ZiSense

Towards Interference Resilient Duty Cycling in Wireless Sensor Networks

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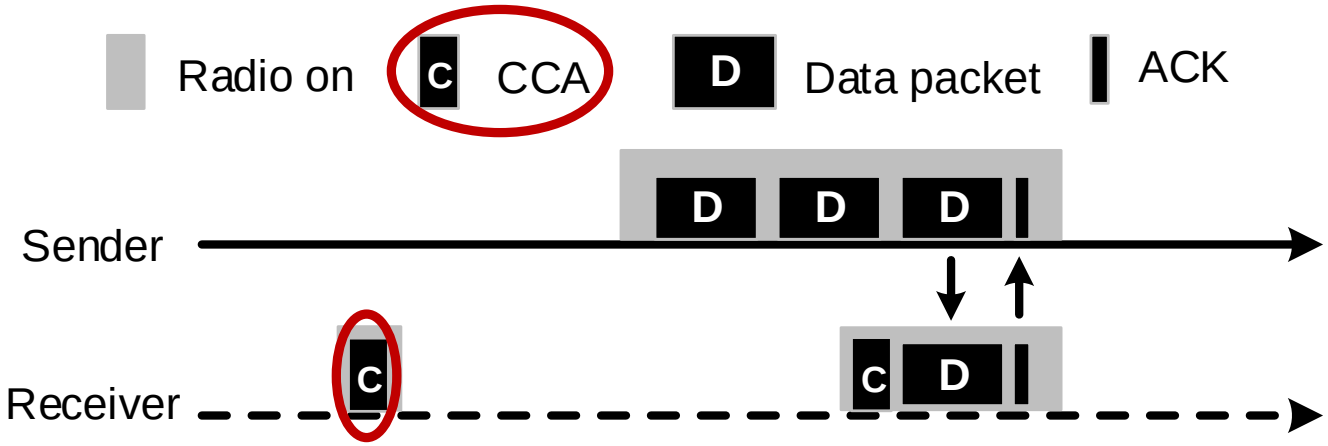
Existing low-power method

- **Radio**: major source of energy consumption
- Duty cycling: Low Power Listening
  - Schedule nodes: sleep (radio off) or wake up (radio on)

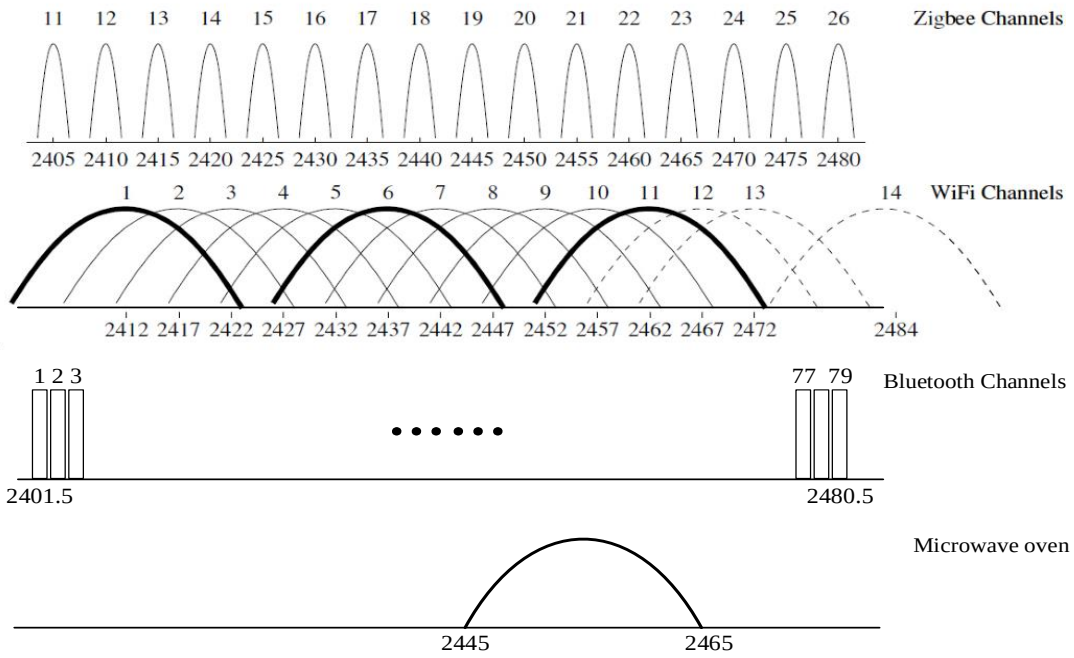


CCA (Clear Channel Assessment)

- Decides a node wake up or not
  - Energy detection by threshold
  - High energy on channel→ Busy channel → Possible transmissions → Wake up nodes
  - Effective energy efficient method in ***clean*** environments

Interference is ignored!

