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University of Electronic Science and Technology of China

MICMOTE
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Go Beyond RFID: Rethinking the Design of RFID Sensor Tags for Versatile Applications

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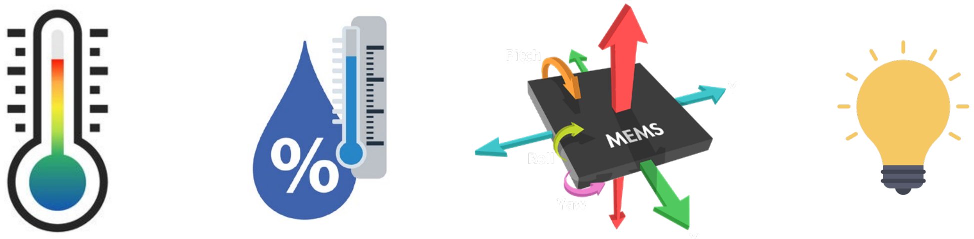
RFID tags + sensors = an ideal low-cost solution

*RFID Market Global Forecast to 2030, Markets and Markets

$14.5 billion → $35.6 billion (2030)

Driver of market: Increasing need for RFID systems to incorporate *versatile sensors* for improving productivity in manufacturing



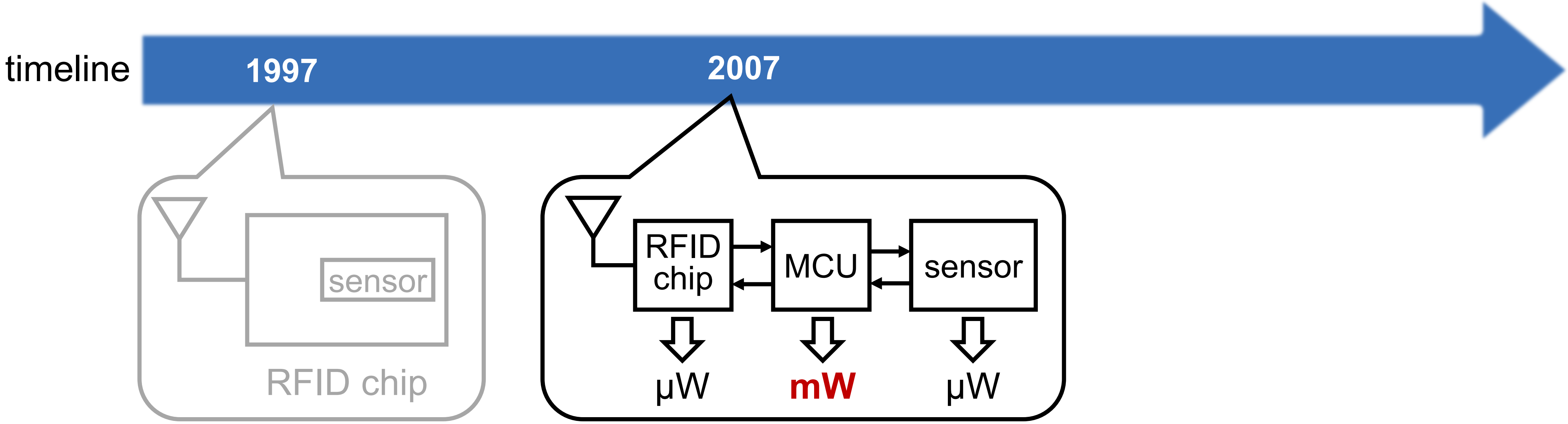
Next generation RFID:
ID + Sensing

Trend of RFID sensor tag

Conventional tag

- basic sensor (most temp.)
- Infeasible to change sensor

Trend of RFID sensor tag



Conventional tag
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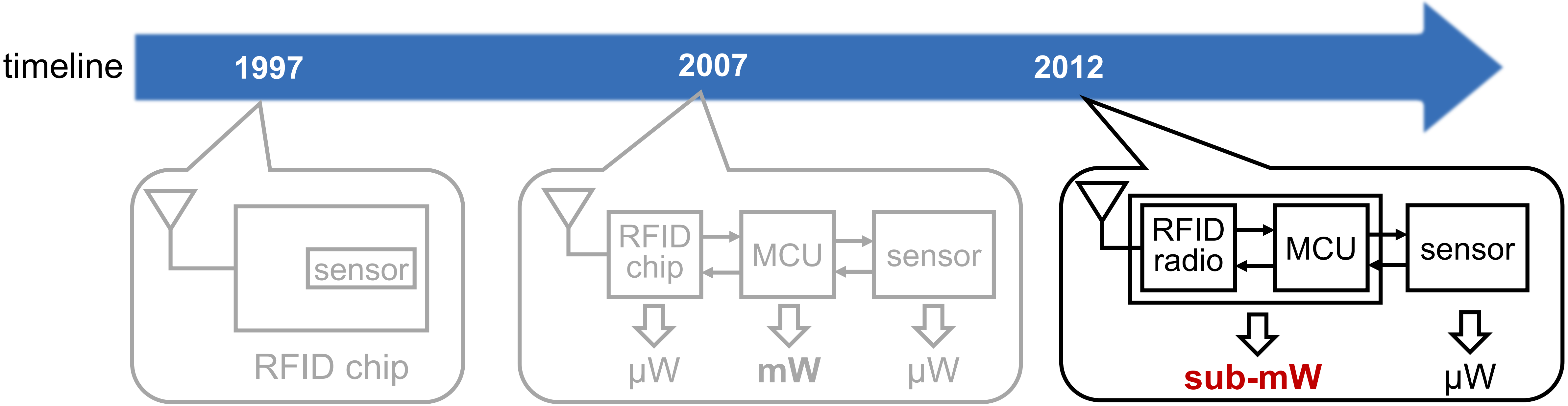
MCU-based tag
- versatile and low-cost
- high power from MCU

