Efficient and Reliable Ultra Low Power RFID Networks

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Microsoft · CISCO · Telefonica · ST · intel · amazonkindle · MEDIATEK

Motivation

Machine-Generated Data

RFID will be a major source of such traffic

- In Oil & Gas – about 30% annual growth rate
- In Healthcare – $1.3B revenue annually
- "number of RFID tags sold globally is projected to rise from 12 million in 2011 to **209 billion** in 2021."
  – *McKinsey Big Data Report 2011*

Are Our Wireless Protocols Ready?

- Wireless protocols require power and computation

  WiFi · ZigBee →

- **RFIDs are very flaky**
  - No power source
  - Ultra-low cost → not much circuitry
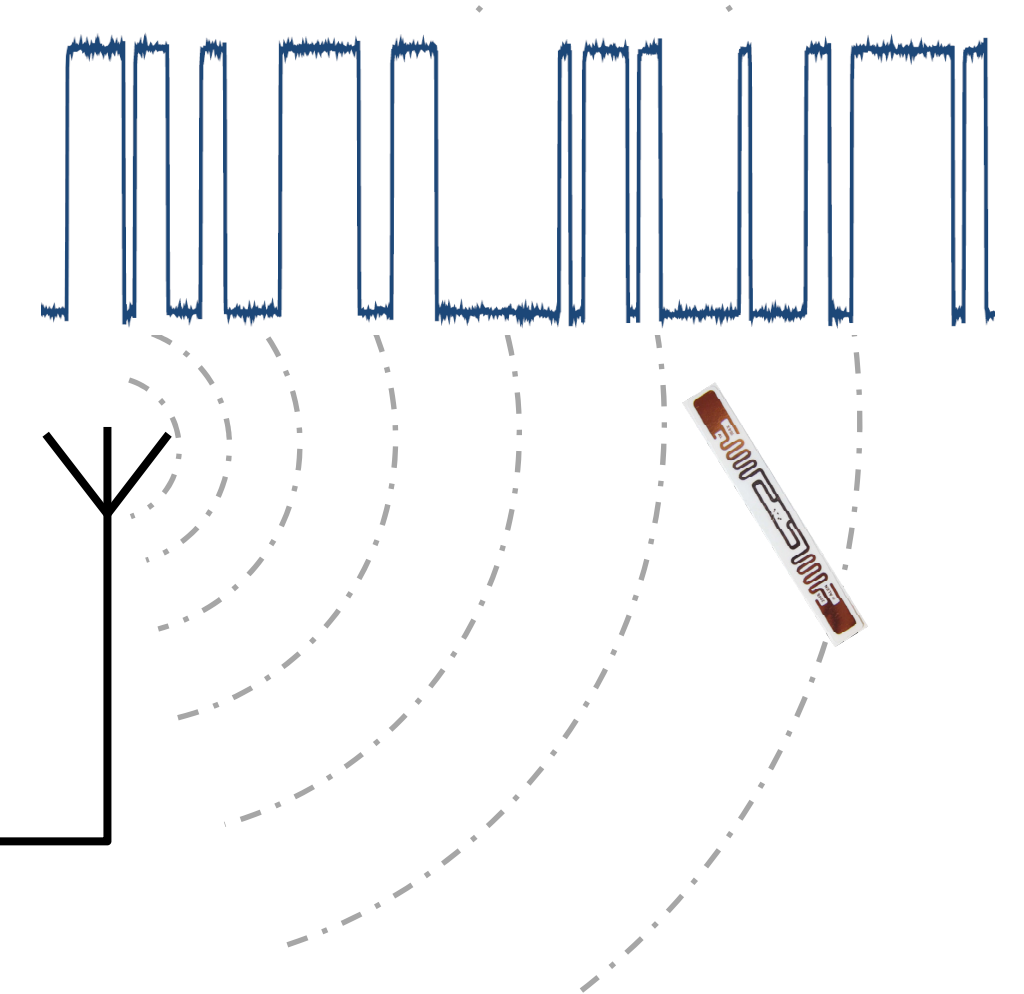- **RFIDs can't perform typical functions like carrier sense or rate adaptation**