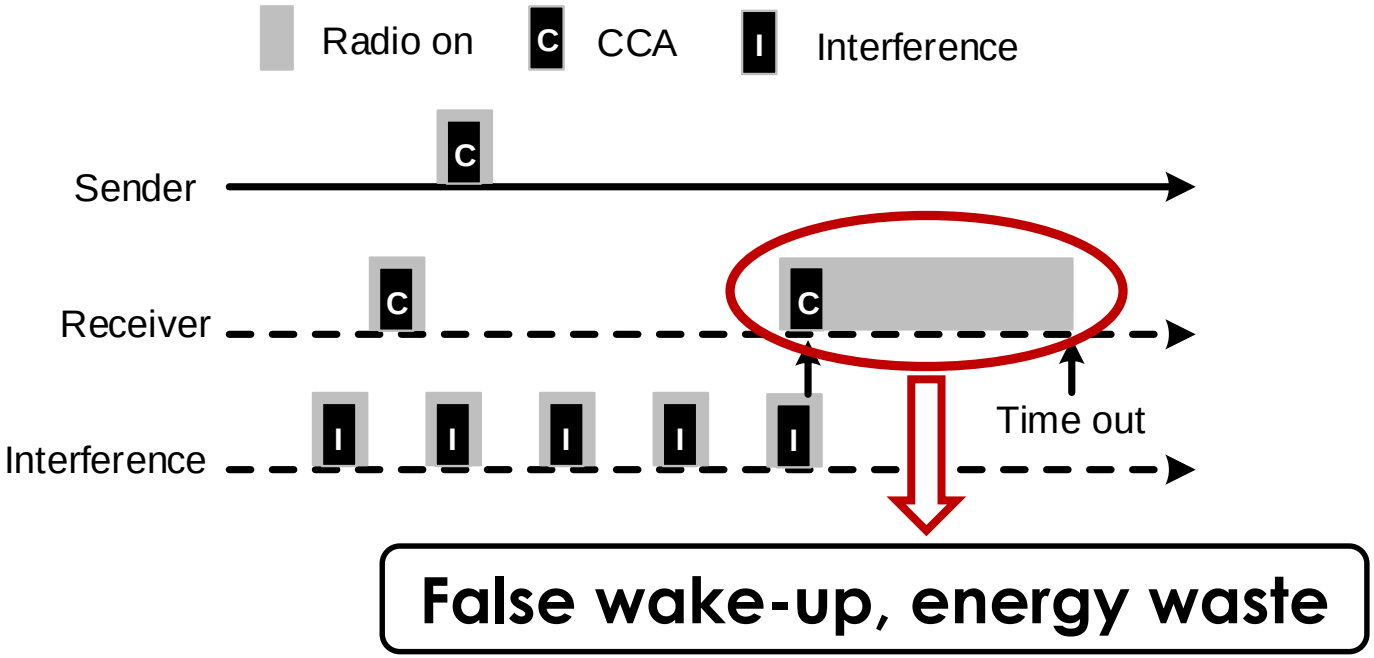
Channel overlapping



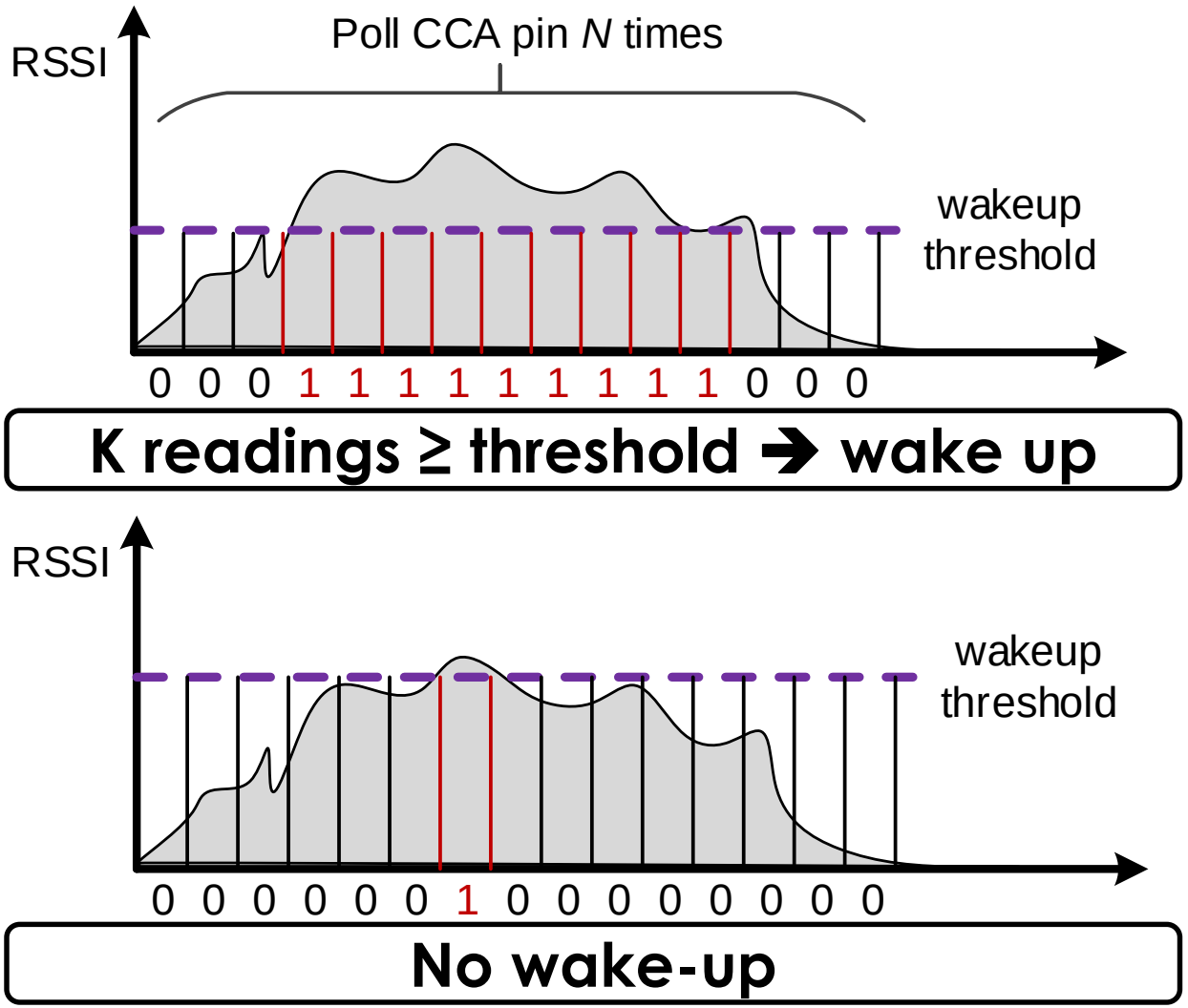
No clean channel away from interference all the time

Impacts on LPL

- **False wake-up problem**
  - Heterogeneous interference unnecessarily wakes up the receiver!

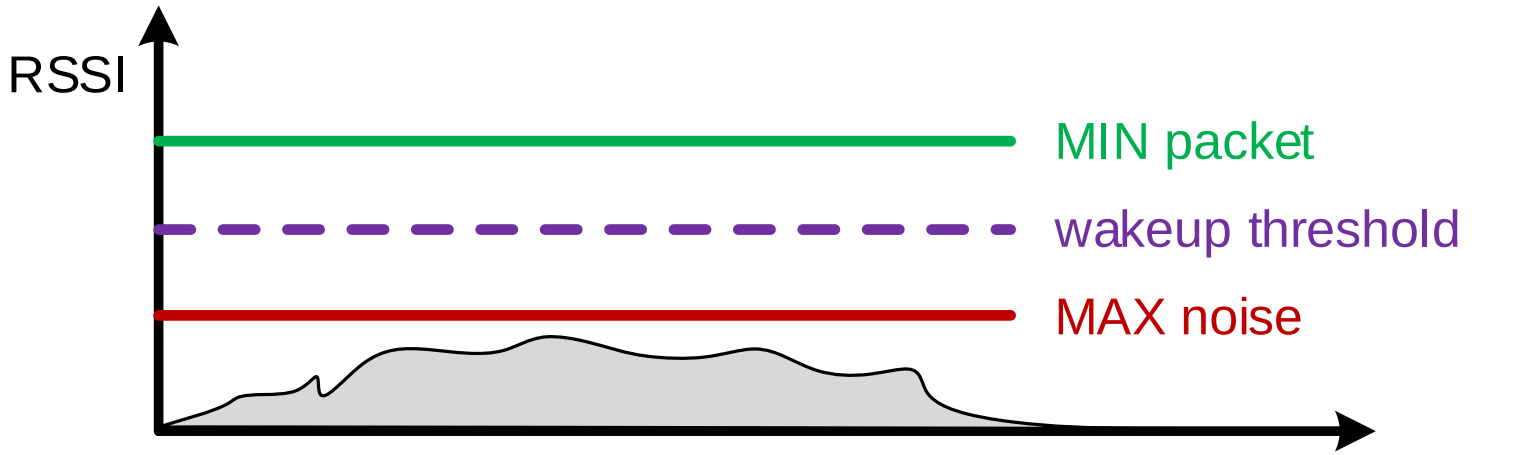


Adaptive Energy Detection Protocol[1]