Trend of RFID sensor tag

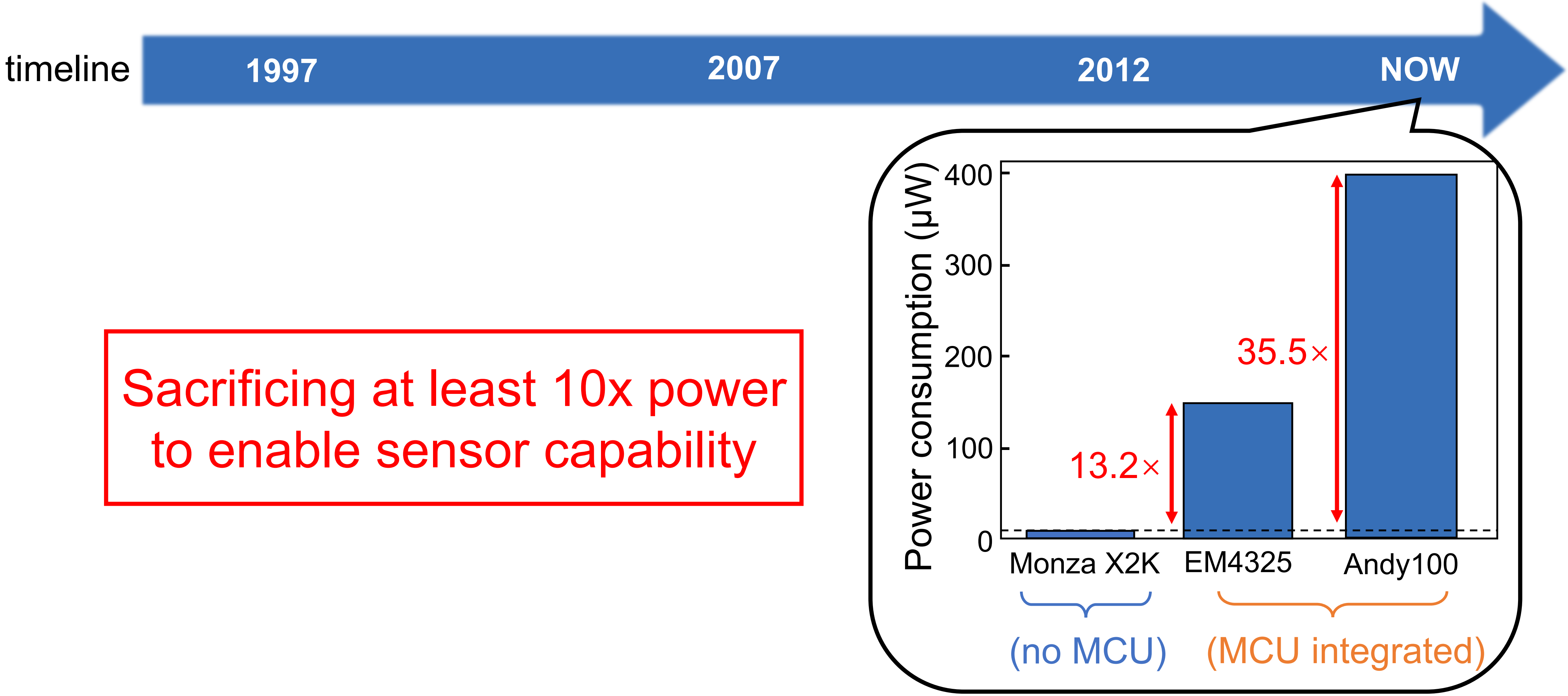


Conventional tag
- basic sensor (most temp.)
- Infeasible to change sensor

MCU-based tag
- versatile and low-cost
- high power from MCU

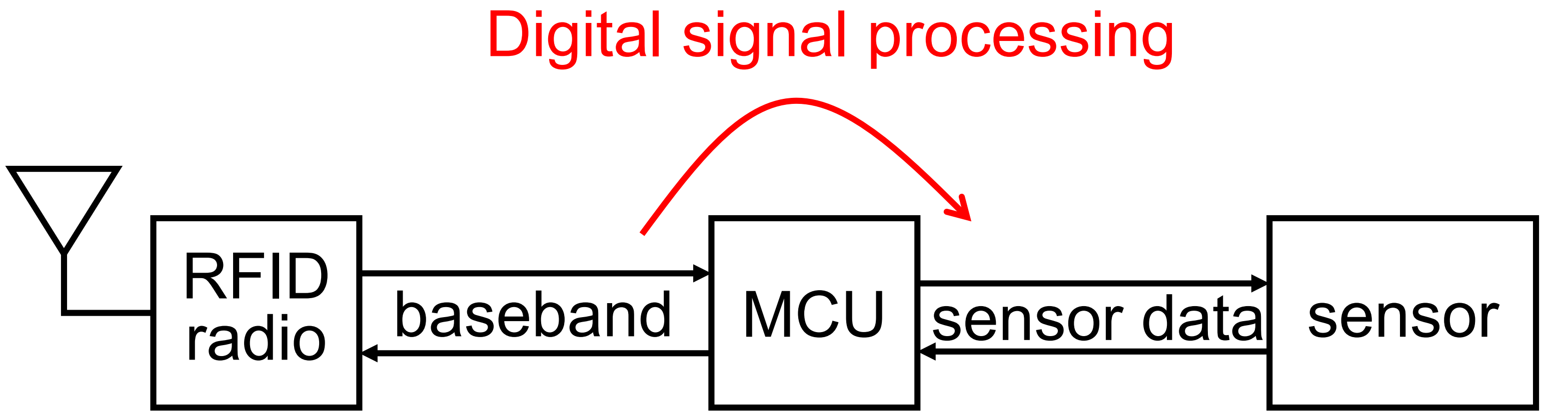
MCU-integrated tag
- Reader controls sensor
- relay-like operation

Trend of RFID sensor tag



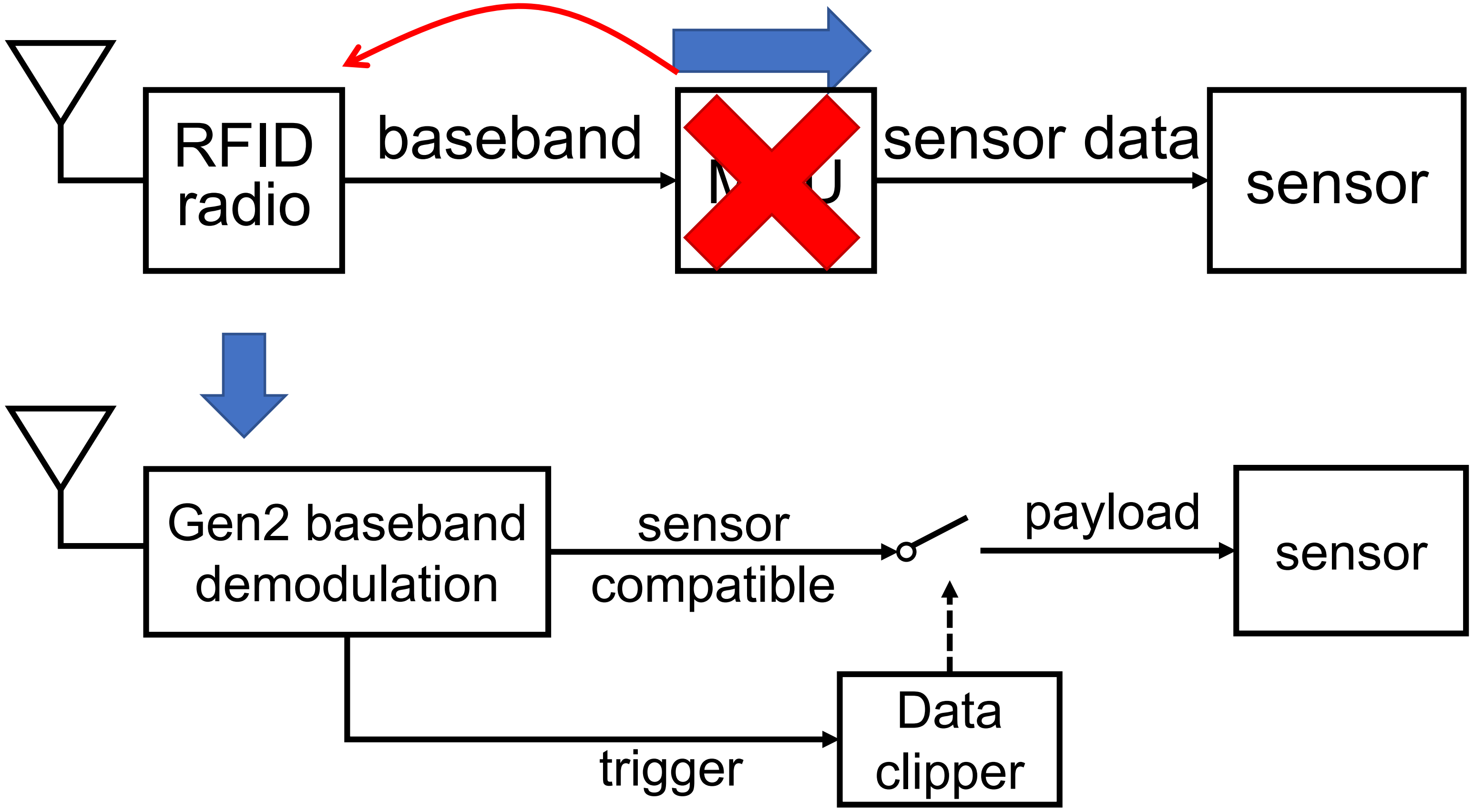
Sacrificing at least 10x power to enable sensor capability

Why MCU-based design is power-starving?



