Smoggy-Link:
Fingerprinting Interference for Predictable Wireless Concurrency

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ZigBee Communication

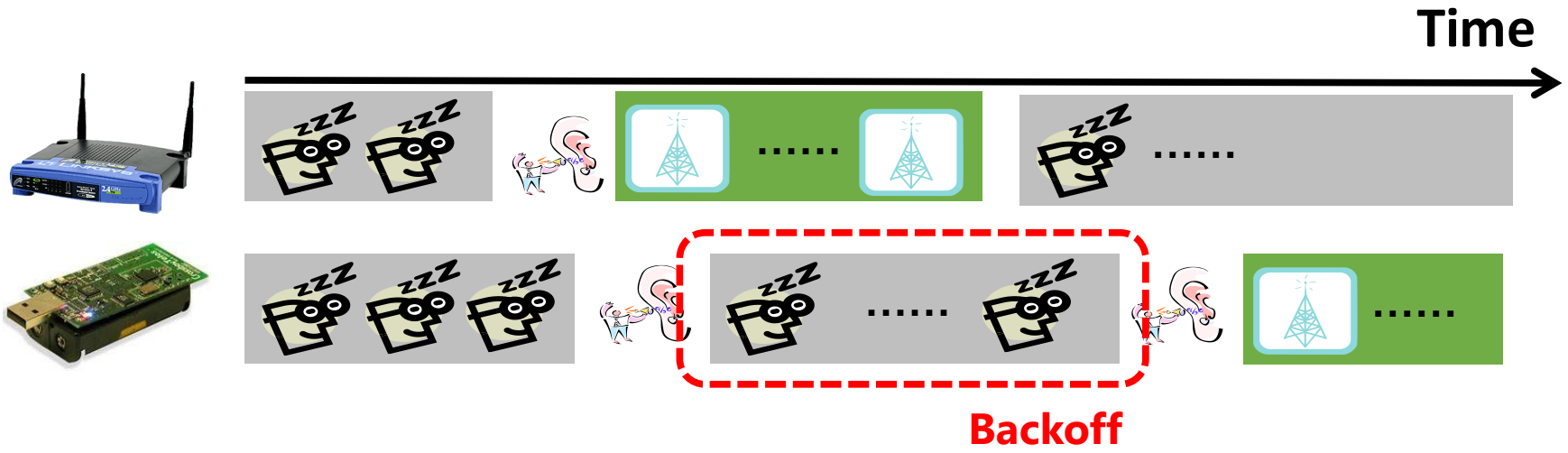
Standard: IEEE 802.15.4

Applications:

Sensor networks; Smart homes; Internet of things; Industrial control; ……

Wireless is Everywhere

Interference Avoidance?



Built upon **CSMA**

- ✓ Exclusive mode for channel access

With CSMA mechanism, senders transmit data packets in **exclusive mode** to avoid interference