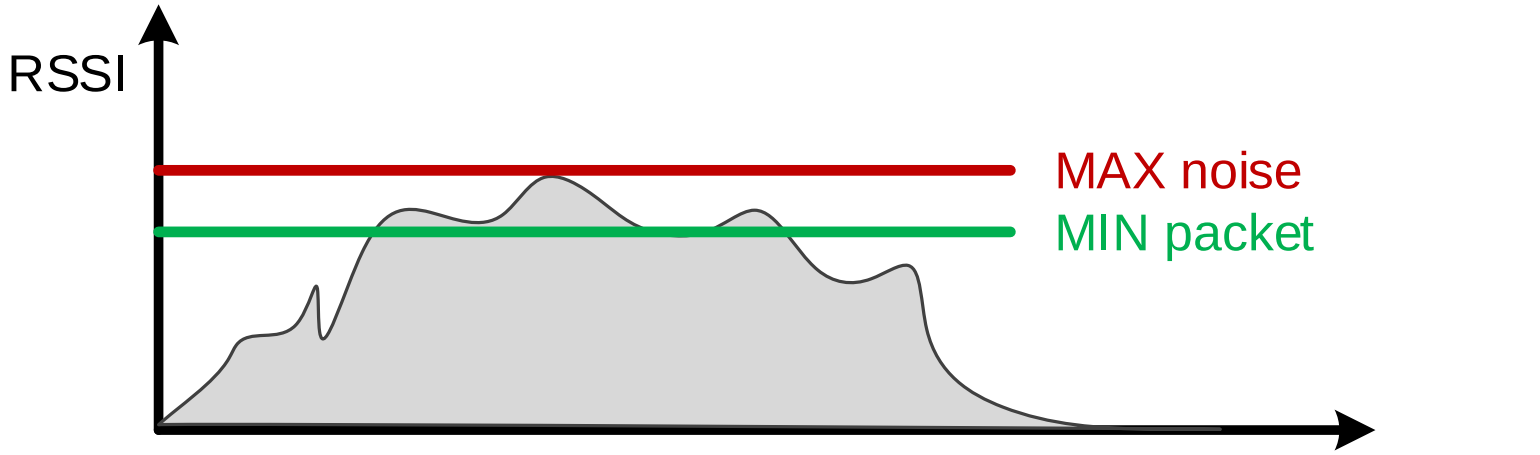


[1] Mo Sha et al. ***Energy-efficient low power listening for wireless sensor networks in noisy environments***, IPSN'13

Limitation



Min packet > Wake-up threshold > Max noise



Key insight

- Energy detection is too simple to filter out the interference
  - High energy on channel → Busy channel → possible ZigBee transmissions

  - No matter how good the threshold is set, false wake-up problem still exists

Can we recognize ZigBee by some other information instead of energy?

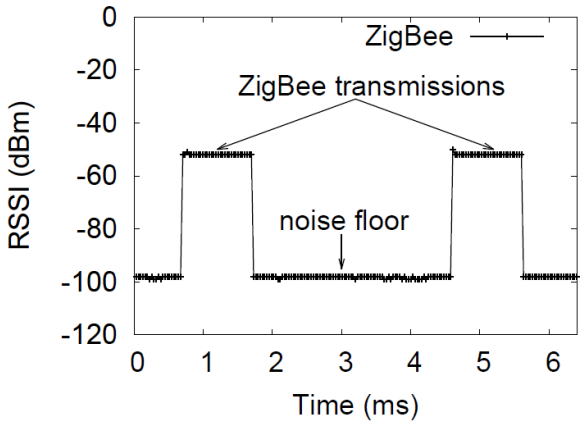
Roadmap

- Background
- Motivation
- **Observations**
- Design of ZiSense
- Evaluation
- Conclusion

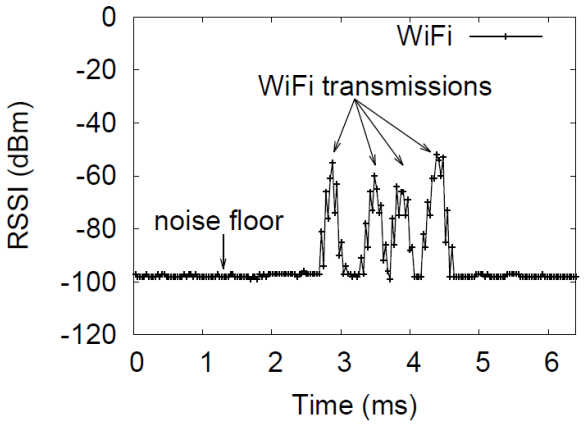
Recognize ZigBee

- Limited information provided by the radio hardware
  - RSSI (Received Signal Strength Indicator)
- Key observation:
  - Different technologies in 2.4GHz leave distinguishable patterns on the time-domain ***RSSI sequence***.