- Baseband: cannot directly talk to sensor
- MCU: conversion between baseband and sensor data
- High power consumption especially on the downlink

baseband processing:
digital → analog



- Baseband processing: digital → analog
- Demodulation: is compatible with sensor data
- Data clipper (logic): Pass-through control

We introduce GoodID (**Go** bey**o**n**d** RF**ID**)

Cross-layer design for the next-generation RFID sensor tags

- Ultra-low power
- Interface sensors

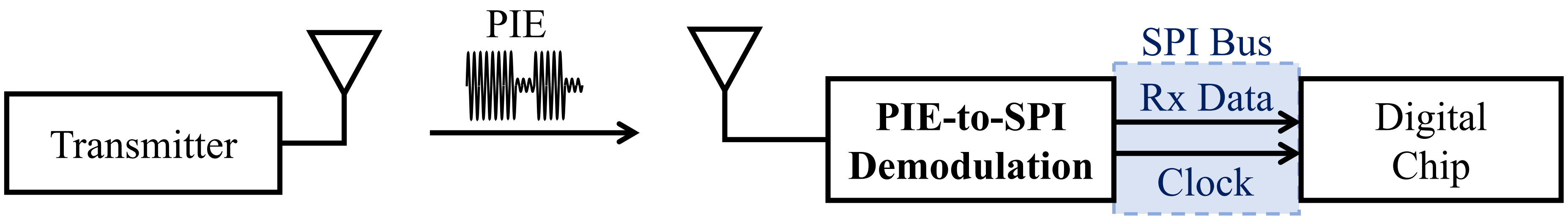
- PHY layer: Hybrid analog-digital Gen2 baseband demodulation
- Link layer: Downlink-uplink co-designed transmission frame

Evaluation with commercial RFID readers

- Ultra-low power: 2.3x lower than relay-like design
- Goodput: 40 kbps (downlink, 11.8x higher)
  160 kbps (uplink, 3.7x higher)
  over Access commands (Read, Write…)

PHY layer: Gen2 baseband demodulation

Recent work: Radio-to-bus (R2B) [Mobicom 20]



Direct conversion: PIE baseband to SPI signal

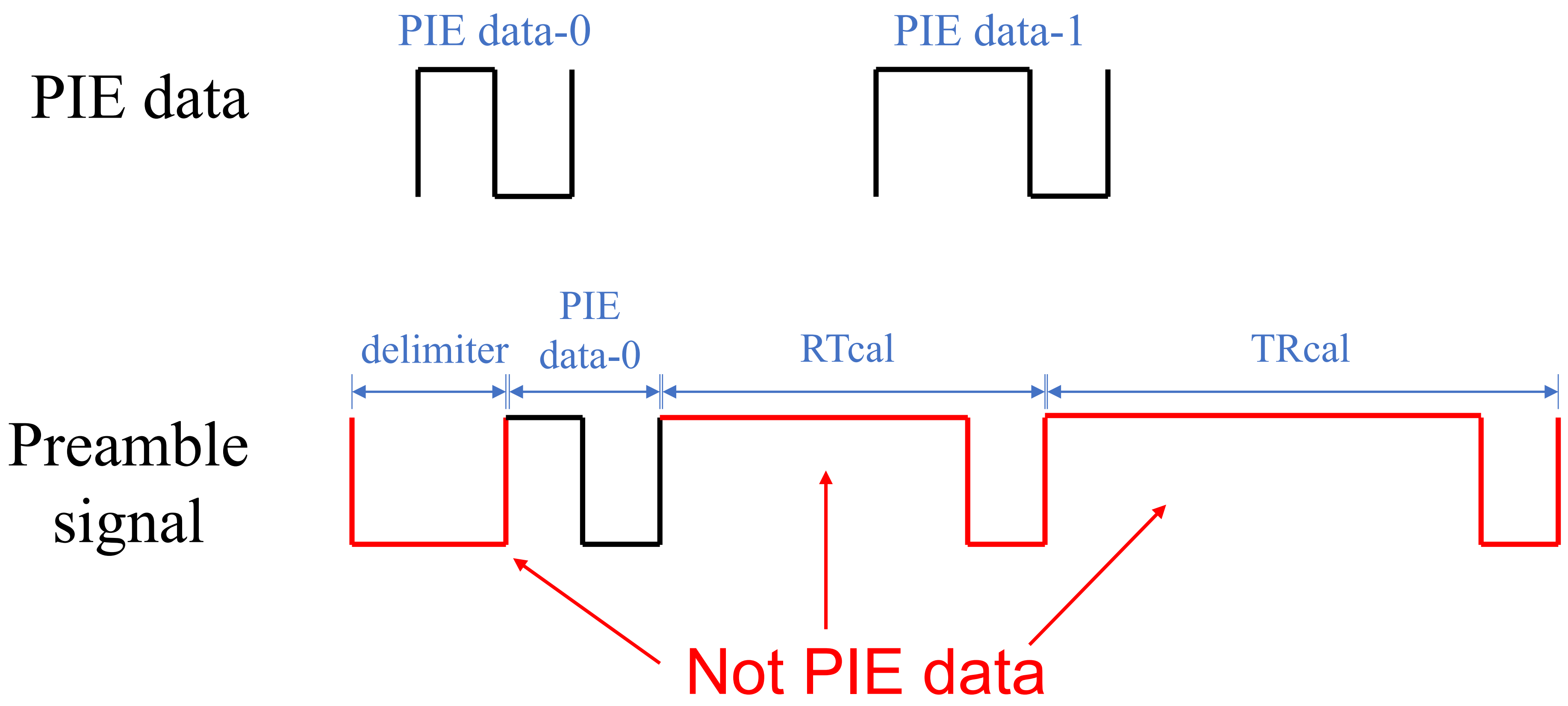
Problem: Gen2 baseband contains special defined signals (non-PIE symbols)

Downlink packet structure

R2B cannot correctly detect the preamble
→ Error data will send into the sensor

PHY layer: Gen2 baseband demodulation

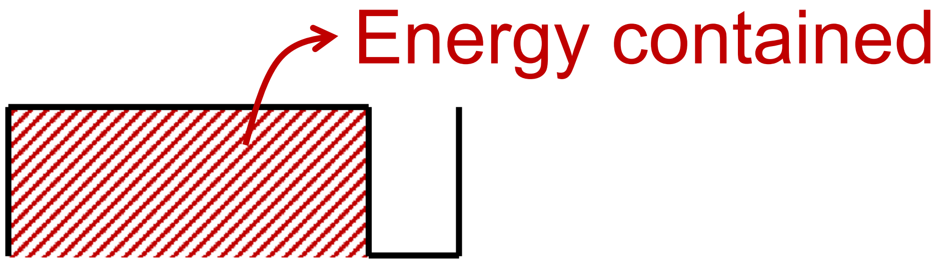
Challenge: demodulate both PIE data and non-PIE preamble signal