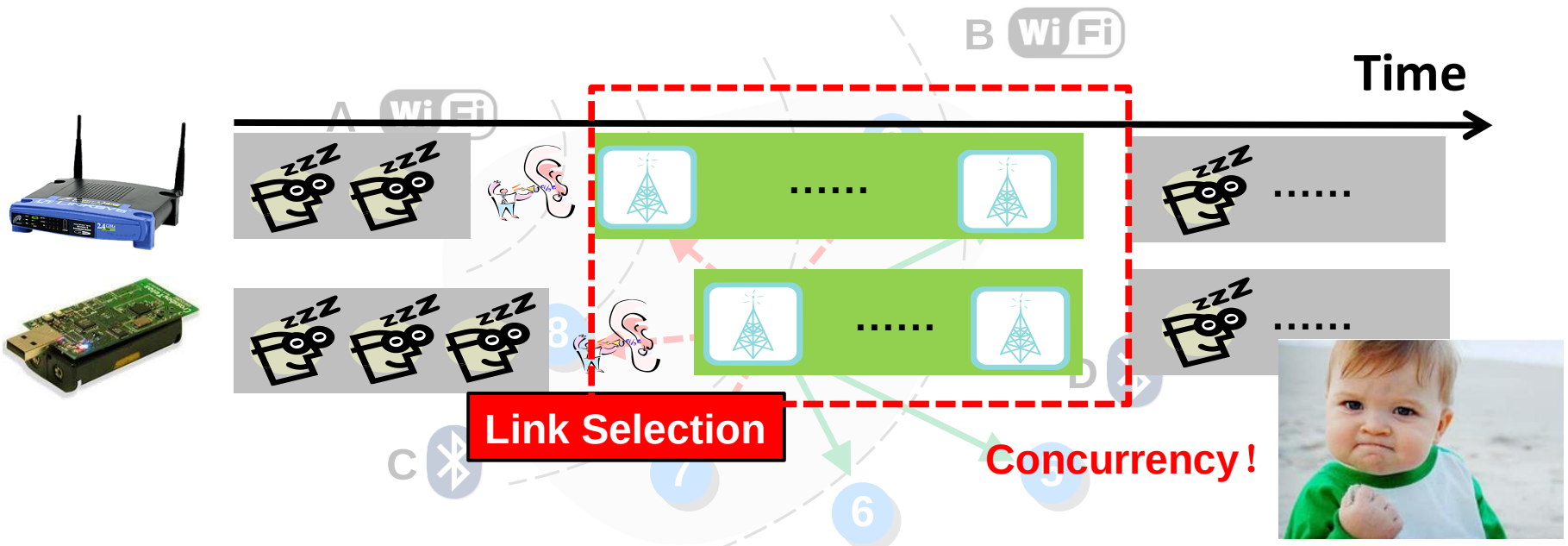
Exclusive transmission mode usually results in **long waiting time** and **low channel utilization**.

Concurrency

Should different technology transmit data packets always in exclusive mode?

NO!

Actually, due to exposed terminal phenomenon…



Smoggy-Link

Goal: Concurrent transmission with cross-technology interference exploiting exposed terminal

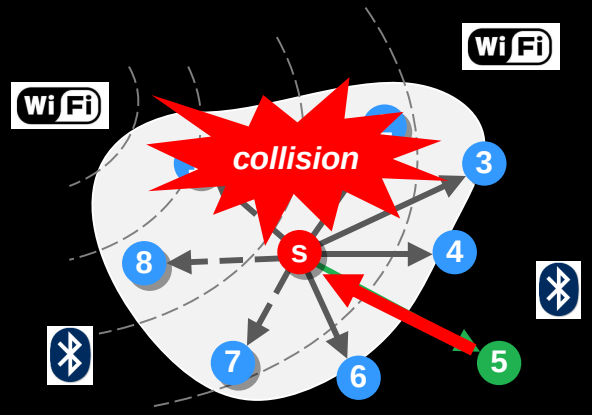
Challenges

#1 Find the “good” Link

- ✓ Link quality is changeable and unpredictable.
- ✓ Frequent measurement for all the link incurs high energy consumption.

#2 Schedule the Transmission of ACK

- ✓ Link asymmetry.
- ✓ ACKs must arrive at the sender between interference frame clusters.