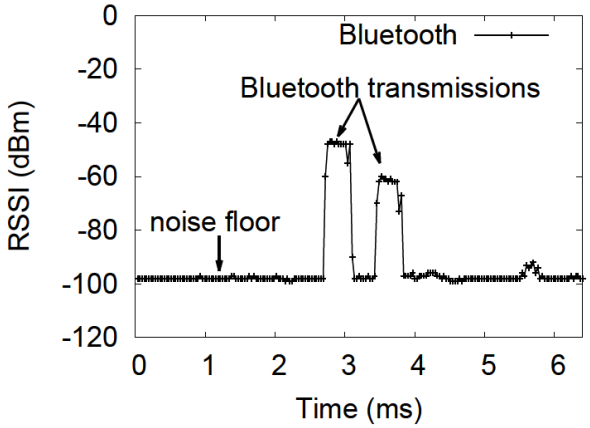
Observations



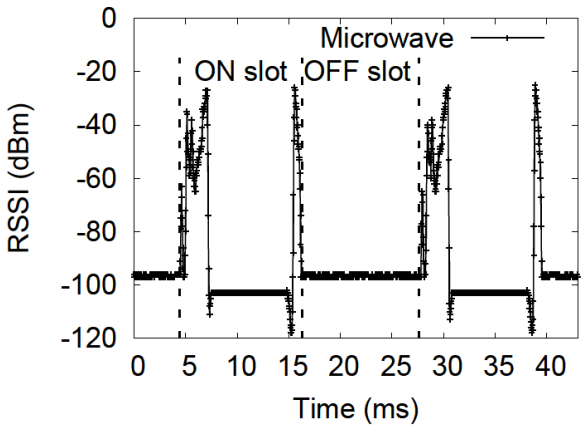
(a) ZigBee



(b) WiFi

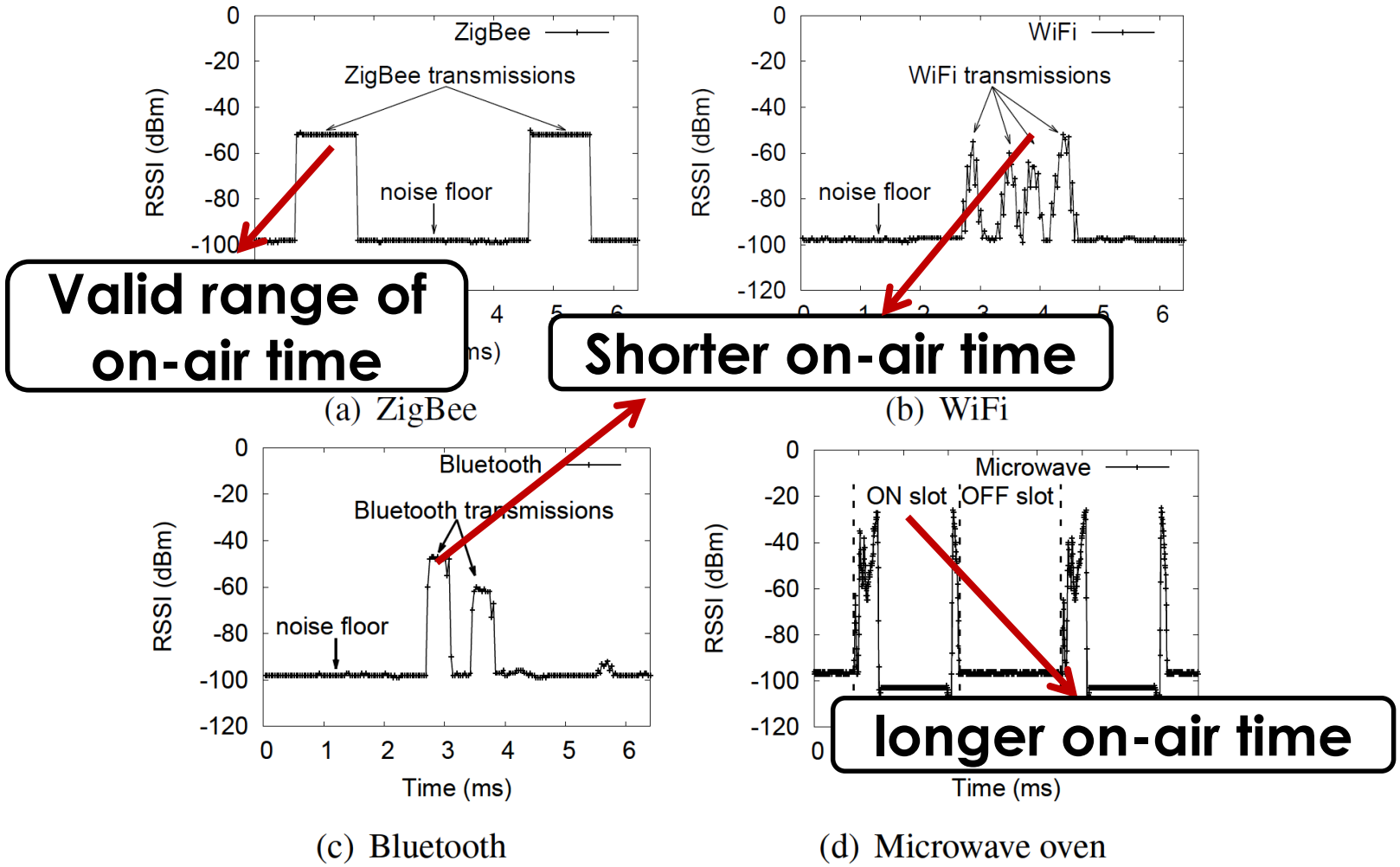


(c) Bluetooth

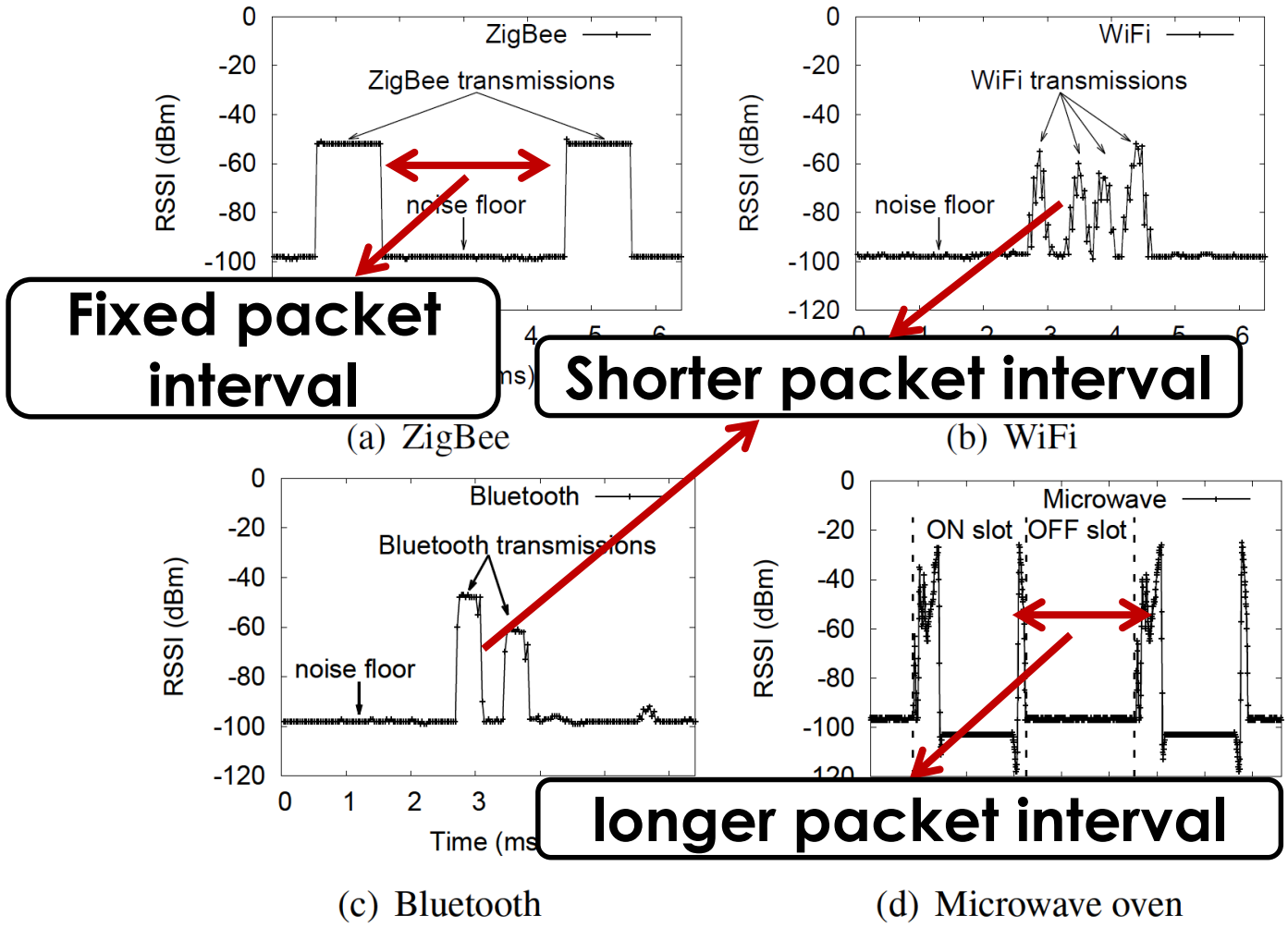