PHY layer: Gen2 baseband demodulation

Our method: distinguish featured symbols instead of the whole signal

Leverage energy difference between such symbols

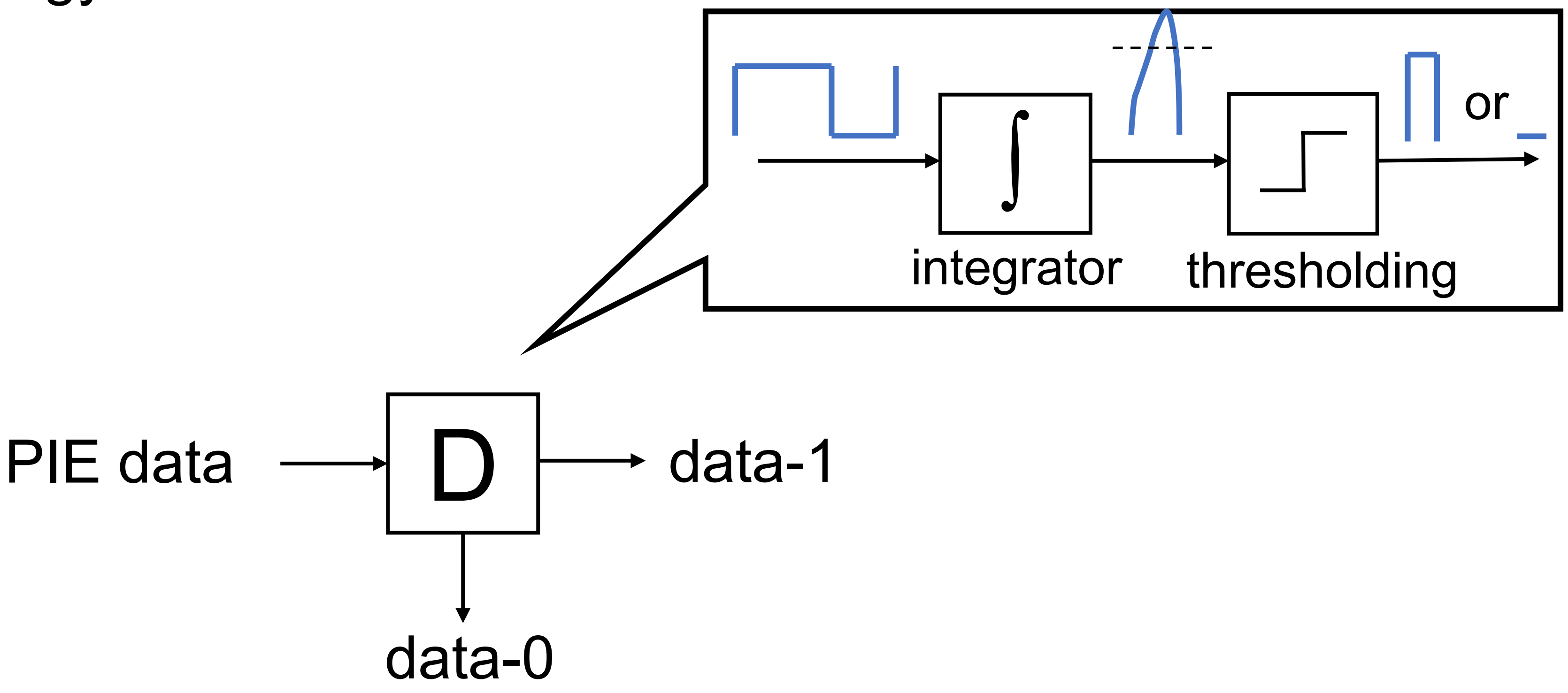


data-0 < data-1 < RTcal < TRcal

PHY layer: Gen2 baseband demodulation

Problem: complex demodulation design with four symbols

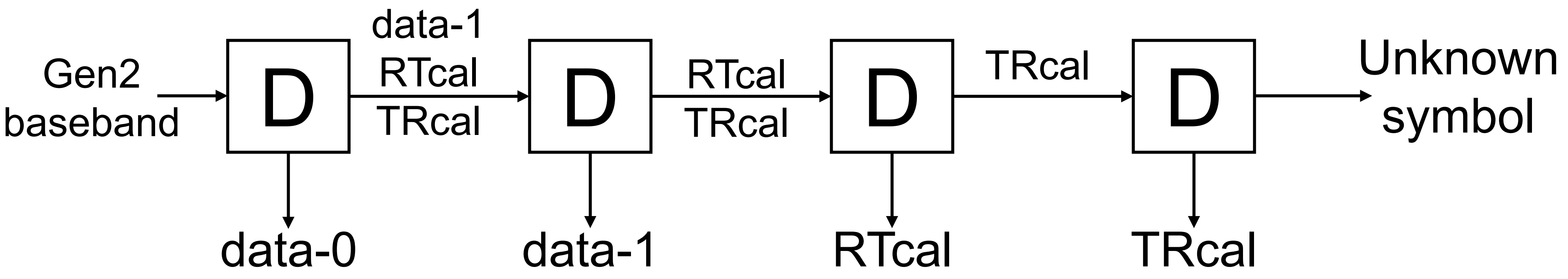
- Conventional energy-based discriminator



PHY layer: Gen2 baseband demodulation

Problem: complex demodulation design with four symbols

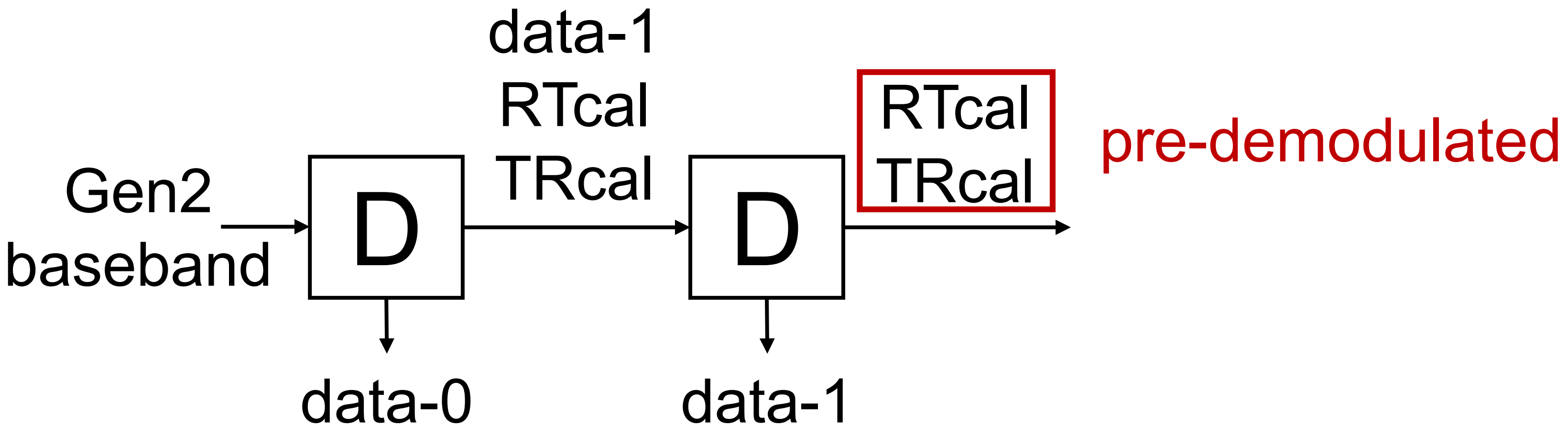
- Strawman design for Gen2 baseband



Redundant design, 4× power consumption

PHY layer: Gen2 baseband demodulation

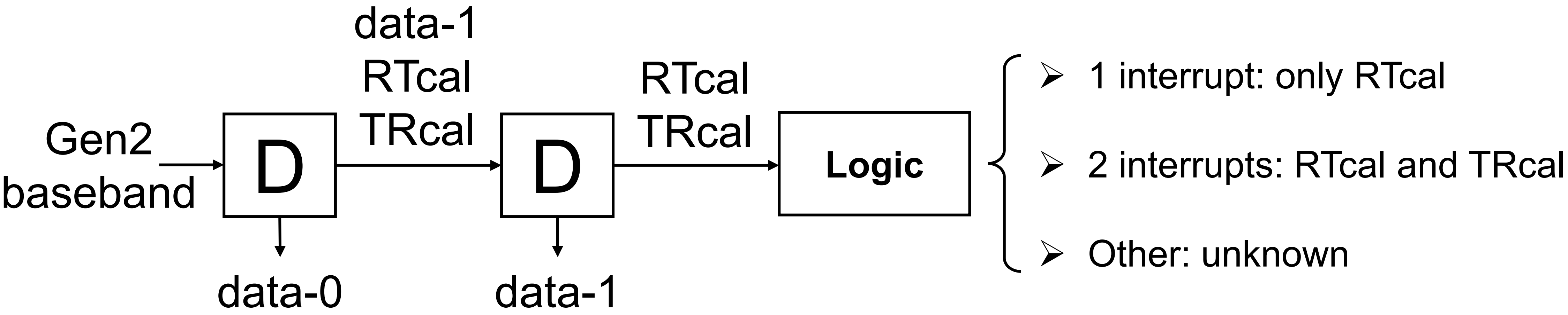
Solution: Hybrid analog-digital demodulation



- Analog part:
  - two-stage discriminator → demodulate PIE data
  - pre-demodulated RTcal and TRcal: interrupt signals

PHY layer: Gen2 baseband demodulation

Solution: Hybrid analog-digital demodulation



■ Analog part:

