TagFree: Passive Object Differentiation via Physical Layer Radiometric Signatures

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Object Distinguishing

- **Object distinguishing has wide applications**

Security Check	Asserts Managing	Novel HCI

- **Some applications have additional requirements**
  - No additional device
  - No impairment to object
  - Being pervasive

Precious Goods	Security
	Gaming

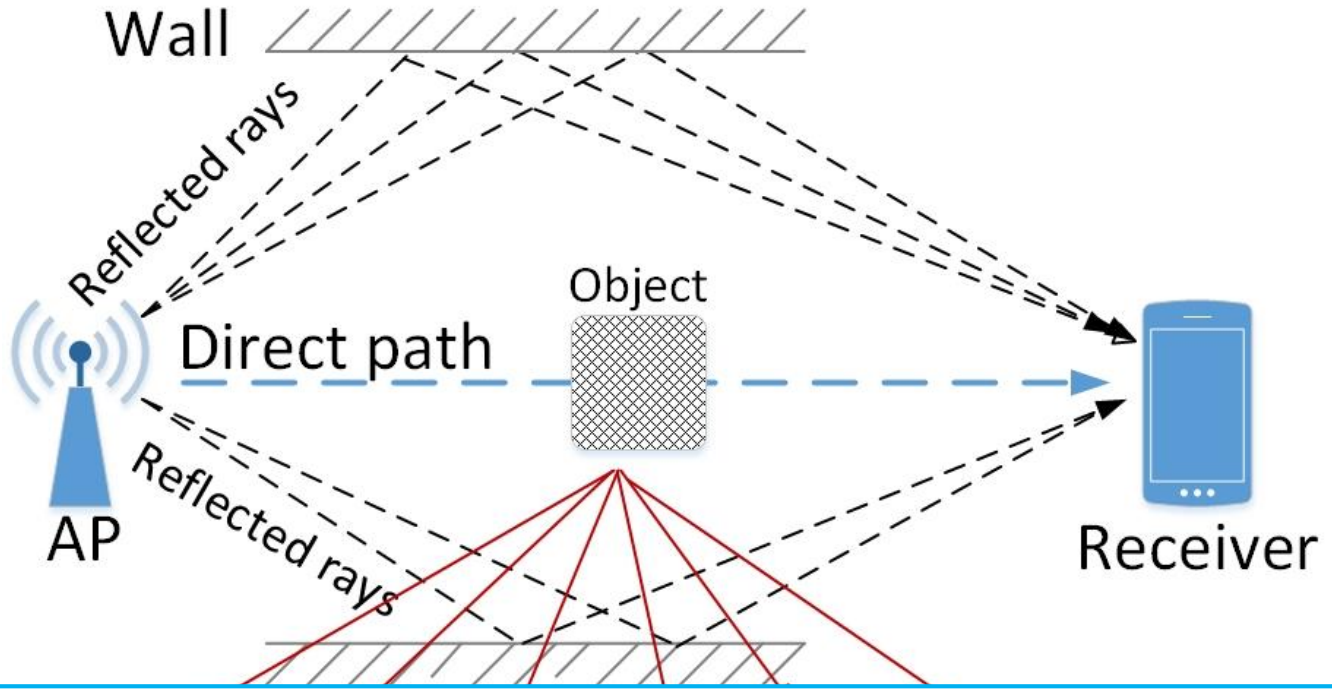
Existing Techniques

- **Computer Vision**
  - Sensitive to background variation
  - Require good ambient light condition
- **RFID**
  - Need to attach tags on objects
- **Radar**
  - Specialized equipment
  - High cost

Question

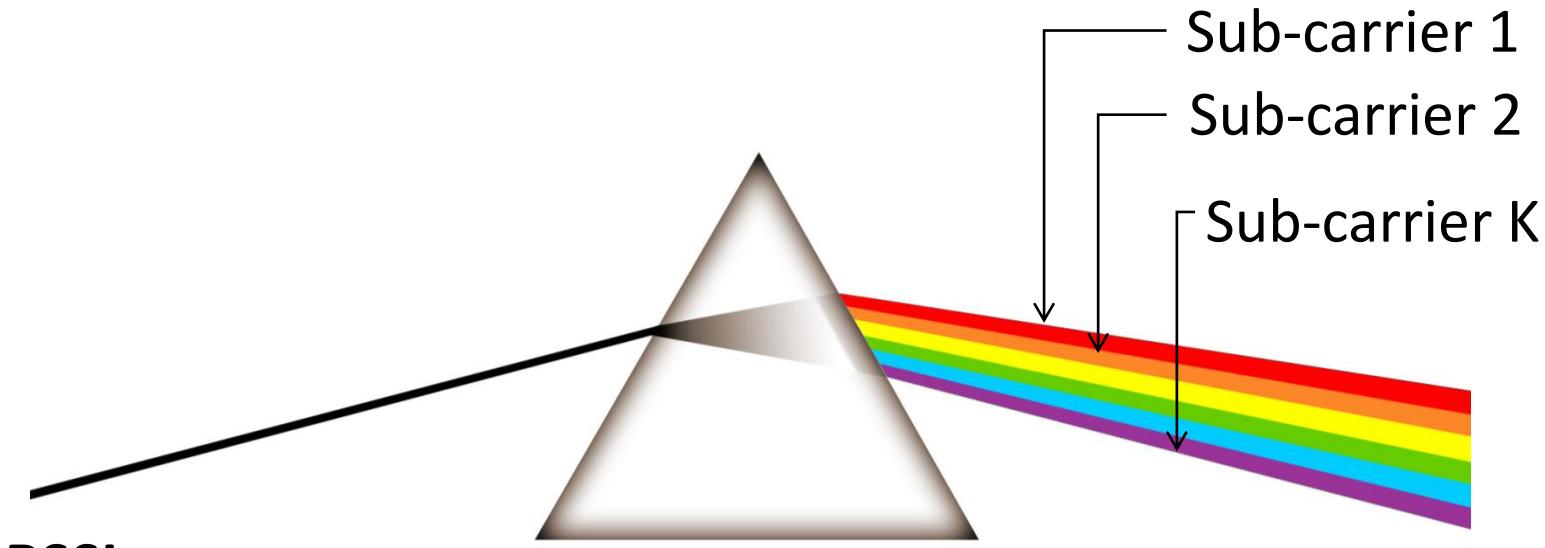
Can we develop a method to distinguish objects with low-cost pervasive devices in a passive way?