(d) Microwave oven

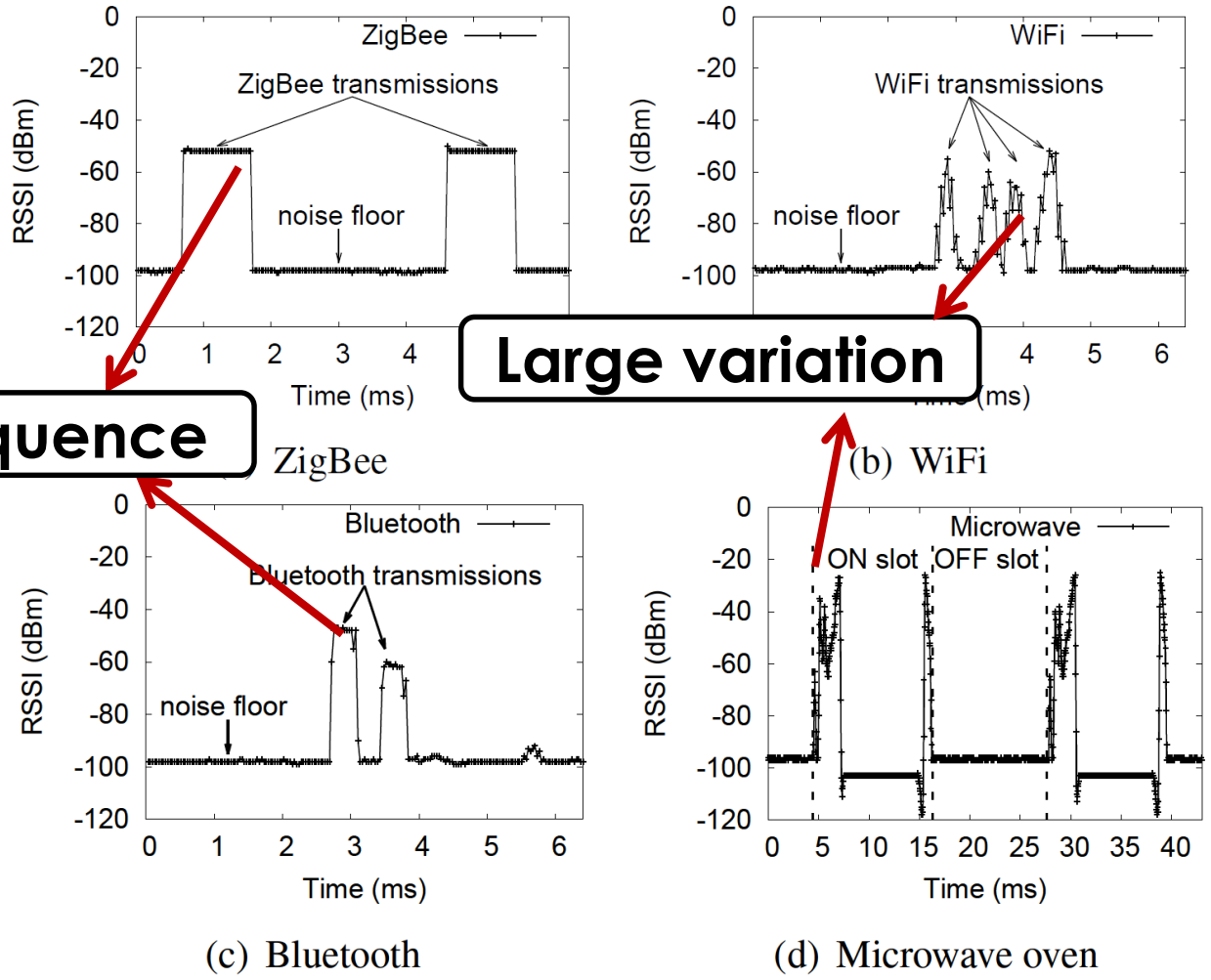
Feature #1: on-air time



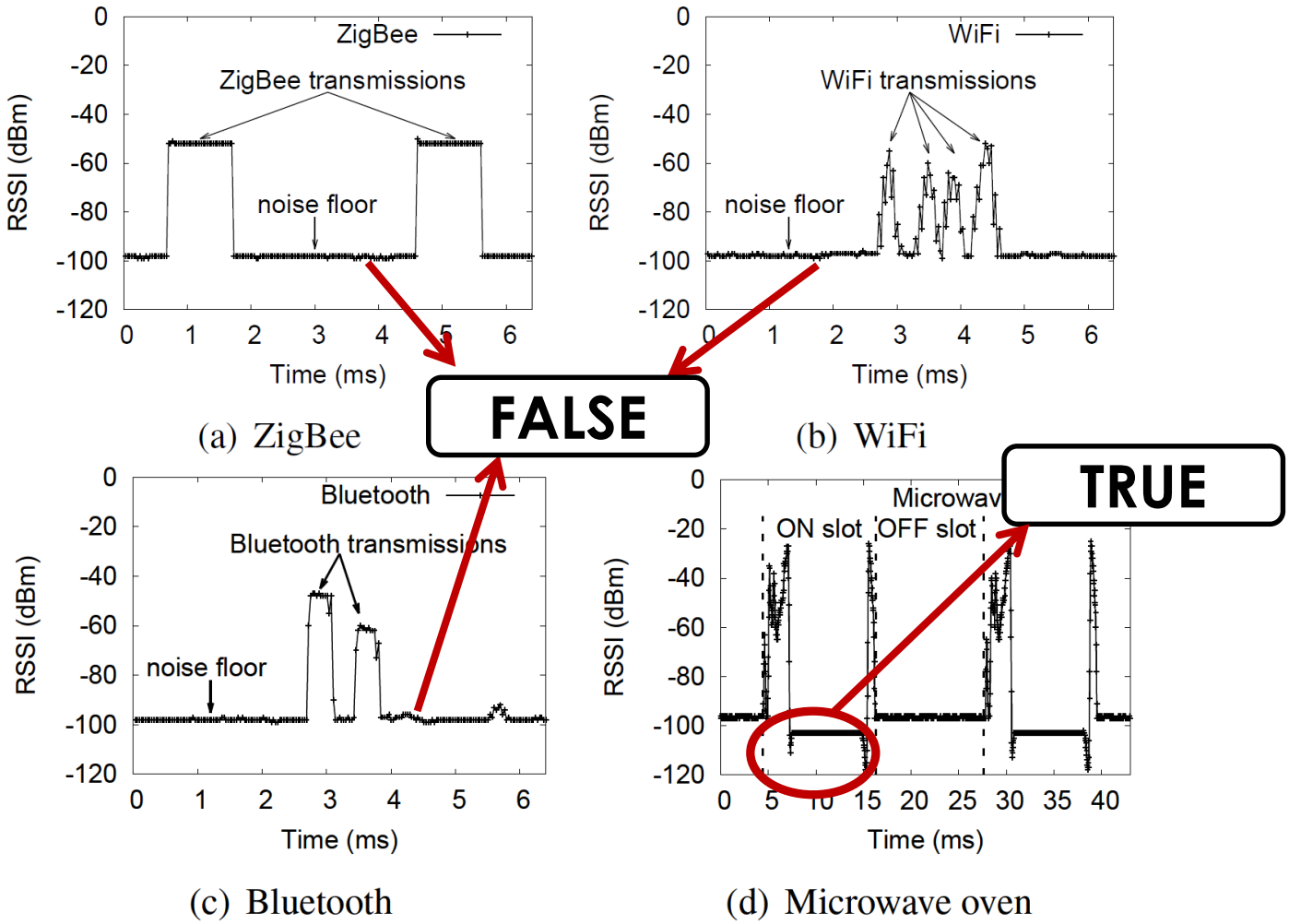
Feature #2: packet interval



Feature #3: PAPR (Peak-to-Average Ratio)



Feature #4: RSSI < noise floor



