RF-Wise: Pushing the Limit of RFID-based Sensing

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Content

- Motivation
- RF-Wise Design
- Evaluation
- Conclusion
Motivation

Radio Frequency Identification

Retail

Access Control

Storage
Motivation

Radio Frequency Identification

Material identification

Localization

Gesture recognition
Motivation

Single-dimensional sensing feature!

Phase / RSS/Doppler shift
Motivation

Antenna Array

Tag Array

Higher cost

Collision
Motivation

Frequency hopping

Large latency

ISM band

Wide band sensing

Large overhead

ISM band
Motivation

Can we improve RFID sensing without such extra costs and overhead?

RF-Wise brings a positive answer!

- Multiple-frequency sensing
- No extra devices
- One tag only
- Within the ISM band
RF-Wise Design

➤ RFID communication

CW with a constant amplitude

- Query
- ACK

Reader's query
Tag's response
RF-Wise Design

Observation

- Tag’s backscattering is not sensitive to the waveform format of the continuous wave.
RF-Wise Design

- Signal customization

Random sequence → OFDM symbol → Customization

- OFDM symbol
- EPC Gen2 Protocol
RF-Wise Design

➢ Signal customization
RF-Wise Design

Signal customization

\[ L_{OFDM} < \frac{B}{2f_{BLF}} \quad \rightarrow \quad L_{OFDM} < \frac{B}{\mu f_{BLF}} \begin{cases} 
\mu = 2 & \text{for bit 1} \\
\mu = 4 & \text{for bit 0}
\end{cases} \]

Sample number \( M = \frac{B}{f_{BLF}} \)
RF-Wise Design

- Signal customization

Random sequence → OFDM symbol → Customization

- $E_{OFDM} < E_{require} \rightarrow$ No tag’s reply
- $\alpha \cdot E_{OFDM} > E_{require} \rightarrow$ Tag’s reply cannot be decoded
- $\beta \cdot E_{OFDM} + E_{CW} > E_{require} \rightarrow$ Tag functions well
RF-Wise Design

- Harnessing wider band

Graph showing the ISM band from 902 MHz to 928 MHz, with narrow band several hundreds of kHz.
RF-Wise Design

- Harnessing wider band
  - Inappropriate bandwidth
  - → integrator-comb (CIC) roll-off
RF-Wise Design

- Harnessing wider band
  - Inappropriate bandwidth
    - → integrator-comb (CIC) roll-off
  - → RFID parameters

\[
\max\{\theta_B\} \ B, \quad s.t. \ \begin{align*}
  & 1 \ B \leq B_u, \\
  & 2 \ \frac{r}{B} \in \{2^i\}, \ i = 1, 2, \ldots, \\
  & 3 \ L_j(B, \theta_B) \in N_+, \ j = 1, \ldots, 4,
\end{align*}
\]
RF-Wise Design

- Harnessing wider band
  - Inappropriate bandwidth
    - → integrator-comb (CIC) roll-off
  - → RFID parameters

Setting of RFID’s meta parameters used in RF-Wise. The central frequency of RFID communication is set to 915 MHz.

<table>
<thead>
<tr>
<th>$f_{BLF}$</th>
<th>$P_{TR_{cal}}$</th>
<th>$P_{RT_{cal}}$</th>
<th>$P_{T_{ari}}$</th>
<th>$P_{T_1}$</th>
<th>$P_{T_2}$</th>
<th>$P_{DC}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 KHz</td>
<td>160 $\mu$s</td>
<td>60 $\mu$s</td>
<td>20 $\mu$s</td>
<td>180 $\mu$s</td>
<td>380 $\mu$s</td>
<td>90 $\mu$s</td>
</tr>
</tbody>
</table>
RF-Wise Design

- Harnessing wider band
RF-Wise Design

Feature extraction

\[ f_{\text{target}} + f_{\text{env}} \]

\[ f_{\text{env}} \]

\[ F_{\text{sta}} = \frac{1}{q_1} \sum_{i=1}^{q_1} H_i^1(\text{on}) - \frac{1}{q_2} \sum_{j=1}^{q_2} H_j^1(\text{off}) \]

\[ F_{\text{dyn}} = \mathcal{H}^{0/1} = \left\{ H_i^{0/1} \right\}_{i=1}^{q_3} \]
Evaluation