Our basic intuition



Can Wi-Fi signals Be Used to Differentiate Objects?

Insight: *Channel State Information*



RSSI:
Sunbeam

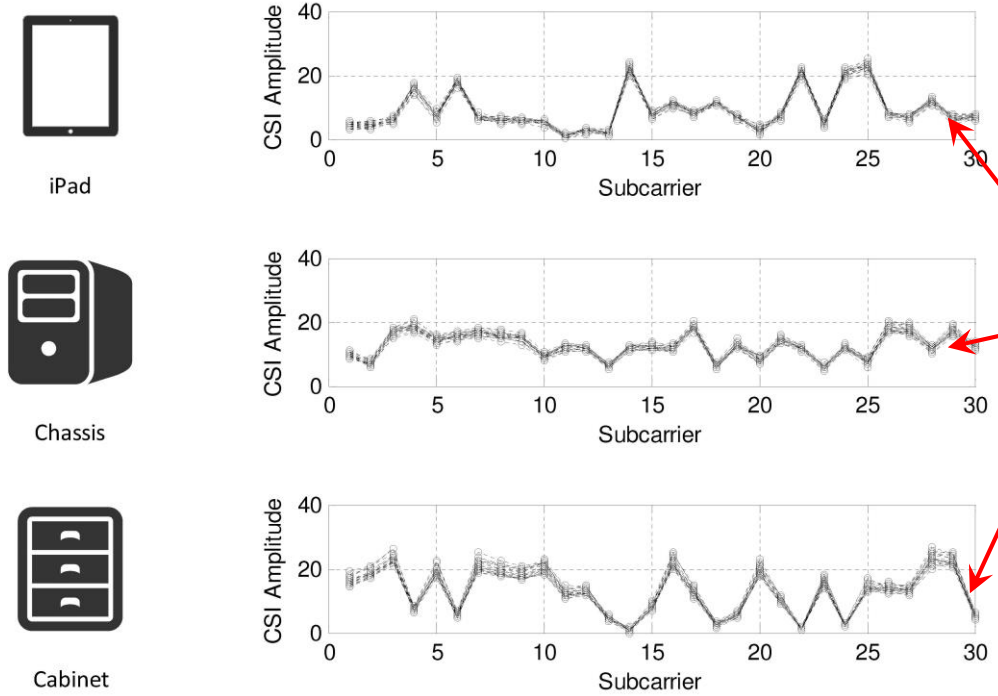
OFDM:
Prism

CSI:
Dispersed Lights

CSI VS RSSI

	Layering	Time Resolution	Frequency Resolution	Stability	Ubiquity
RSSI	MAC Layer	Packet level	N/A	Low	Handy access
CSI	PHY Layer	Multipath clusters	Sub-carrier level	High for CFR	Commercial WiFi

