{ant}} \]

\[ L_a \]

\[ C_a \]

\[ R_m \]
An RFID Challenged Application
Tag Localization Challenge

- RFID Tag
- Asset
- Portal Reader
- UHF Signal Bounce
How does RFID work within a system?
Multi-Technology RFID System

Sensor Based Application Dashboards

Sensor Logs, Alerts, Actuates

UHF Reader

RTLS

Wi-Fi AP

860-960 MHz

Wi-Fi RFID Readers

EPC Fixed Readers

TCP/IP LAN

ERP System

LAN / WAN / INTERNET

ERP

• Data Filtering & Storage
• Application Adapters
• Web Services API
• ERP Interfaces

Web Data Consumers
Summary

• **RFID is an important technology in transportation**
  – Electronic toll collection
  – Supply chain asset visibility
  – Emerging transportation markets
    – Combo transit pass, cashless payment, and access control
    – Real-time locating systems (RTLS)
    – Multi-modal asset tracking and condition monitoring
    – Product safety and security
  – No one RFID technology addresses all needs

• **The technology must be deployed with care**
  – Simple in concept, but complex in practice
  – Game changing potential if used wisely