- ➢ two-stage discriminator → demodulate PIE data
- ➢ pre-demodulated RTcal and TRcal: interrupt signals

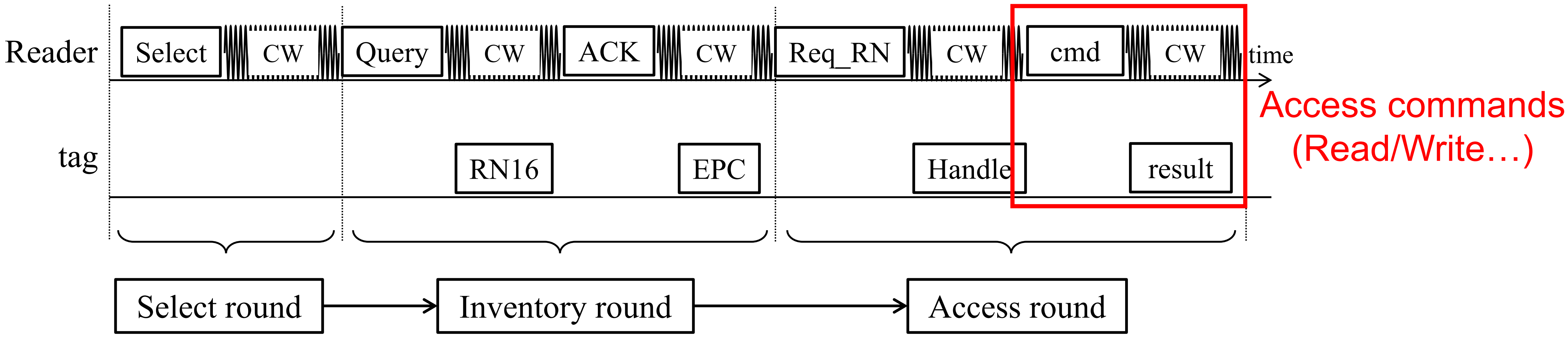
■ Digital part :

- ➢ directly recognize RTcal and TRcal without processing
- ➢ count the number of interrupts

Details in the paper

Link layer: efficient transmission for sensor operation

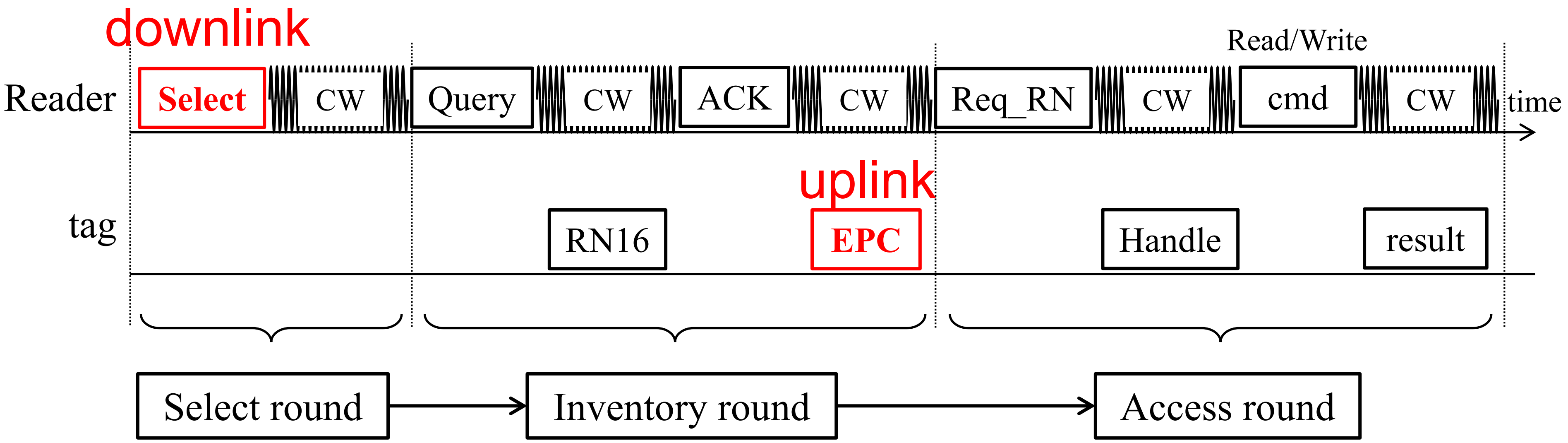
Gen2 protocol: Access commands (Read/Write…)
for data exchange between reader and tag



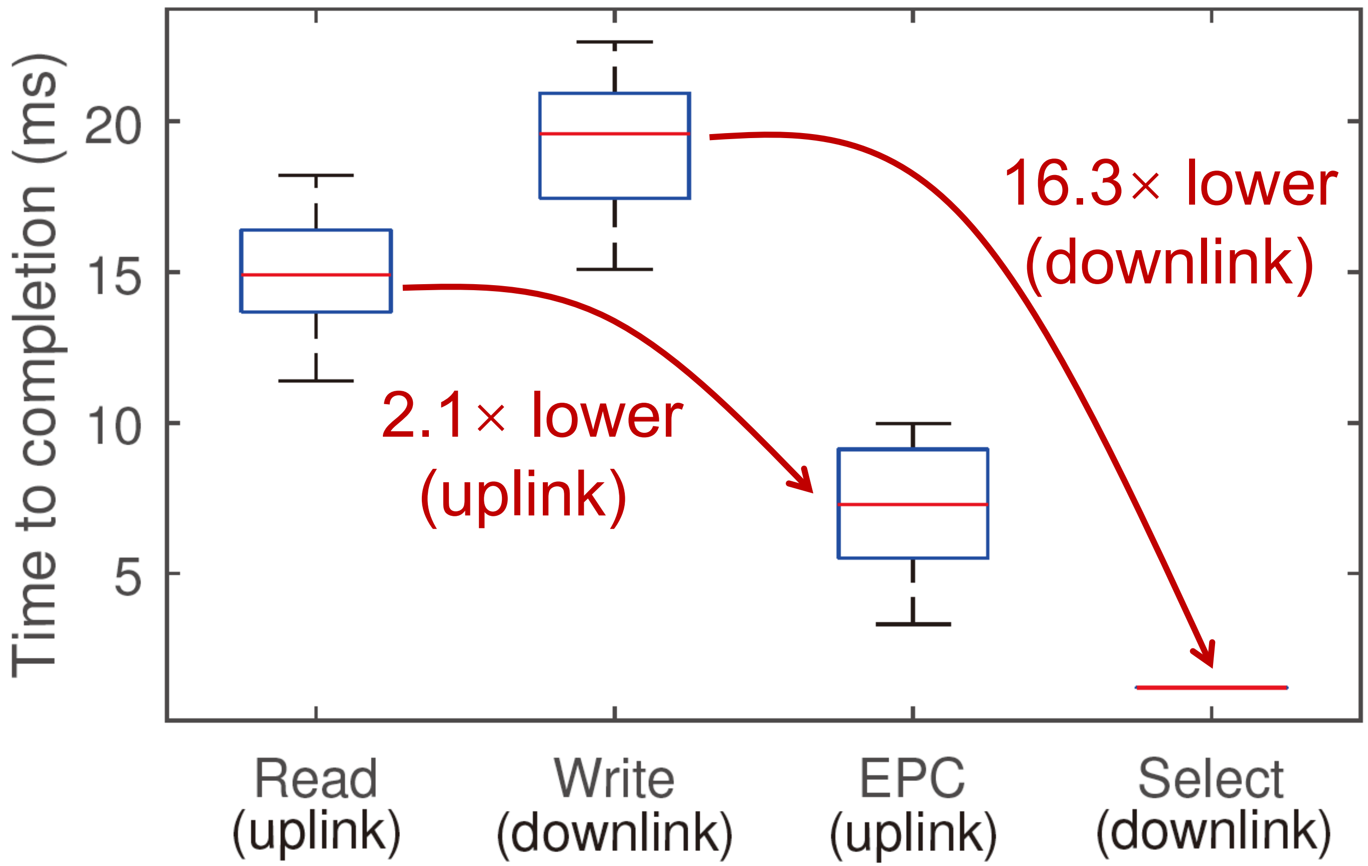
Problem: inefficient transmission for sensor operation