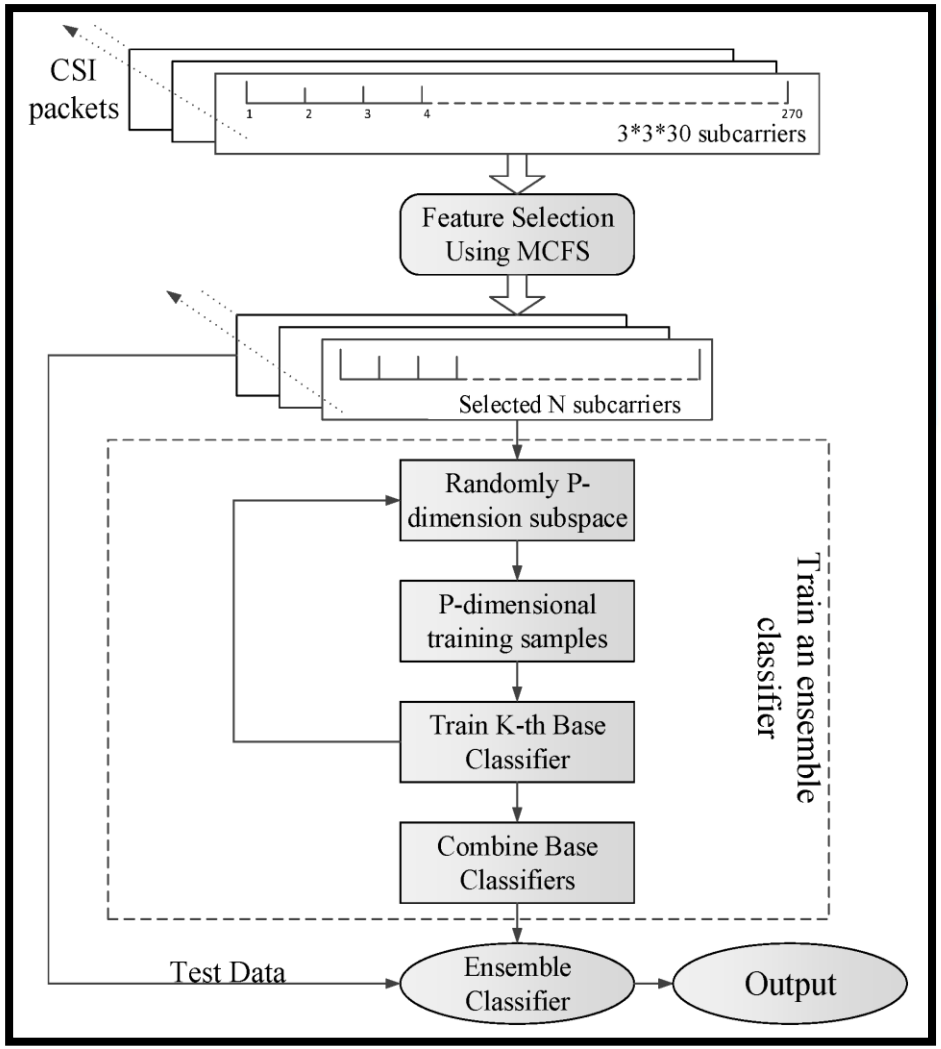
Preliminary Study

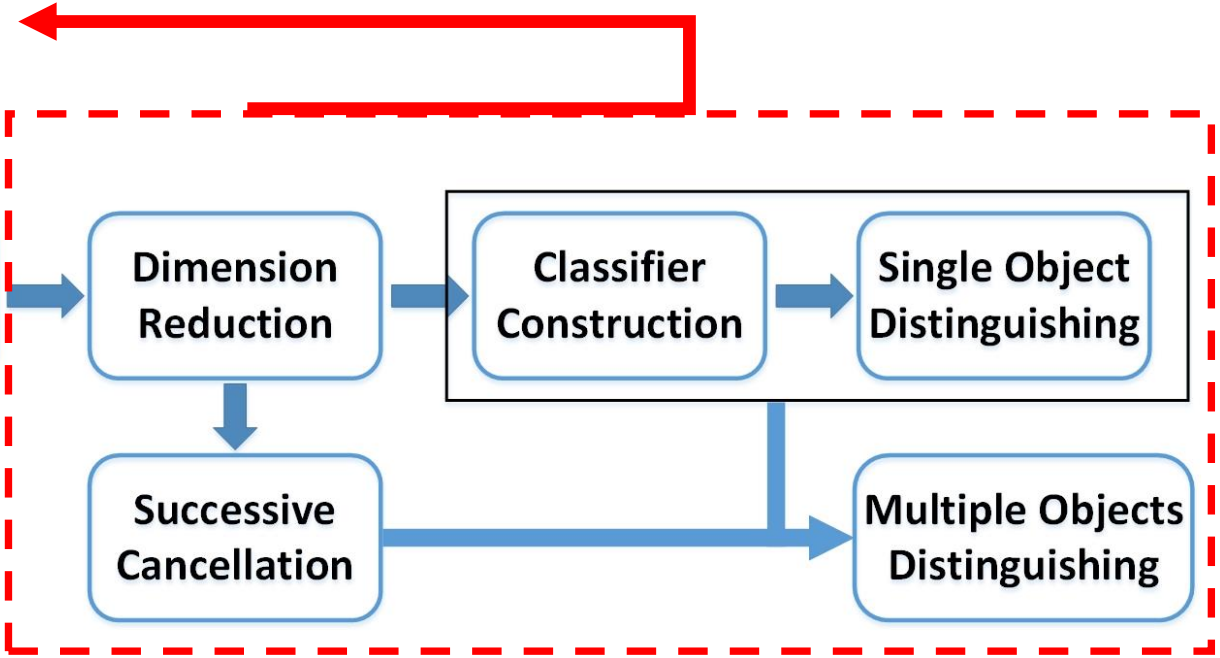


30 times experiments for each

- **The CSI of a same object share consistent pattern**
- **The CSI of different objects differ in patterns**