Challenges

#1 Find the “good” Link

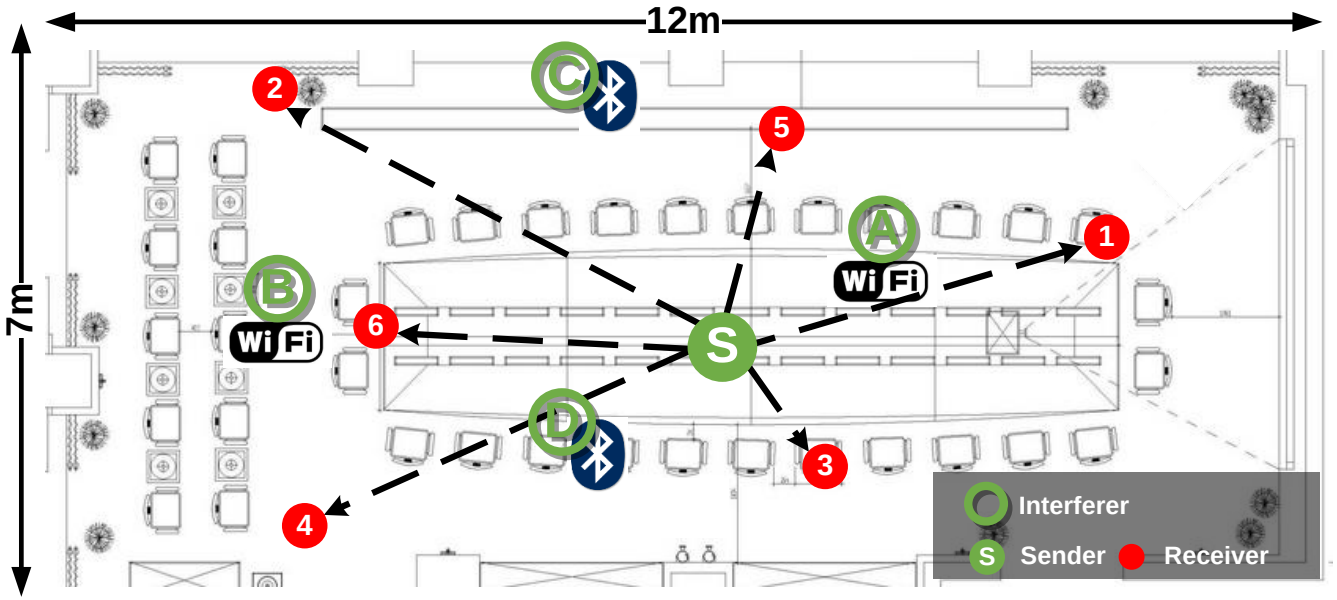
#2 Schedule the Transmission of ACK

Interference v.s. Link Quality

How different interference impact ZigBee?