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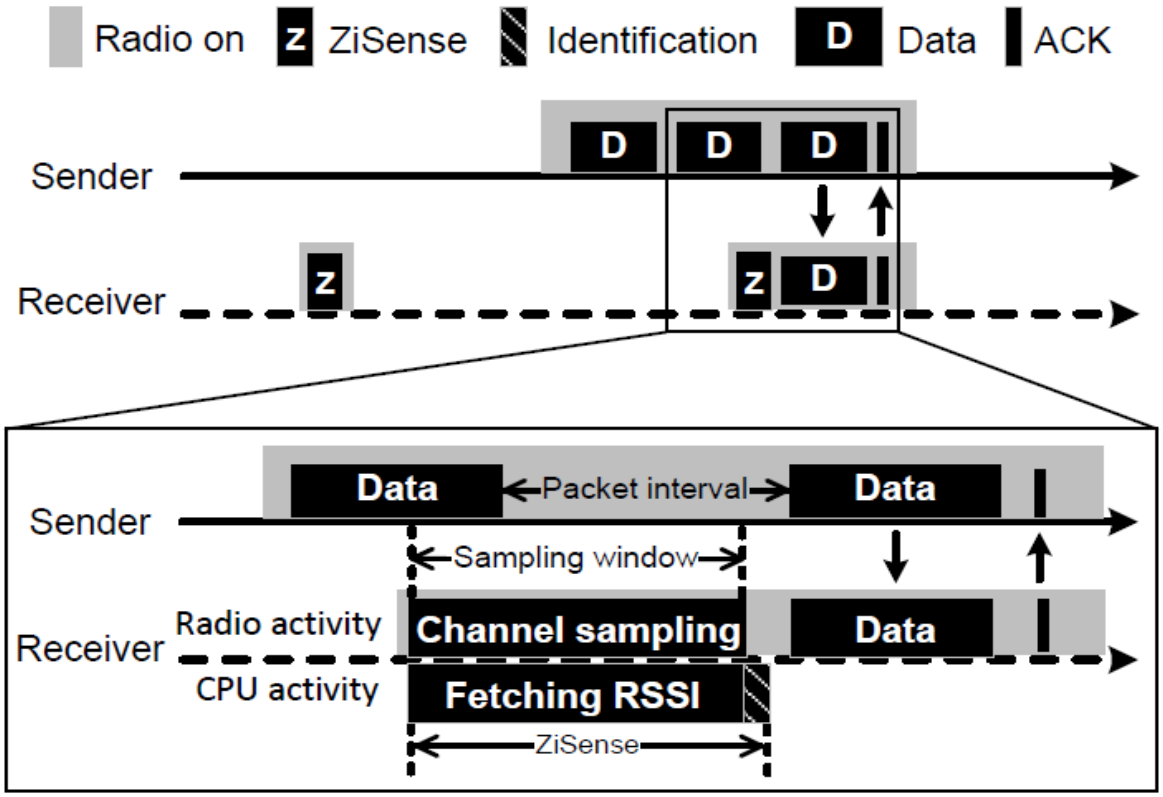
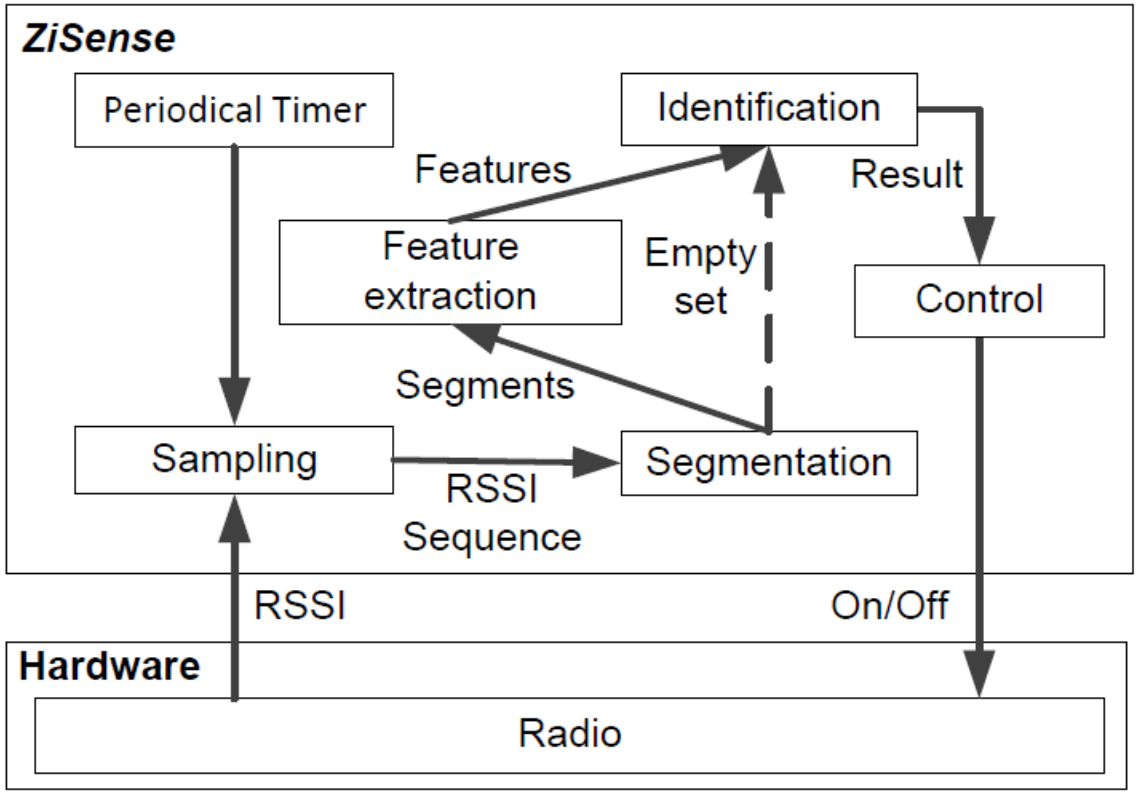
ZiSense: Design

- **Sense** ZigBee and **wake up** nodes **only when** ZigBee signal is detected.