TagFree Architecture

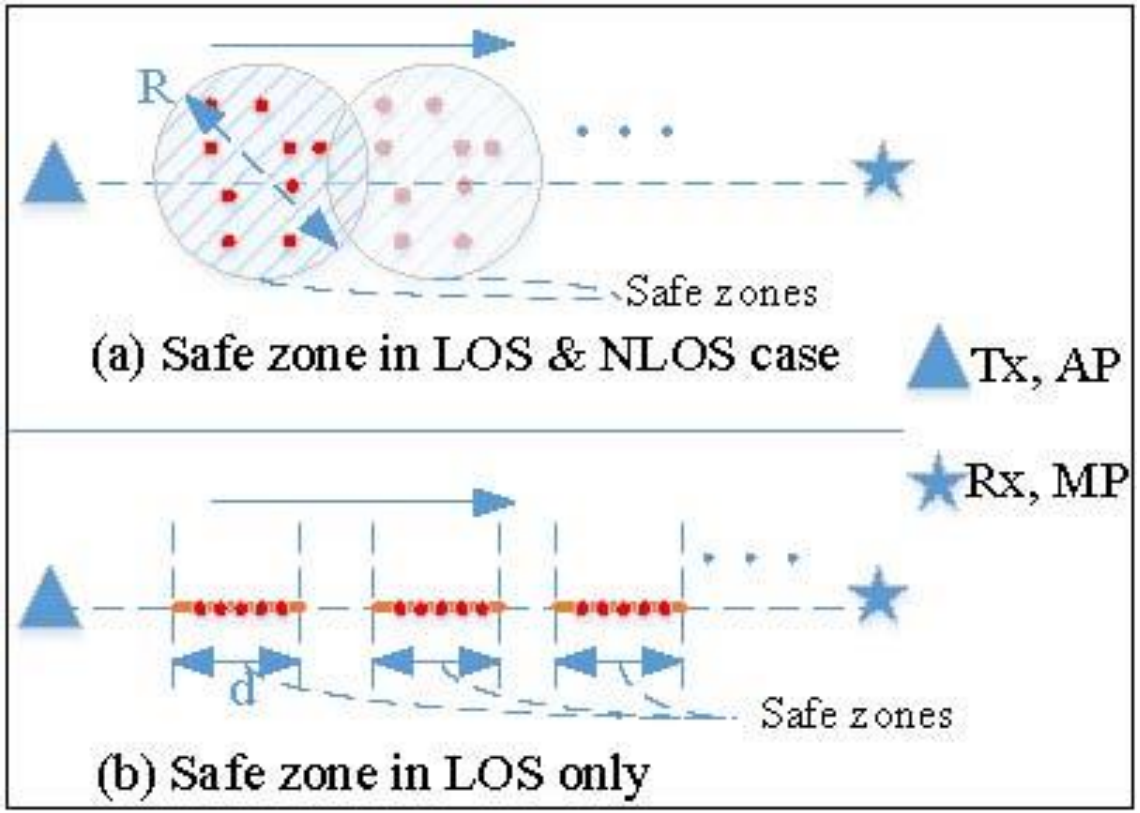




Challenges

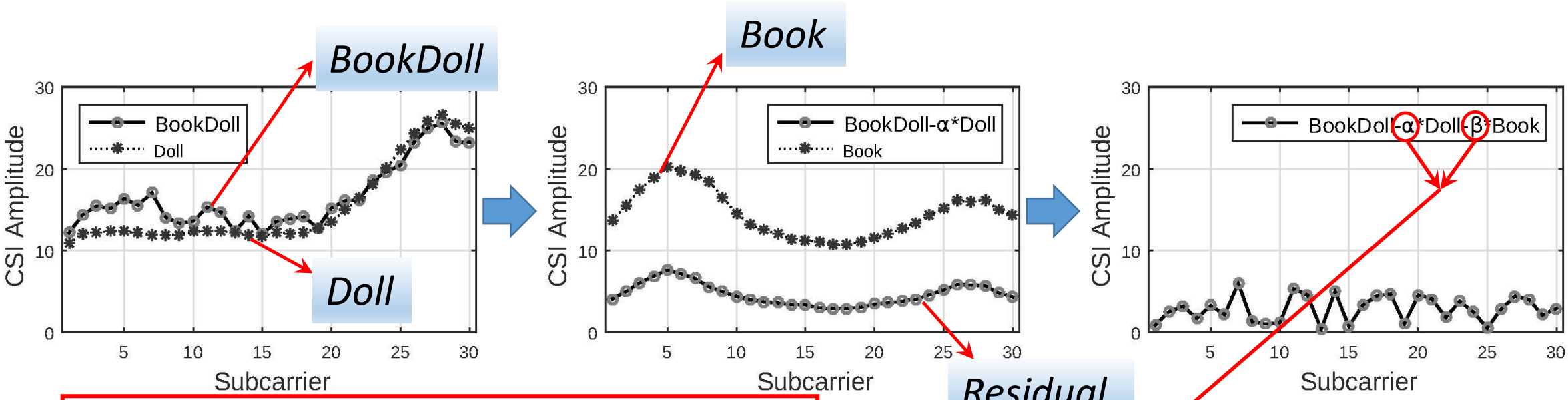
- **How to remove the location dependence?**
  - Objective: Remove location dependence to some extent
  - Key: Safe zone concept
- **How to recognize multiple objects concurrently?**
  - Objective: Recognize multiple objects simultaneously
  - Key: Successive cancellation technique

Safe Zone



Intuition: a certain region in which object diversity, rather than site-specific propagation, dominates the impact on the channel

Successive Cancellation



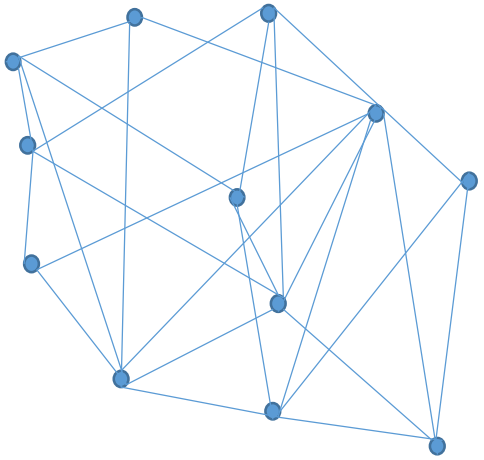
- **Step 1:** Retrieve in the signature database and return the one that best matches the current residual (mixed) signature.
- **Step 2:** Remove the impact of the matched signature by deducing it from the current mixed signature. To cope with the non-linear impact, the matched signature is multiplied by a *correlation coefficient* from a pre-measured correlation coefficient matrix before subtracting it from the mixed signature.