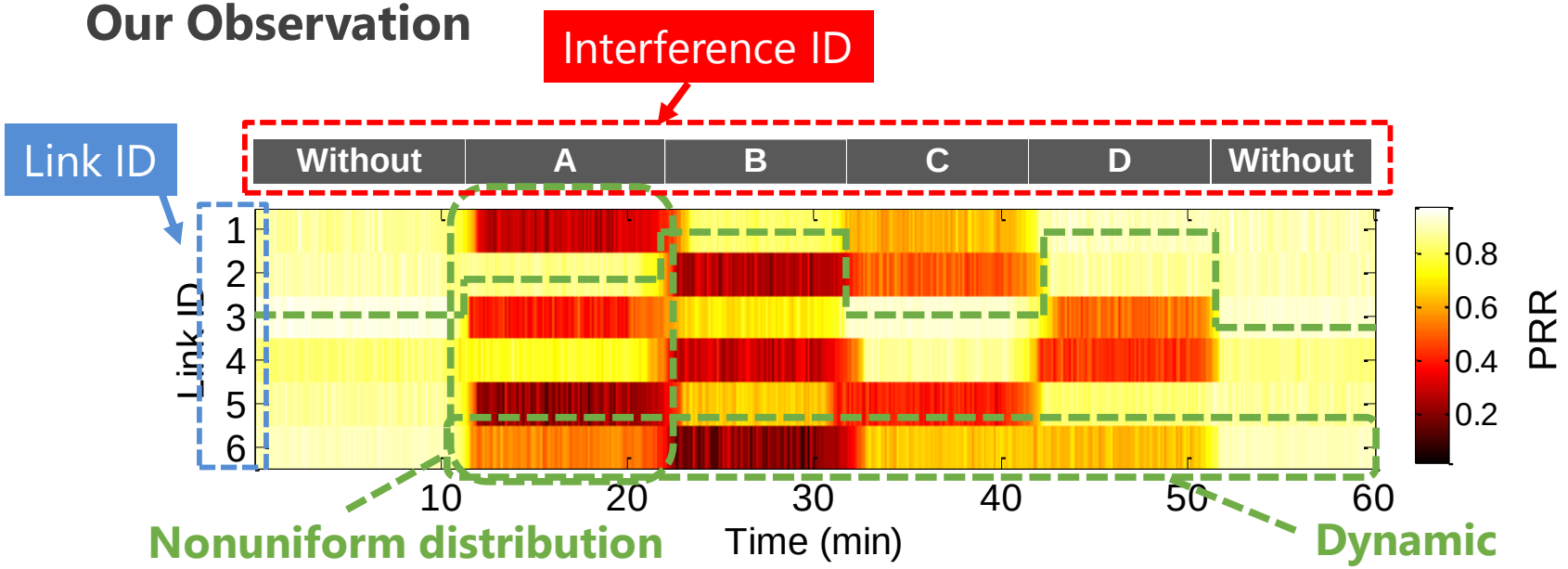
Preliminary Experiment

- ✓ **ZigBee: TelosB mote with TinyOS**
  Channel 12; 2 Kbps
- ✓ **Interference: WiFi (2~8Mbps), Bluetooth (1~2Mbps)**



Interference v.s. Link Quality

Our Observation

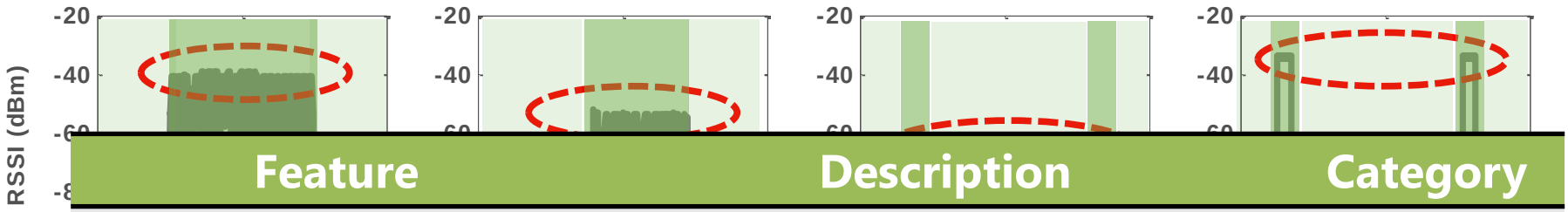


- A specific interference is likely to have different effect on different links
- PRR for each link is fluctuates with and highly correlated to the interference.

Adaptive link selection based on the ongoing interference. Simultaneously achieve high throughput and high PRR.

Feasibility of Interference Identification

However, is it possible to identify the ongoing interference?



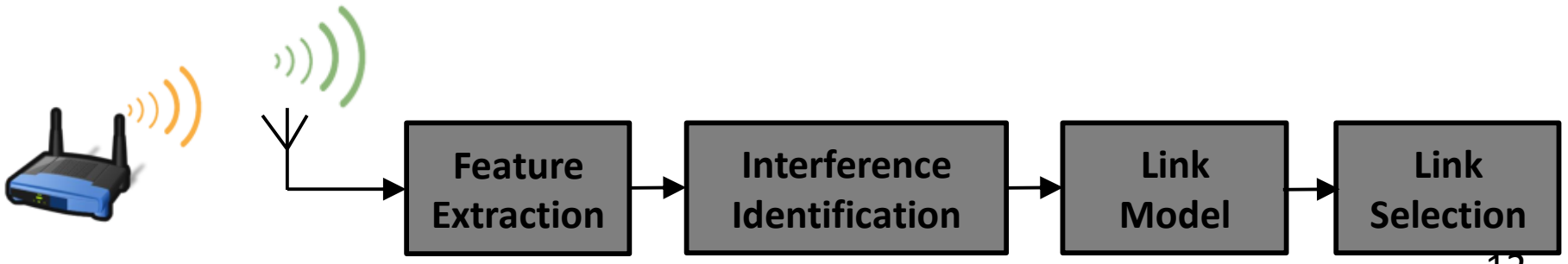
Feature	Description	Category
Energy span during interference	$Range(RSSI_{normalized})$	Energy Level
Energy level during interference	$median(Range(RSSI_{normalized}))$	
Energy variance during interference	$Variance(Range(RSSI_{normalized}))$	
Peak to average power ratio	$\lvert max(RSSI_{normalized}) - min(RSSI_{normalized})\rvert$	
Average on-air time	Time span of consecutive busy sample of RSSI	Occupancy Level
Average packet interval	Time span of consecutive idle sample of RSSI	