Link layer: efficient transmission for sensor operation

In GoodID, we leverage tag identification process for data exchange



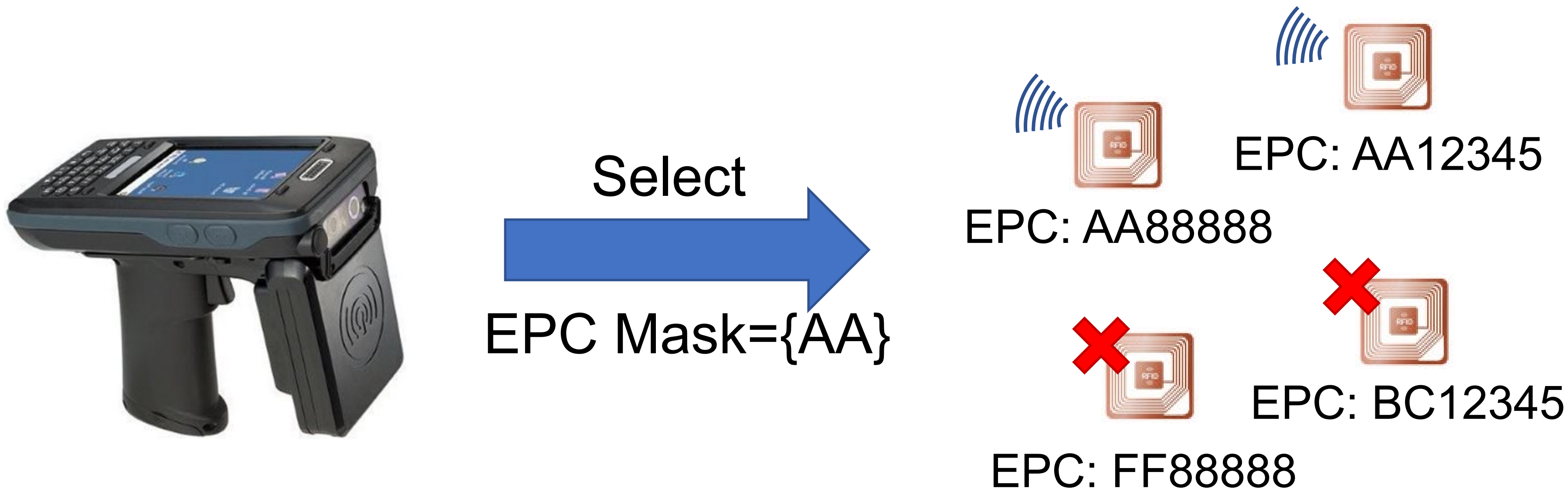
Link layer: efficient transmission for sensor operation



Time cost to convey the same payload data

Link layer: efficient transmission for sensor operation

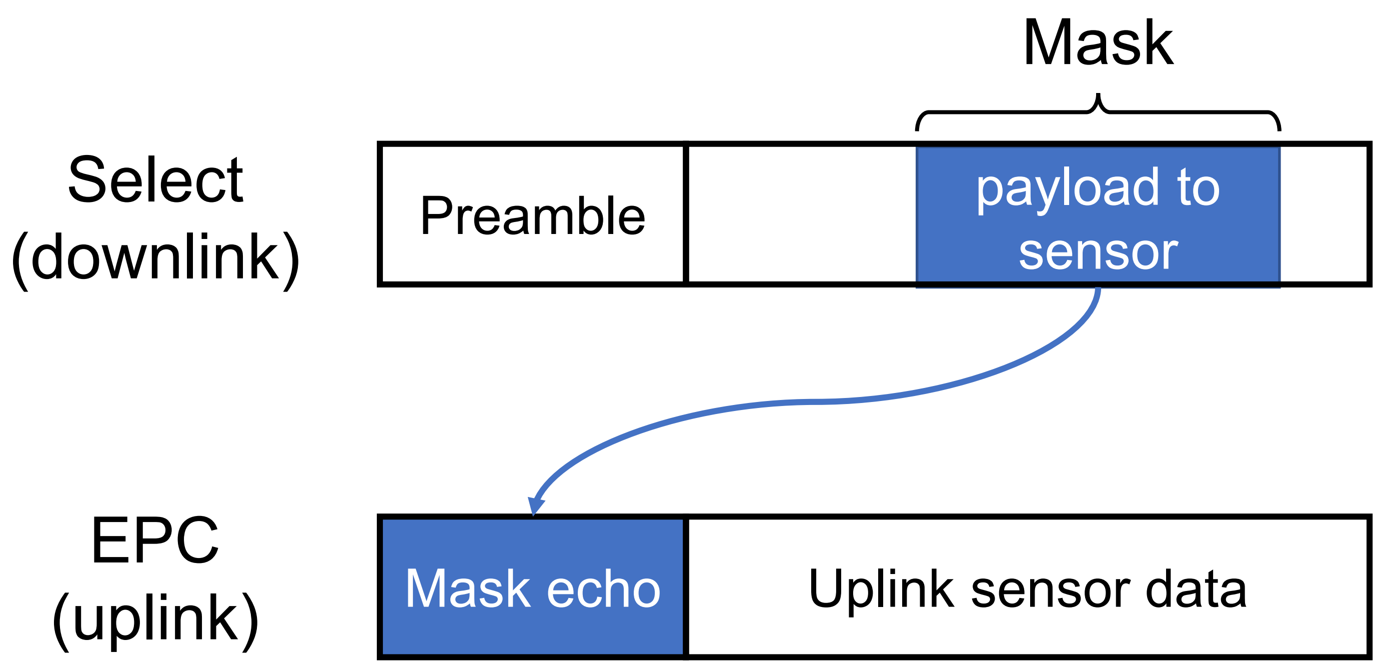
Problem: Select is intended to filter tags for selective reading



Using Select for downlink → uplink EPC reply may become invalid

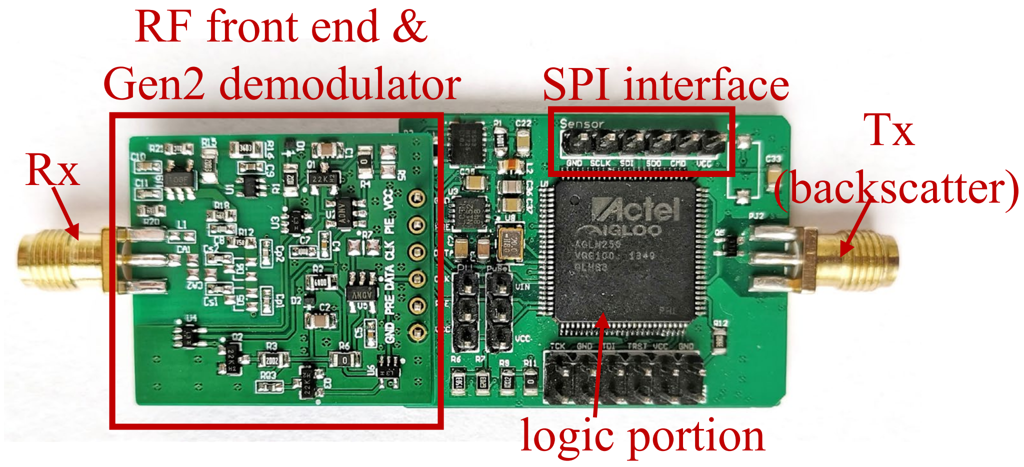
Link layer: efficient transmission for sensor operation