α, β: *correlation coefficient*

$$\min \sum_{i=1}^{M} \frac{\|C_{i,j} \times H_{i,j} - \mathbb{H}_i\|^2}{N_i}$$

$$\text{Subject to } \forall \mathbb{H}_i \neq 0 \ , \ C_{i,j} \neq 0$$

Feature Selection: *Multi-Cluster/Class Feature Selection*



N CSI data points $P = [p_1; p_2; \ldots; p_N]$

$$W_{i,j} = e^{-\frac{\|p_i - p_j\|^2}{\epsilon}}$$

$$Lv = \lambda Av$$

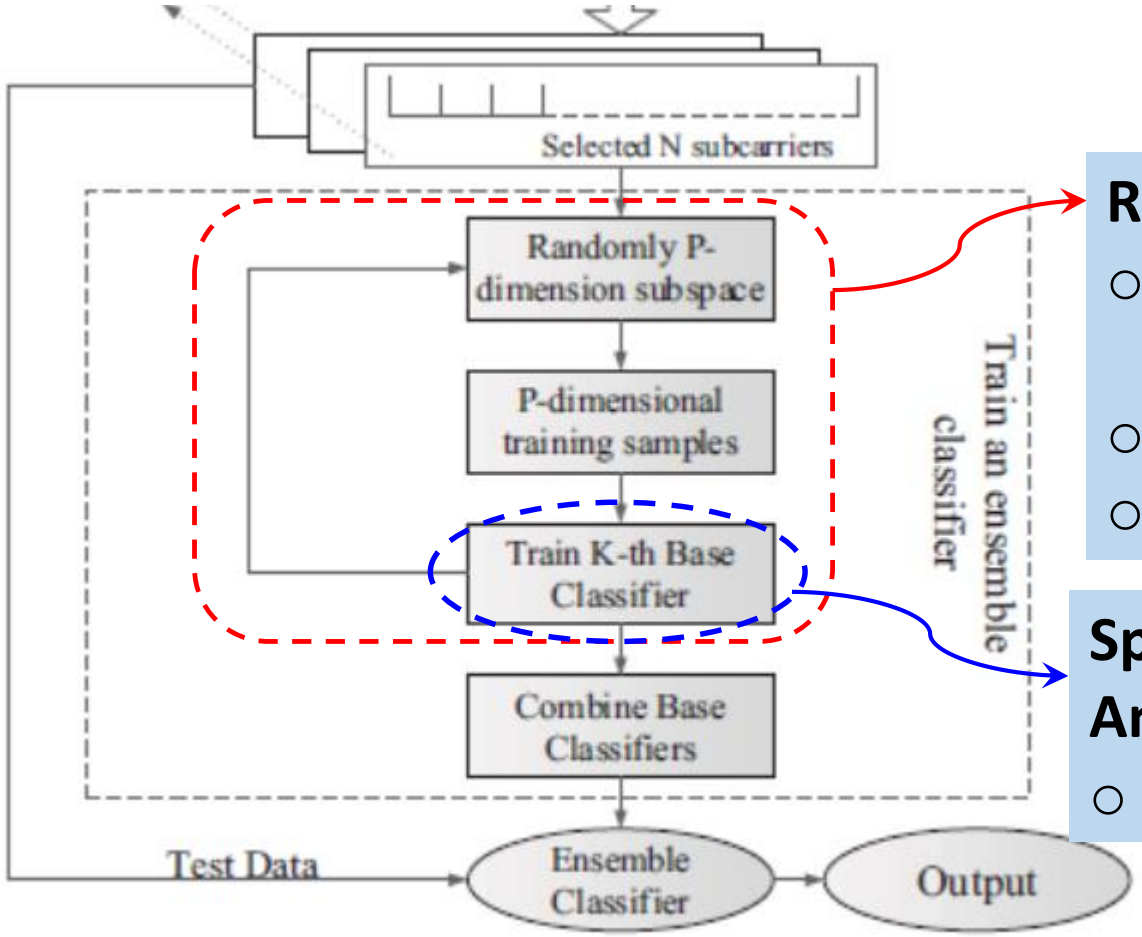
Where, $A_{ii} = \sum_j W_{ij}$, $L = A - W$

$$\min_{\alpha_k} \|v_k - P^T \alpha_k\|^2 + \gamma |\alpha_k|$$

Where $|\alpha_k| = \sum_{j=1}^{M} |\alpha_{k,j}|$

$$Score(j) = \max_k |\alpha_{k,j}|$$

Learning Algorithm



Random Subspace Method

- Ensemble learning instead of single classifier
- Further reduce data dimensions
- More robust to signal perturbation

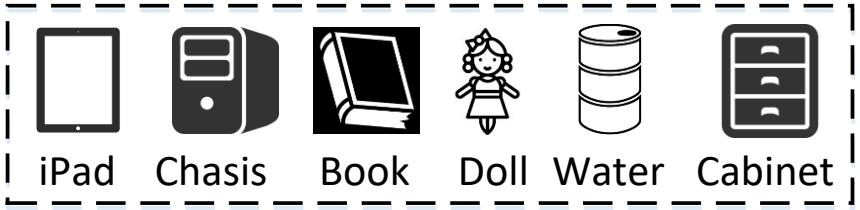
Spectral Regression Discriminant Analysis