✓ Occupancy Level

A node can get fine-grained link information based on low cost PHY information of the interference

Find the “Good” Link

- **Interference identification**
- **Link estimation**



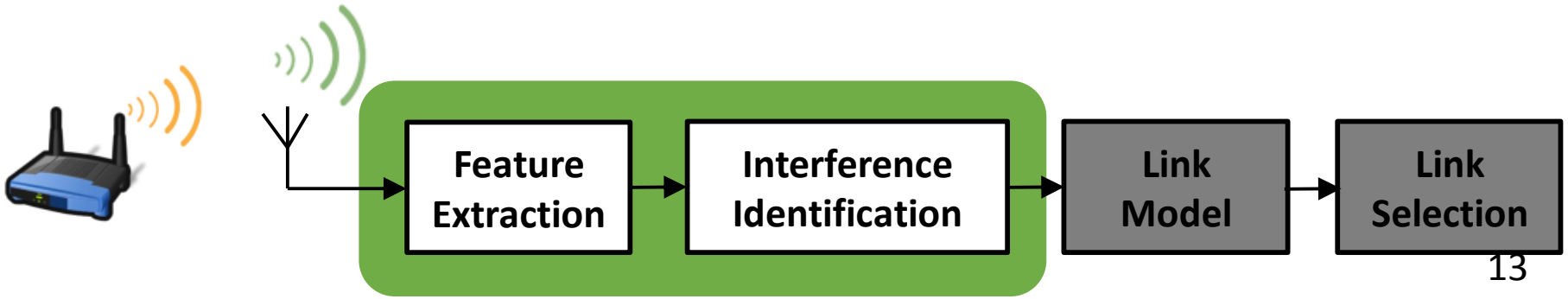
Interference Identification

A node can distinguish different interferences by using their "fingerprint":

- ✓ Each interference has a Fingerprint

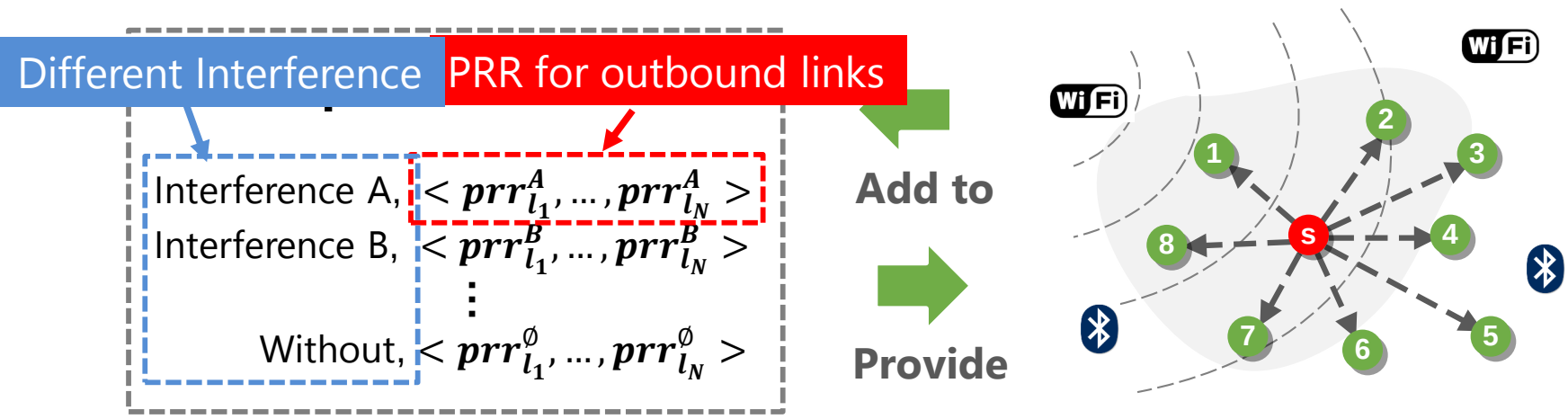
$$\boldsymbol{FTalbe} = \{\boldsymbol{F_1}, \ldots, \boldsymbol{F_M}\} \rightarrow \boldsymbol{F} = \{f_1, \ldots, f_6\}$$