Our solution: downlink-uplink co-designed echo scheme



Multiple access: *empty* Mask can enable the reply from all tags

Implementation

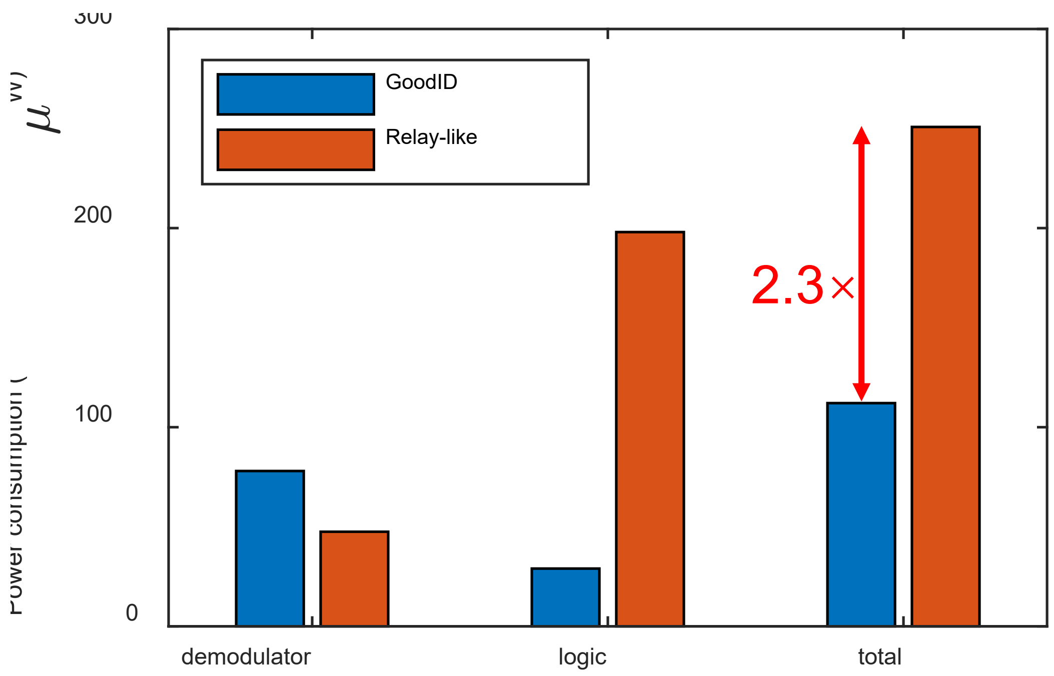


FPGA-based GoodID prototype

Commercial Impinj R420 Reader

Evaluation: power breakdown

Relay-like design:
conventional RFID demodulator [1]
(envelope detection and single-stage discriminator)
Use the Select-EPC frame



Logic (power analysis by SmartPower™)

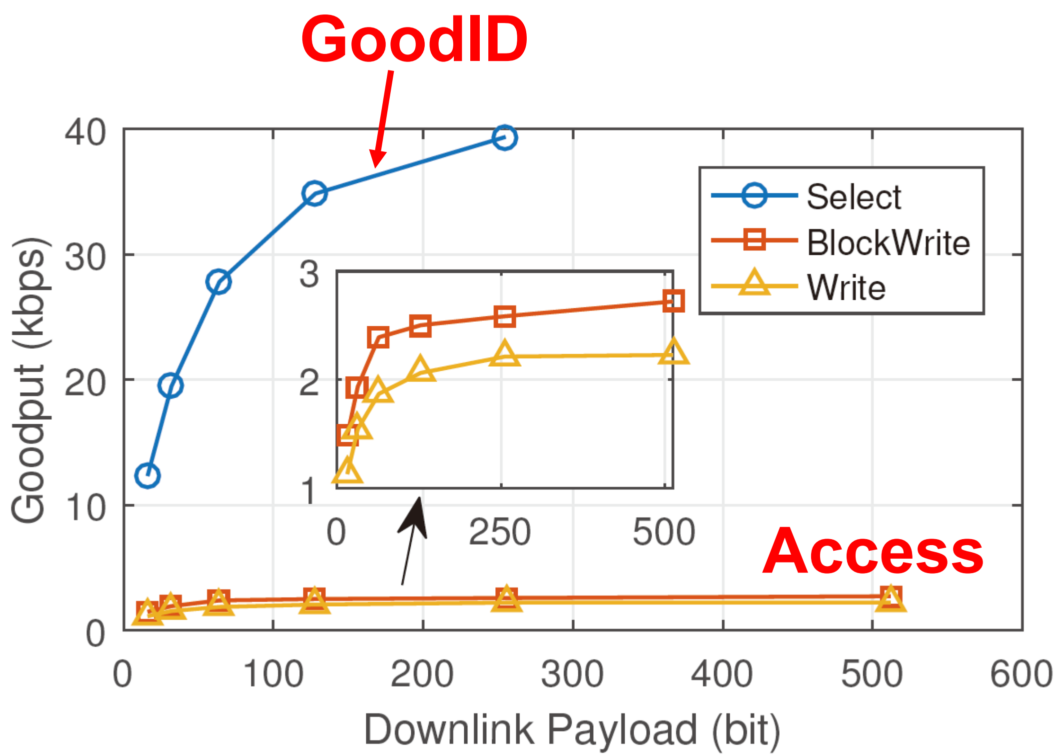
- GoodID: 64 flip-flops
- Relay-like: 562 flip-flops

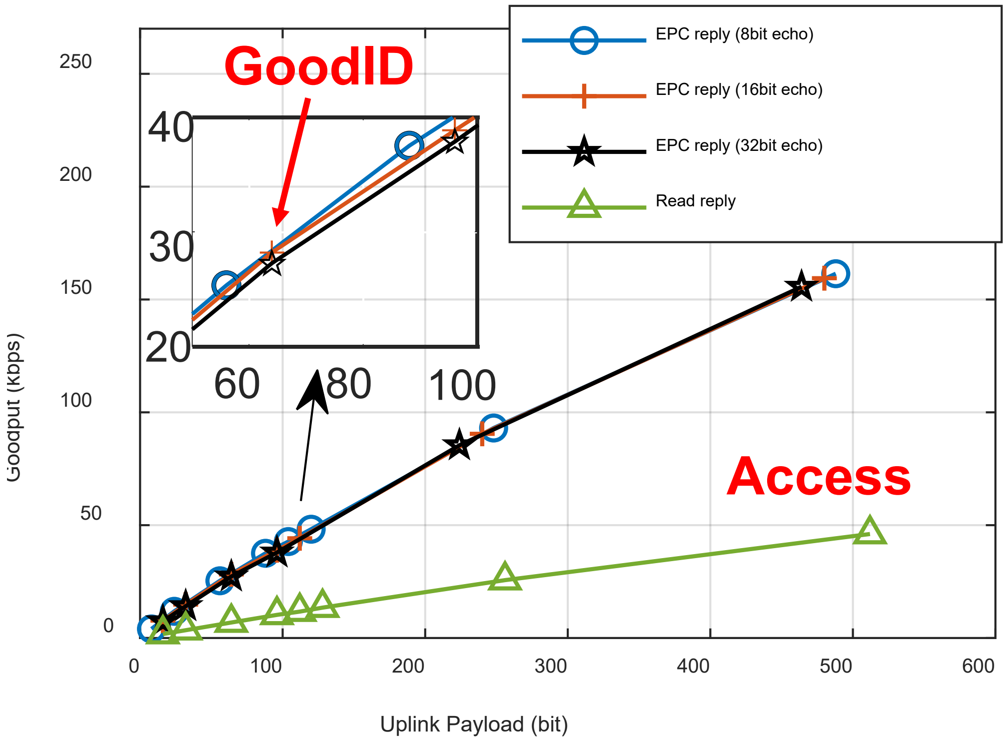
Total power consumption

- GoodID: 107 μW
- Relay-like: 295.5 μW

[1] Karthaus, U., & Fischer, M. (2003). Fully integrated passive UHF RFID transponder IC with 16.7-μW minimum RF input power. IEEE Journal of solid-state circuits, 38(10), 1602-1608.