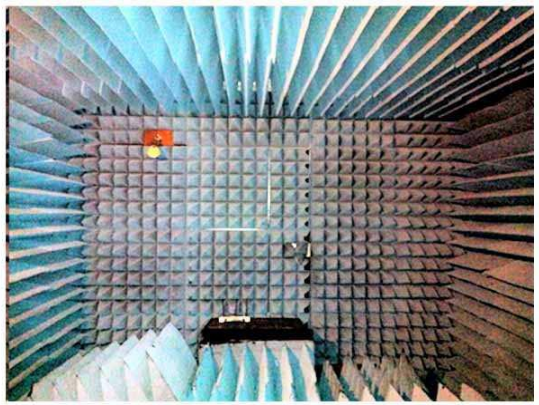
- Low computation redundancy

Implementation and Evaluation Setup

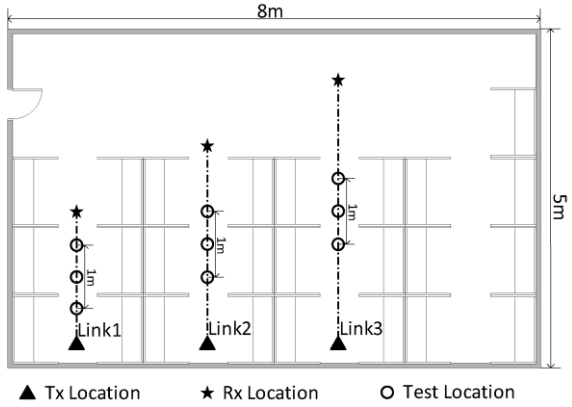
- **Hardware**
  - TP-LINK TL-WDR4300 wireless router
  - 3 omi-directional antennas on both AP and desktop
  - 3.20GHz Intel(R) Pentium 4 CPU 2GB RAM desktop

- **Software**
  - Linux
  - Matlab
- **Testing Objects**
- **Evaluation setup**

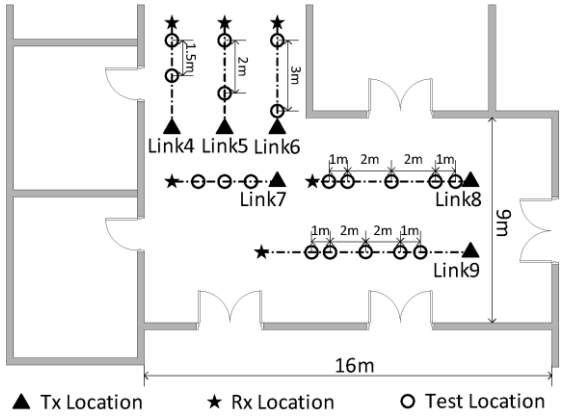




Chamber

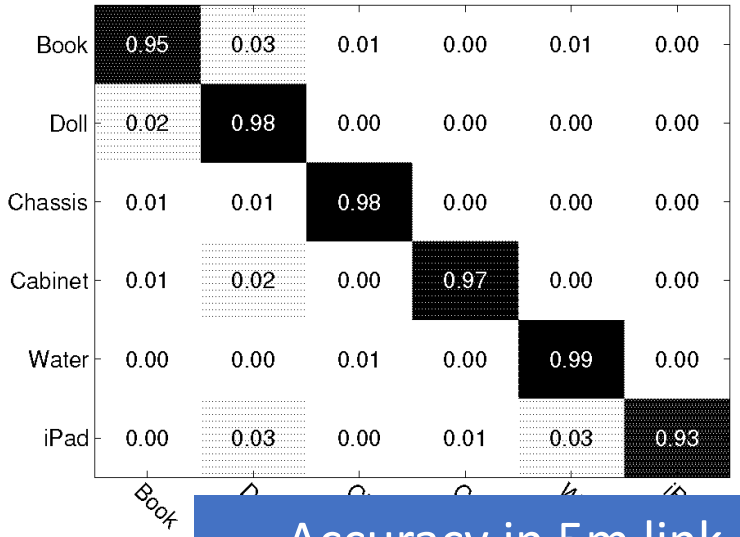


Lab



Lobby

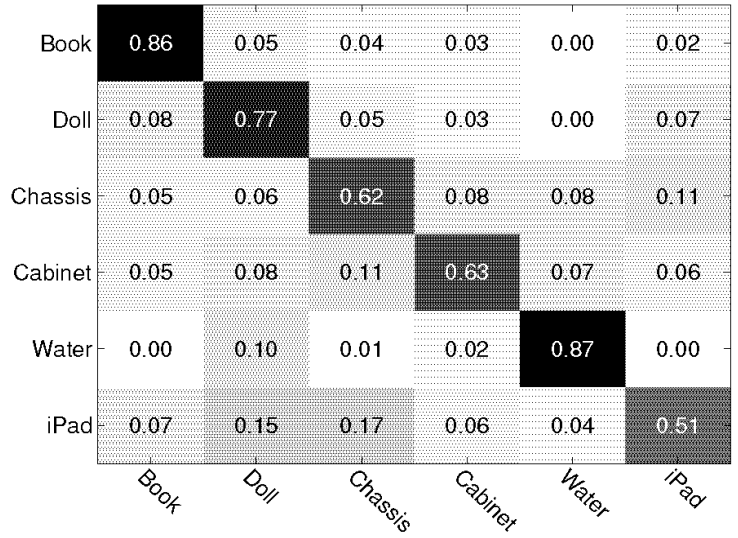
Single Object: *Same-Location Performance*