- ✓ Exploit the **K-Means** clustering to discriminate different interferences based on the **cityblock distance** between fingerprints



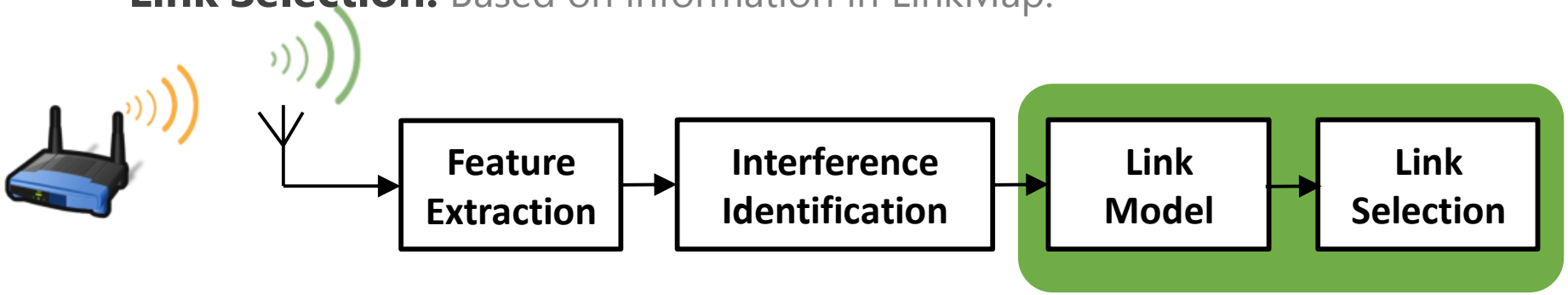
Link Estimation

Translate the interference information to the PRRs of the outbound links



Construction: Burst probing.

Link Selection: Based on information in LinkMap.