ZiSense: Identify ZigBee

- Adopt the decision tree as the classification algorithm



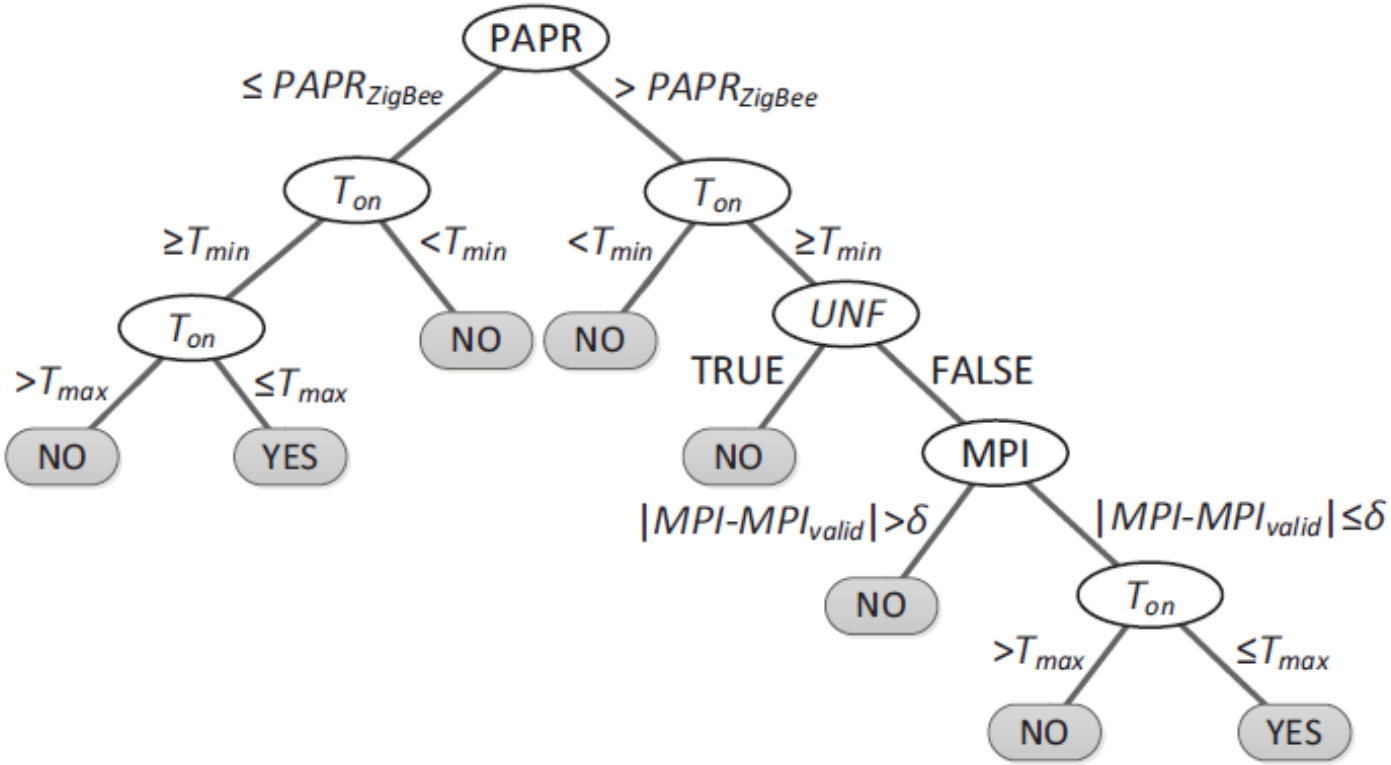
ZiSense: Identify ZigBee

- Rule-based identification algorithm
  - ***Simple*** yet effective, because features are ***stable***
  - Universal to directly use in another system, ***without training***.
- Four conditions as rules
  - C1 : PAPR ≤ PAPRZigBee;
  - C2 : Ton ≥ Tmin;
  - C3 : $|MPI - MPIvalid| \leq \delta$;
  - C4 : UNF = FALSE.
- Valid conditions (C1, C2, C3, C4)
  - (T,T,T,T) → in strict conformance with valid ZigBee sequence
  - (F,T,T,T)
  - (T,F,T,T)

  } deal with some corrupted features

ZiSense: Identify ZigBee

- Decision tree trained by C4.5



Identification Accuracy

Algorithm	TP rate	FN rate	TN rate	FP rate
Rule-based	97.5%	2.5%	97.6%	2.4%
Decision tree	97.3%	2.7%	99.1%	0.9%

- TP(True Positive): correctly recognize ZigBee signals
- FN(False Negative): missing valid ZigBee packets
- TN(True Negative): correctly recognize non-ZigBee
- FP(False Positive): false wake-ups

ZiSense: Identify ZigBee

- Comparable accuracy
  - Compared with specially trained decision tree
- Effective algorithm:
  - False positive (false wake-up) rate: **2.4%**
  - False negative (missing packet) rate: **2.5%**
- General algorithm:
  - *Stable* features which are extracted from hardware and standard specifications
  - *Directly* used in other systems

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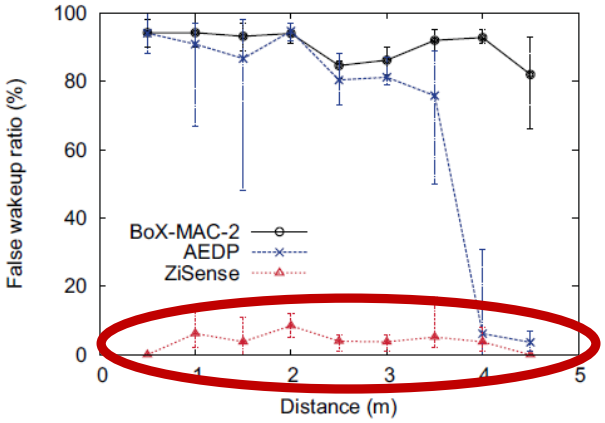
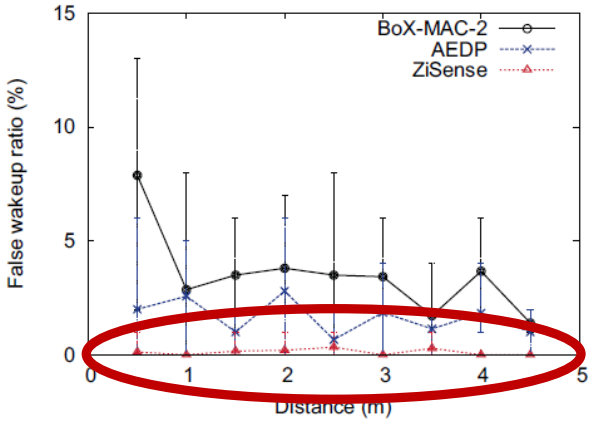
Different Interference Type