Background

Backscatter Communication

Tag reflects the reader's signal using ON-OFF keying

Reader shines an RF signal on nearby RFIDs

Node Identification Problem

Each object has an ID
Reader learns IDs of nearby objects
Applications:

- Inventory management
- Shopping cart

**Challenge: RFIDs cannot hear each other → Collisions**

Data Communication Problem

Data communication in RFID networks performs poorly because it lacks rate adaptation

RFIDs always send 1 bit/symbol

Can't exploit good channels to send more bits → **Inefficiency**

Can't reduce rate in bad channels → **Unreliability**

Network-Based Compressive Sensing

ID = 1, ID = 2, ID = 3, ID = 4, ID = 5, ID = 6 ... ID = N
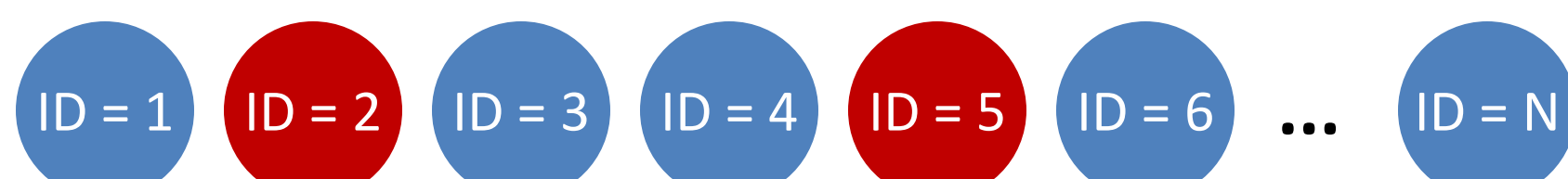
System is represented by a vector $\mathbf{x}$
$x_i = 1$ if node with ID $= i$ is in cart

| 0 | 1 | 0 | 0 | 1 | 0 | ... | 0 |

$$
\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} =
\begin{bmatrix}
0 & 1 & 1 & 1 & & 0 \\
0 & 0 & 1 & 0 & \cdots & 1 \\
1 & 1 & 1 & 0 & & 1
\end{bmatrix}
\times
\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix}
$$

$A_1\ A_2\ A_3\ A_4\ \dots\ A_N$

$\mathbf{x}$ is distributed across all nodes!