Evaluation: payload goodput



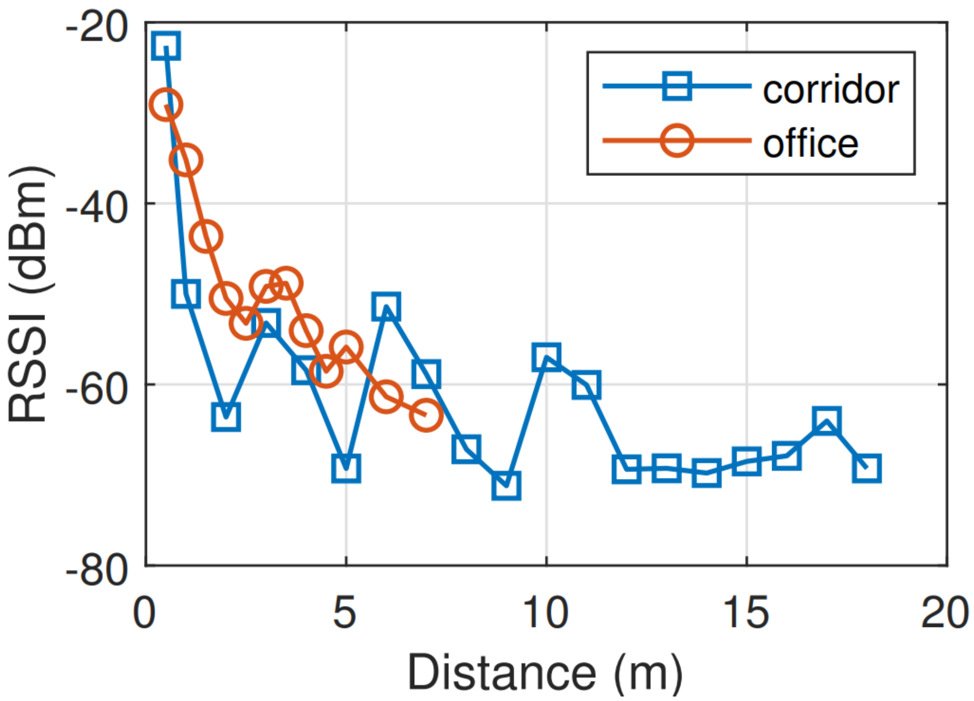


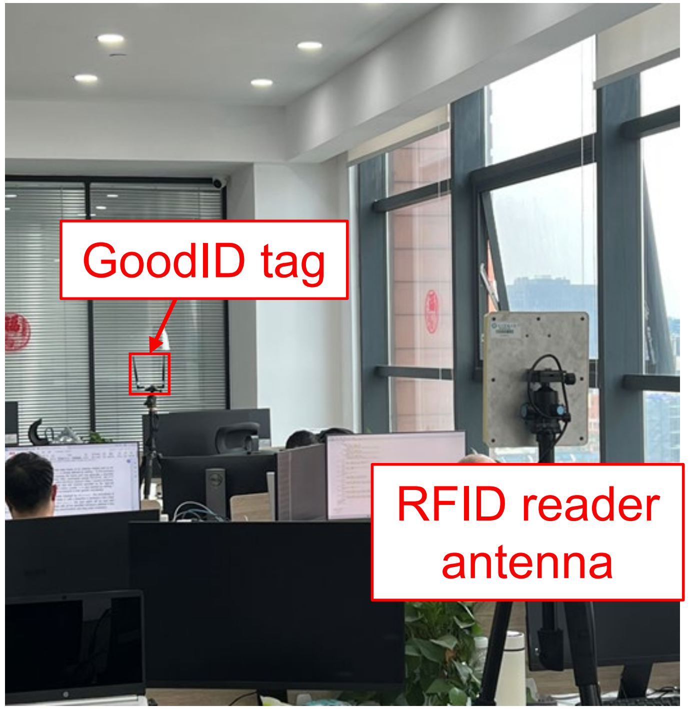
up to 40 kbps
(downlink, 11.8x ↑)

up to 160 kbps
(uplink, 3.7x ↑)

Evaluation: read range

corridor

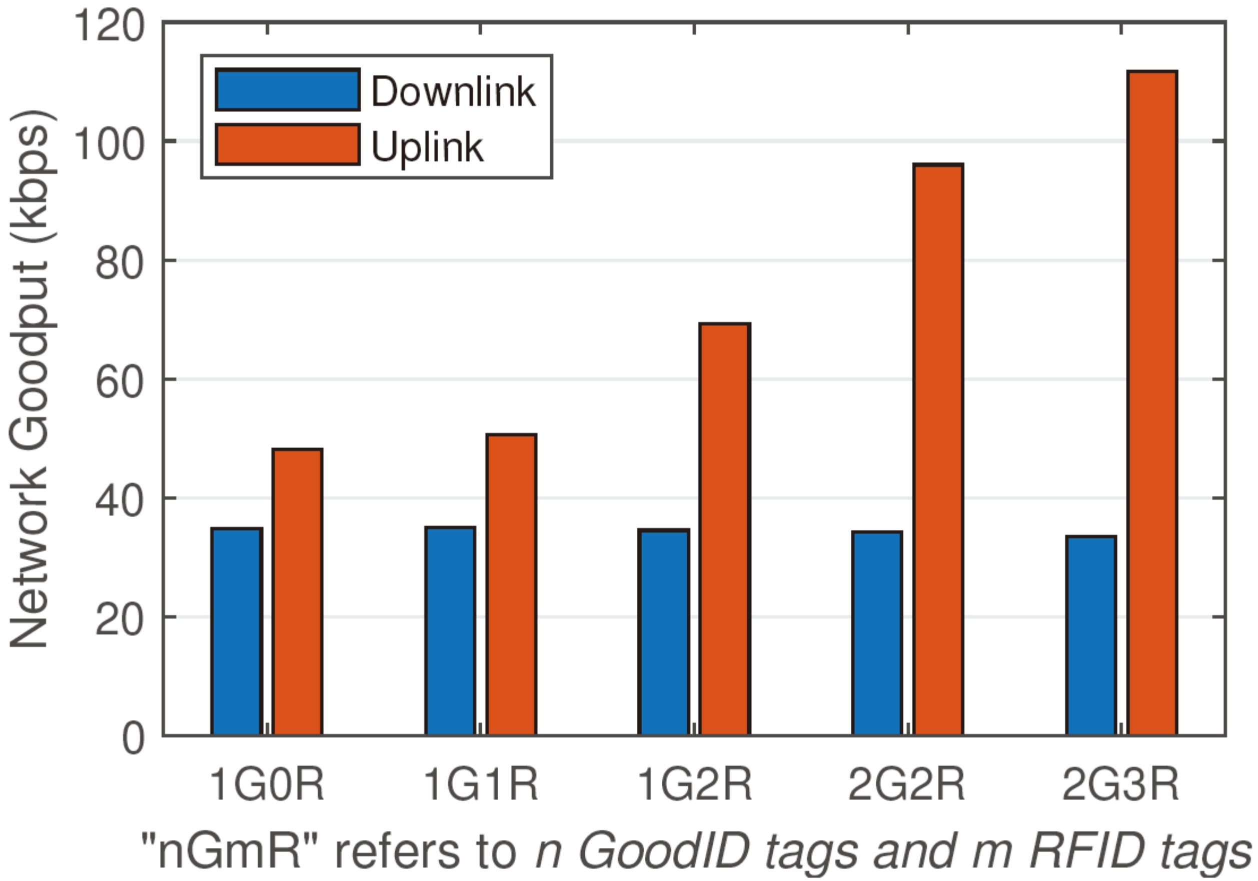




office

Communication distance is up to 20m

Evaluation: multiple tag reading



Downlink: reader talks one-by-one

Uplink: read GoodID first, then normal RFID tags

Conclusion

- Enabling ultra-low power sensor capability on RFID tags

- PHY layer: hybrid analog-digital RFID baseband demodulation

- Link layer: Select-EPC frame for efficient sensor operation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Natick
Grazie
Danke
Ευχαριστίες
Dalu
Obrigado
Thank You
Köszönöm
Tack
Спасибо
Dank
Gracias
谢谢
Merci
Seé
ありがとう