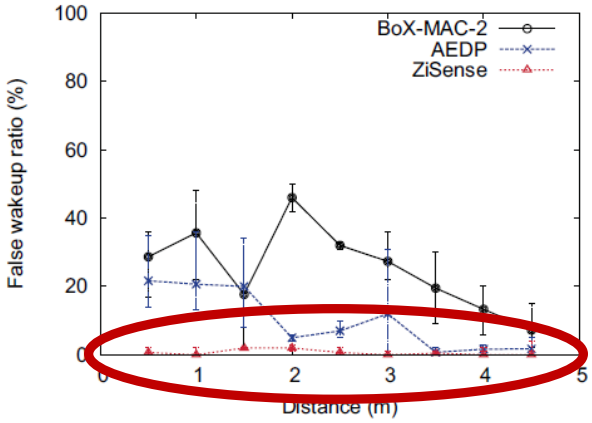
- ***False wake-up ratios*** under different heterogeneous interference environments



(a) WiFi 802.11b/g/n



(b) Bluetooth



(c) Microwave oven

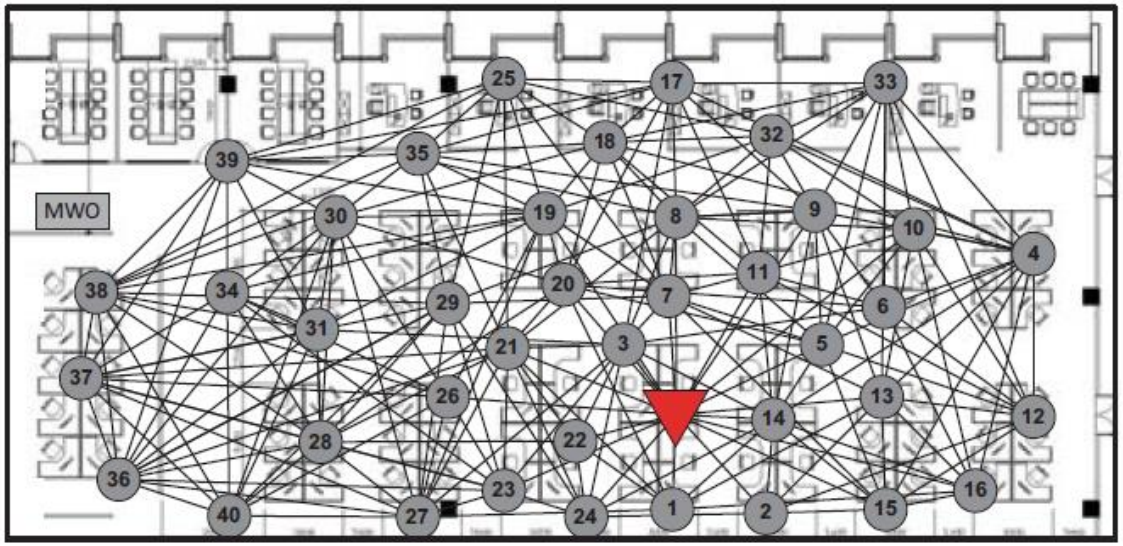
Different Interference Intensity

- *Duty cycle = radio-on time / total time*

	BoX-MAC-2	AEDP	ZiSense
Clean environment	3.31%	3.32%	3.39%
Office environment	10.86%	8.38%	4.21%
Severe interference	21.80%	18.87%	5.14%

Integrated with Routing Protocol

- ***Integrated with CTP***
  - 41 nodes deployed in a 50*100m2 office
  - Each method runs 24 hours



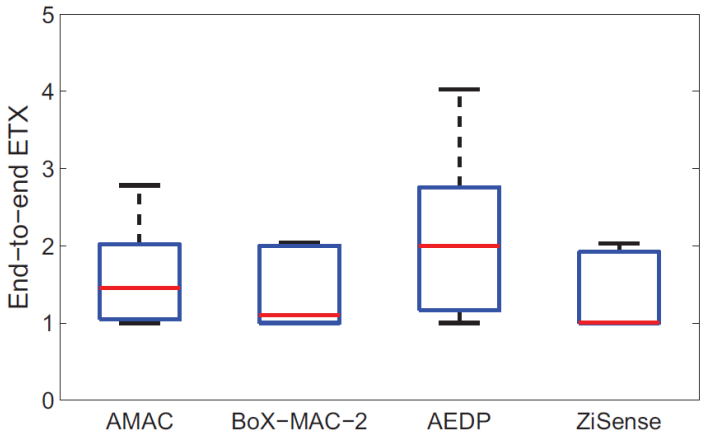
Integrated with Routing Protocol

- ***Integrated with CTP***
  - Improve energy efficiency without extra overhead

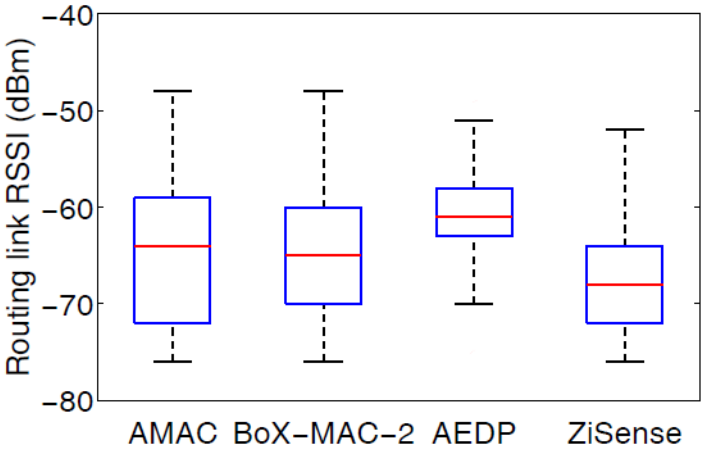
Protocols	Duty cycle	PDR	RTX	Wake-ups per 5 min	Hop count	ETX
A-MAC	4.15%	99.26%	3.34	NA	1.33	1.44
BoX-MAC-2	3.74%	99.48%	0.10	61.61	1.42	1.43
AEDP	4.14%	99.65%	0.04	47.56	2.03	2.05
ZiSense	2.46%	99.79%	0.05	33.41	1.29	1.30

Side effects

- NO Side effects



End-to-end ETX



Routing link RSSI

Conclusion

- ZiSense: interference-resilient duty cycling technique
  - Solve false wake-up problem
  - Recognize valid ZigBee signals by *only RSSI sequence*
- Keep low energy consumption, ZiSense consumes
  - BoX-MAC-2: **24%** (extreme case) and **38%** (office)
  - AEDP: **27%** (extreme case) and **50%** (office)

Thank You!