X is Sparse

Want the network to emulate a compressive sensing sender

Node with ID $= i$ transmits A_i

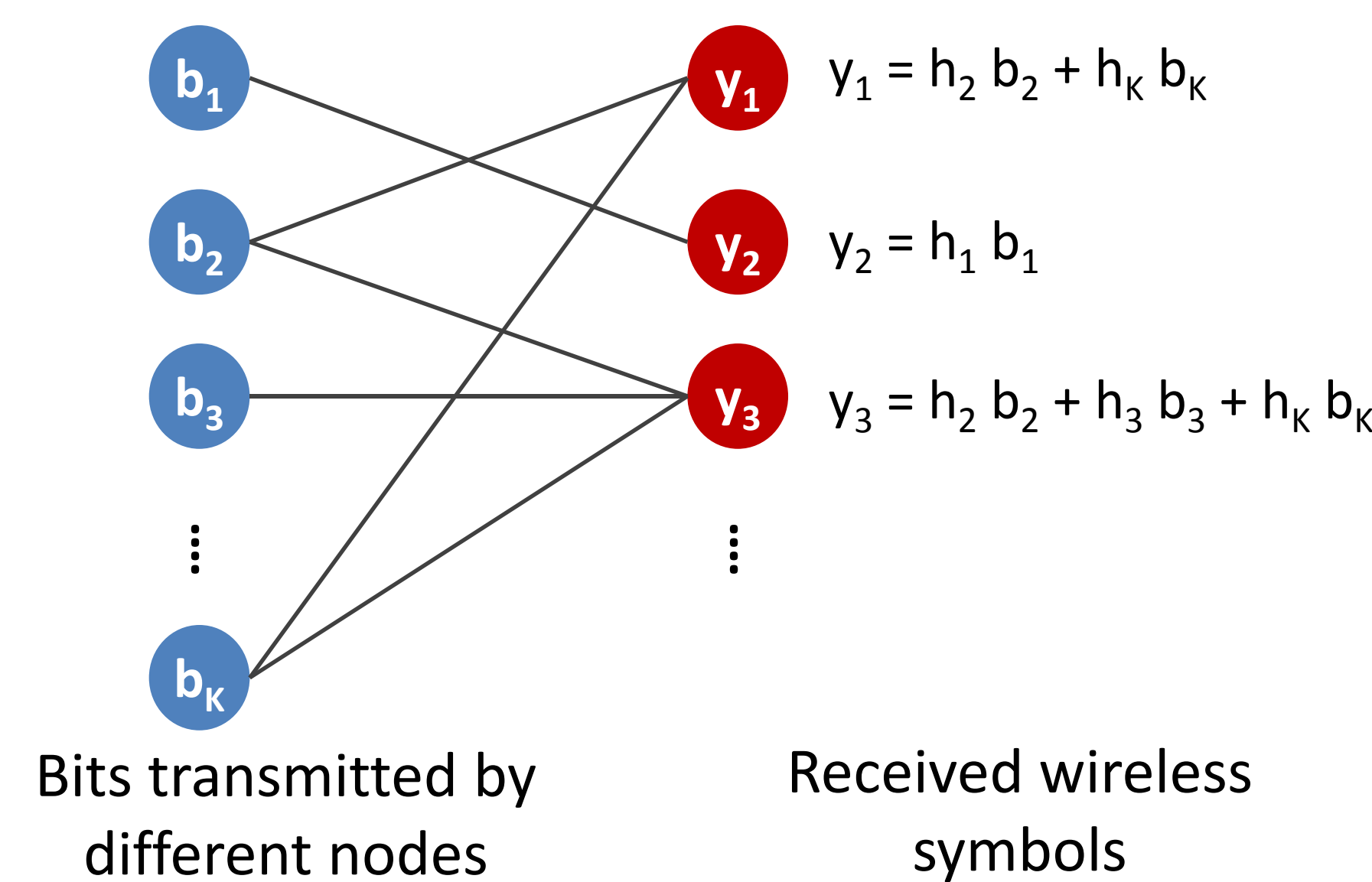**Collisions mix bits on the air**

Reader decodes $\mathbf{x}$ using a **Compressive Sensing decoder**

Network-Based Rate Adaptation

- Nodes transmit messages and collide
- Reader collects collisions until it can decode
  - **good channel** → decode from **few collisions**
  - **worse channel** → decode from **more collisions**

Collisions act as a distributed rateless code

Adapts bit rate to channel quality without feedback

$y_1 = h_2\,b_2 + h_K\,b_K$
$y_2 = h_1\,b_1$
$y_3 = h_2\,b_2 + h_3\,b_3 + h_K\,b_K$