Accuracy in 5m link

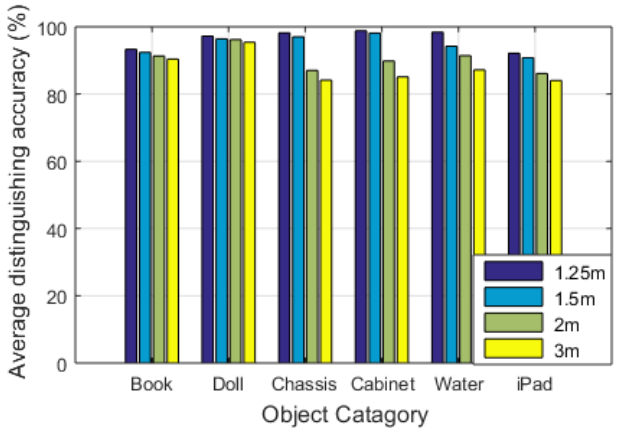
Accuracy in 7m link

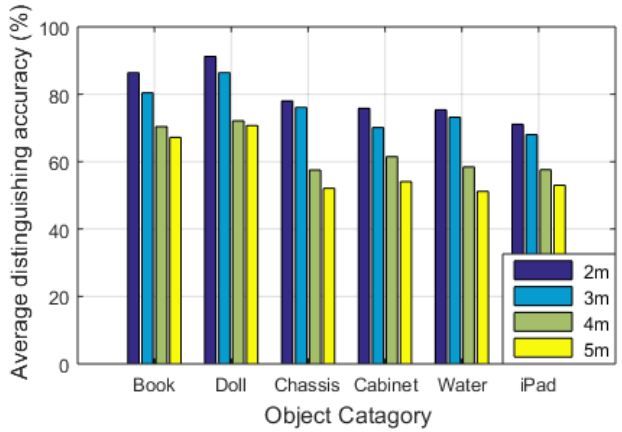
Accuracy in 10 m link



	FPR	FNR	Accu.
5m	0.8%	3%	96.7%
7m	1.8%	9%	90.8%
10m	5.8%	29%	71.0%

Single Object: *Safezone Performance*

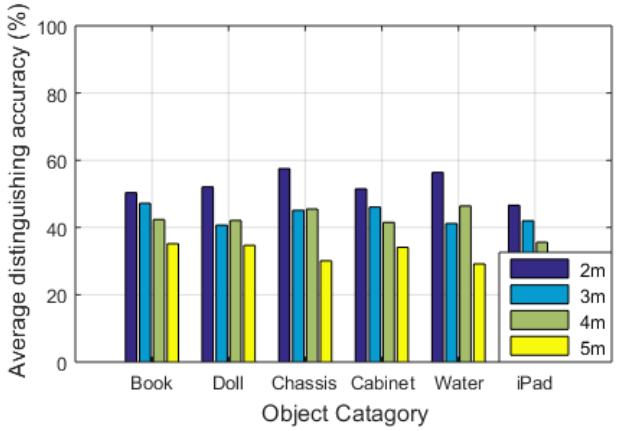




5m Link, different zone

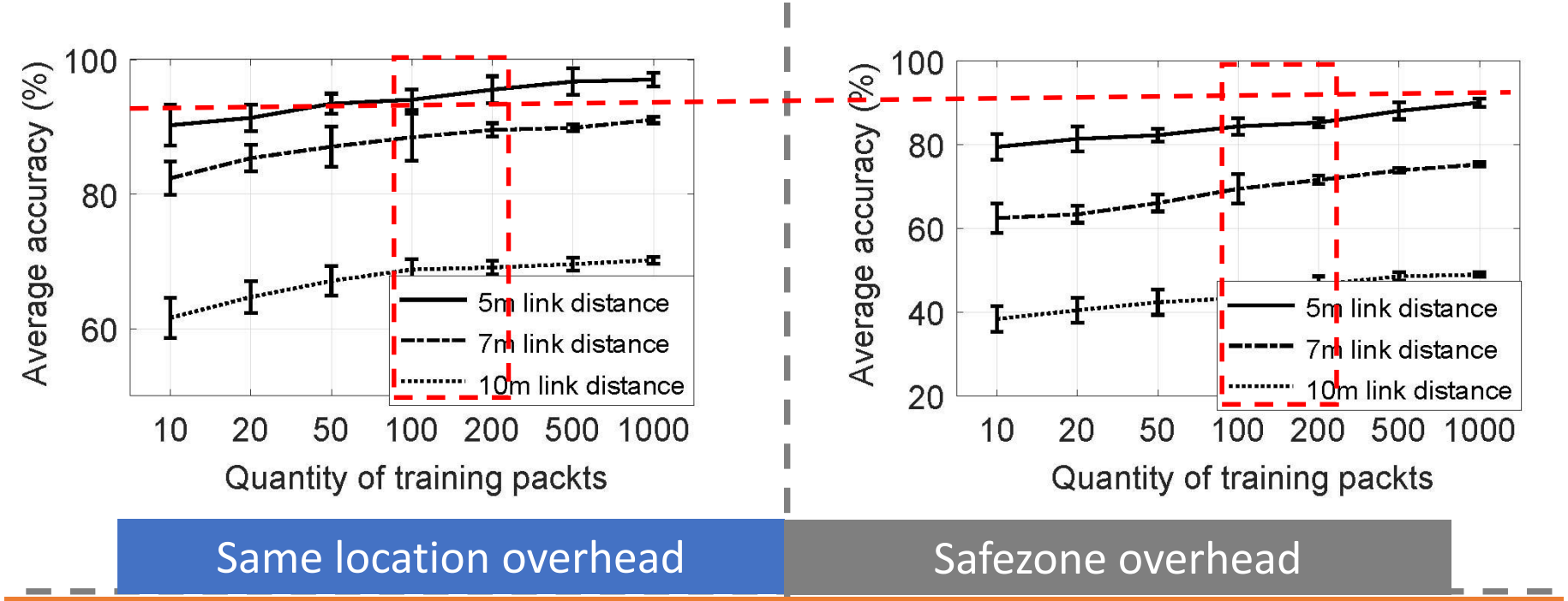
7m Link, different zone

10m Link, different zone



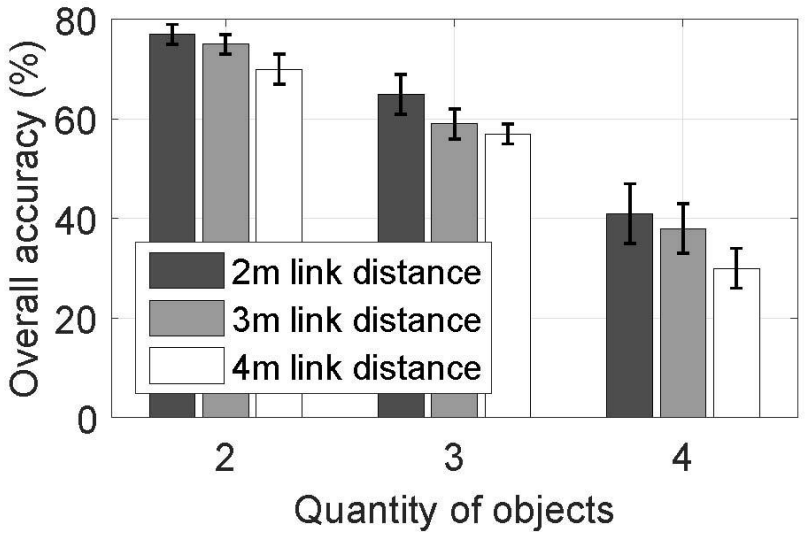
	1.25	1.5	2	3	4	5
5m	96.3%	94.8%	90.3%	87.7%	NA	NA
7m	NA	NA	79.6%	75.7%	62.9%	58.0%
10m	NA	NA	52.4%	43.7%	42.2%	31.8%

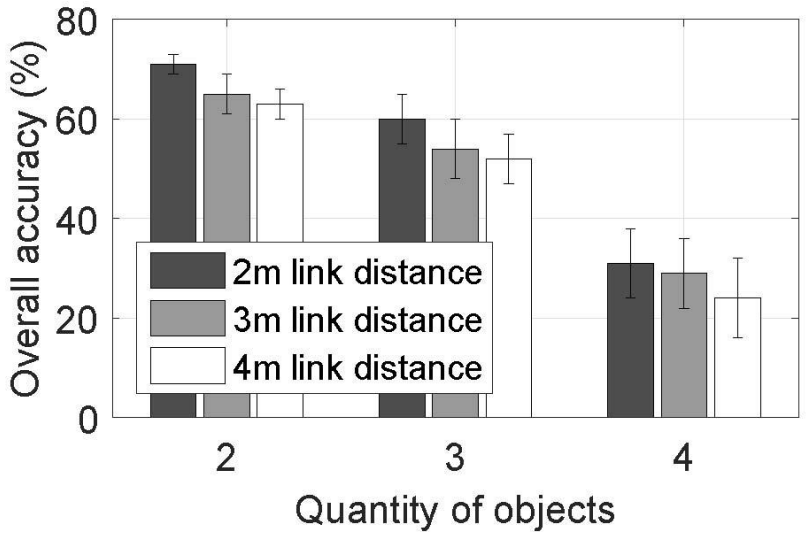
Single Object: *Training Overhead*



- **100~200 packets are enough for training the system**
- **The training overhead is larger in safe-zone case**

Multiple Objects: Accuracy



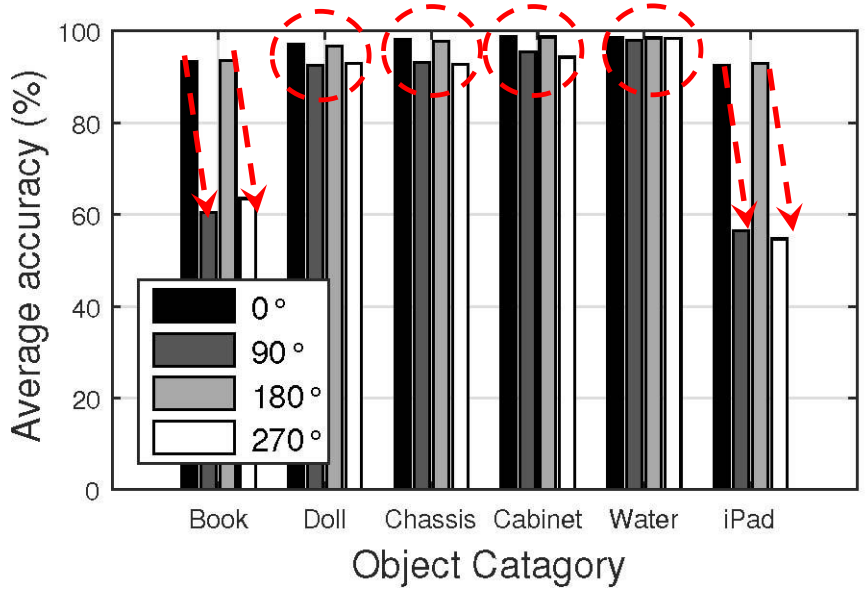


Same location multiple objects

1m Safezone multiple objects

- **The maximum objects to be distinguished concurrently is 3**

Object Orientation



- The distinguishing accuracy varies with the orientation of objects placement
- For objects with approximate syemetric shape, the orientation does not affect the performance much

Future Work

- **LOS requirement**
  - ➢ Only consider the LOS case and need to extend to NLOS case
- **Object category**
  - ➢ Enrich objects categories
  - ➢ More sophisticated analysis
- **Object location**
  - ➢ Further relax the constraint of location and orientation

Conclusion

- **TagFree:** the first step to explore the feasibility of differentiating objects with pervasive WiFi signals
- **Solve two main challenges**
  - Figure out the safe zone to relax Location dependence
  - Propose successive cancellation and recognition scheme to differentiate multiple objects simultaneously
- **Extensive evaluation with commodity WiFi devices**
  - Demonstrate acceptable performance in different cases

Thank you