- **Hardware:**
  - USRP X310 with SBX-40 daughterboard
  - Laird S9028PCR antenna
  - Alien 9640 RFID tag
  - X520-DA1 network adapter
  - 10 Gigabit Ethernet Cable

- **Software:**
  - GNU Radio 3.7
  - UHD 3.15
  - Ubuntu 18.04
Evaluation

Liquid classification

1. **PAR-PHA**: one pair of tags (PAR) and signal’s phase information (PHA)
2. **PAR-HOP**: one pair of tags (PAR) with frequency hopping (HOP)
3. **ARY-HOP**: tag array (ARY) and the frequency hopping (HOP)
4. **RF-Wise**: one tag, frequency multiplexing and 25 MHz bandwidth
## Evaluation

### Liquid classification

|   | 1   | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   | 16   | 17   | 18   | Liquids       |
|---|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----------------|
| 1 | 1   |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | 1 Beer         |
| 2 |     | 0.95 |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | 2 Coffee       |
| 3 |     |      | 0.96 |      |      |      |      |      |      |      |      |      |      |      |      |      |      | 3 Coke         |
| 4 |     |      |      | 0.98 |      |      |      |      |      |      |      |      |      |      |      |      |      | 4 Detergent    |
| 5 |     |      |      |      | 0.99 |      |      |      |      |      |      |      |      |      |      |      |      | 5 Juice        |
| 6 |     |      |      |      |      | 0.99 |      |      |      |      |      |      |      |      |      |      |      | 6 Honey        |
| 7 |     |      |      |      |      |      | 0.99 |      |      |      |      |      |      |      |      |      |      | 7 Oil          |
| 8 |     | 0.01 |      |      |      |      |      | 0.96 |      |      |      |      |      |      |      |      |      | 8 Pepsi        |
| 9 |     |      |      | 0.01 |      |      |      |      | 0.99 |      |      |      |      |      |      |      |      | 9 Red Bull     |
|10 |     |      |      |      |      |      |      |      |      | 0.99 |      |      |      |      |      |      |      | 10 Saline water|
|11 |     |      |      |      |      |      |      |      |      |      | 0.03 |      |      |      |      |      |      | 11 Skimmed milk|
|12 |     |      |      |      |      |      |      |      |      |      |      | 0.98 |      |      |      |      |      | 12 Sprite      |
|13 |     |      |      |      |      |      |      |      |      |      |      |      | 0.98 |      |      |      |      | 13 Sweet water|
|14 |     |      |      |      |      |      |      |      |      |      |      |      |      | 0.98 |      |      |      | 14 Vinegar     |
|15 |     |      |      |      |      |      |      |      |      |      |      |      |      |      | 0.98 |      |      | 15 Water       |
|16 |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      | 0.99 |      |      | 16 Whole milk  |
|17 |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | 0.97 |      | 17 Wine        |
|18 |     |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      | 18 Yogurt      |
Evaluation

Liquid classification

After 1 hour
After 2 hours
After 4 hours

Fresh Milk

w/ 2.5% water
w/ 5.0% water
w/ 7.5% water

Wine
Evaluation

Gesture recognition

- **PAR-PHA**: one pair of tags (PAR) and the phase information (PHA)
- **PAR-HOP**: one pair of tags (PAR) with frequency hopping (HOP)
- **ARY-PHA**: tag array (ARY) and signal’s phase information (PHA).
- **RF-Wise**: one tag, frequency multiplexing and 25 MHz bandwidth
Evaluation

Gesture recognition

(a) Features from Frequency Hopping

(b) Features from RF-Wise
Evaluation

- Compatible to RFID communication

(a) Reading rate v.s. Bandwidth
(b) Decoding rate v.s. Bandwidth
(c) Reading distance v.s. Bandwidth
Evaluation

- Latency
Conclusion and Q&A

• First work to collect the fine-grained CSI-like sensing features from the RFID signal.

• https://cui-zhao.github.io/RF-WISE/