Bits transmitted by different nodes — Received wireless symbols

Collisions act as a sparse random code

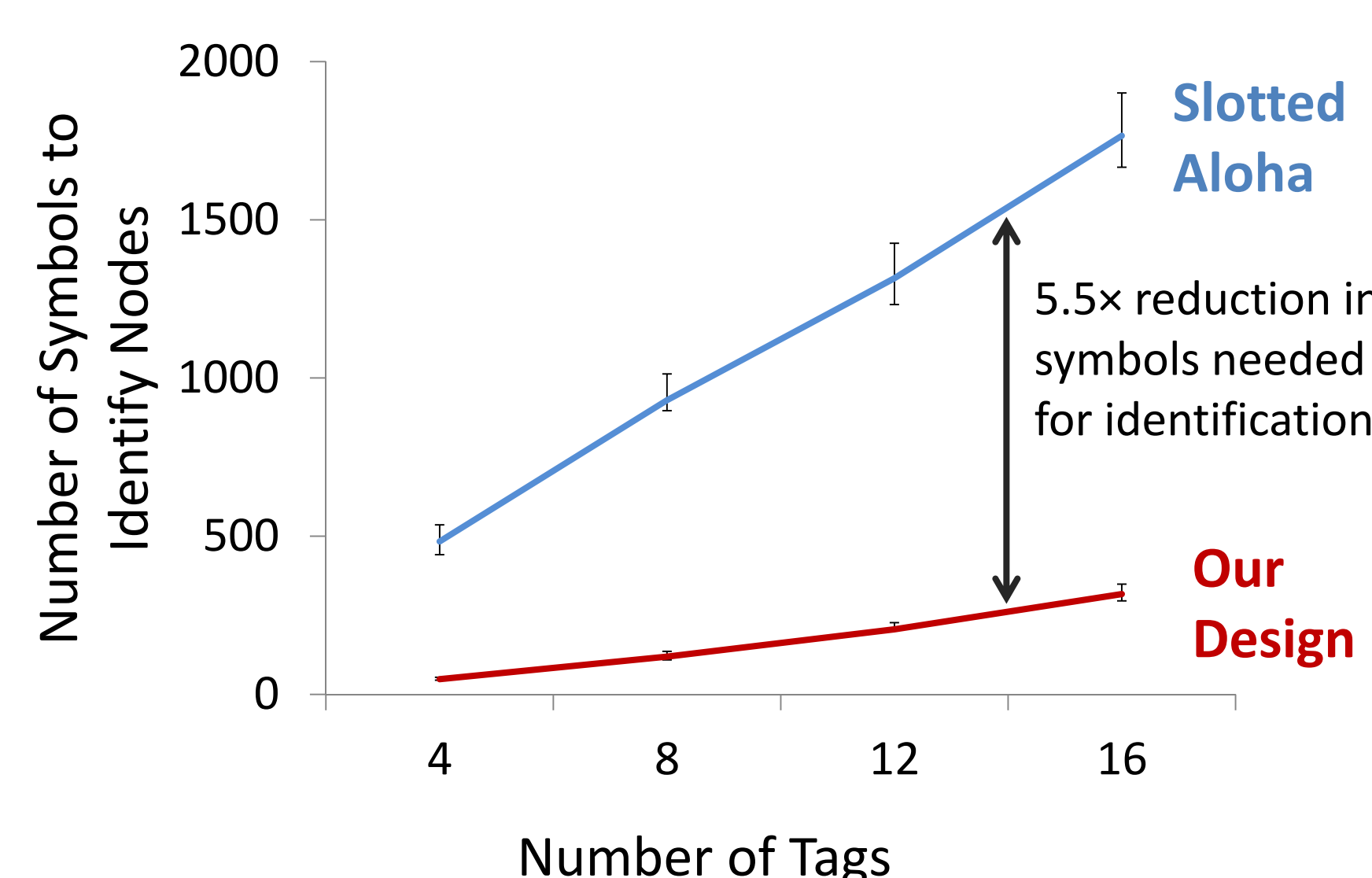Quickly decode using a **Belief Propagation decoder**

Evaluation

- Reader implementation on GNURadio USRP
- UMass Moo programmable RFIDs

Efficiency

Number of Symbols to Identify Nodes vs Number of Tags

Slotted Aloha
Our Design
5.5× reduction in symbols needed for identification

Reliability

Message Loss Rate

- CDMA 42%, TDMA 27%, Our Design 0% (Low SNR 0dB – 4dB) — 0.57 bits/symbol
- CDMA 16%, TDMA 12%, 0% (Medium SNR 5dB – 9dB) — 1.7 bits/symbol
- 0%, 0%, 0% (High SNR 10dB – 20dB) — 3.2 bits/symbol
- Our Design