Challenges

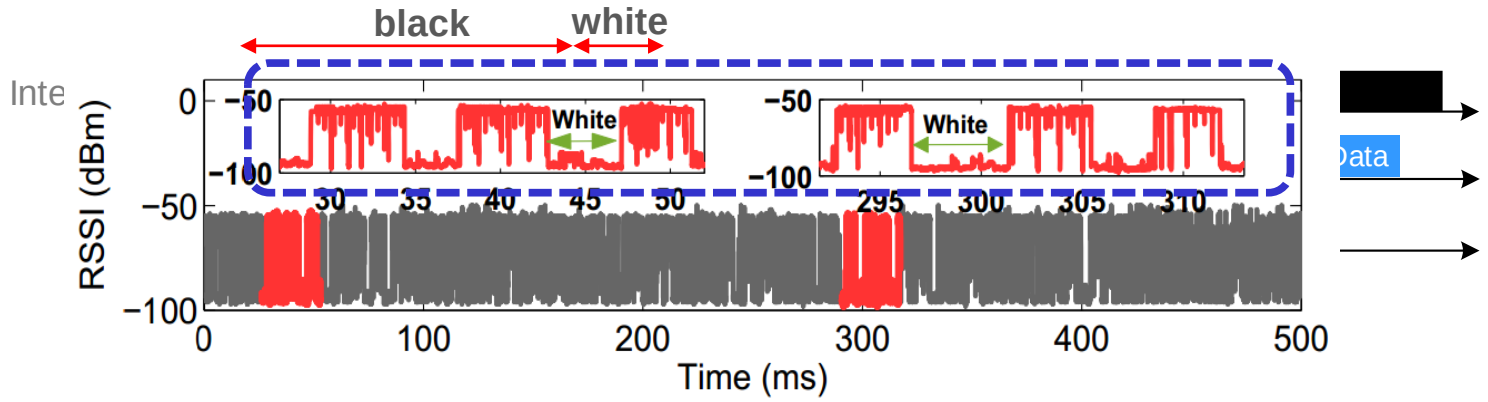
#1 Find the “good” Link

#2 Schedule the Transmission of ACK

Schedule the Transmission of ACK

ACKs must arrive between interference frame clusters.

Predict the alternating pattern of the white/black space!

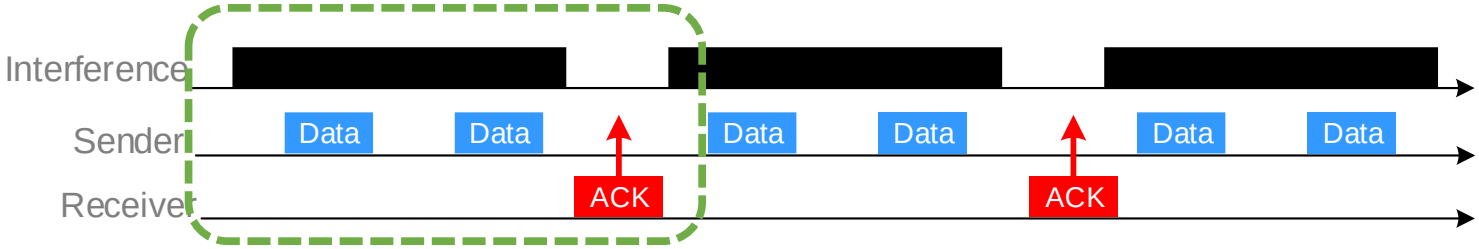


Modeling the white/black space pattern:

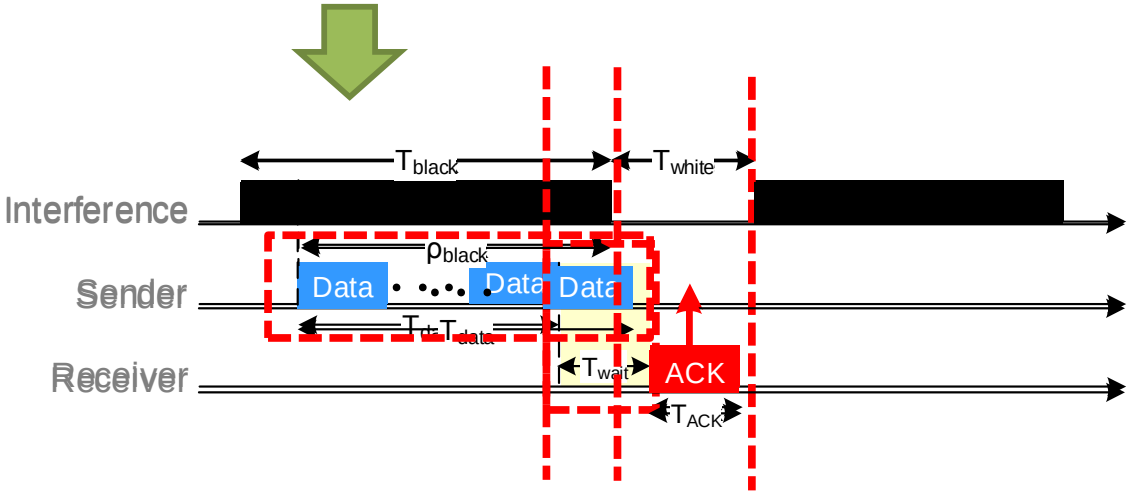
Pareto model

$$P(x > t) = \begin{cases} (\frac{\alpha}{t})^{\beta} & t > \alpha \\ 1 & otherwise \end{cases}$$

Schedule the Transmission of ACK

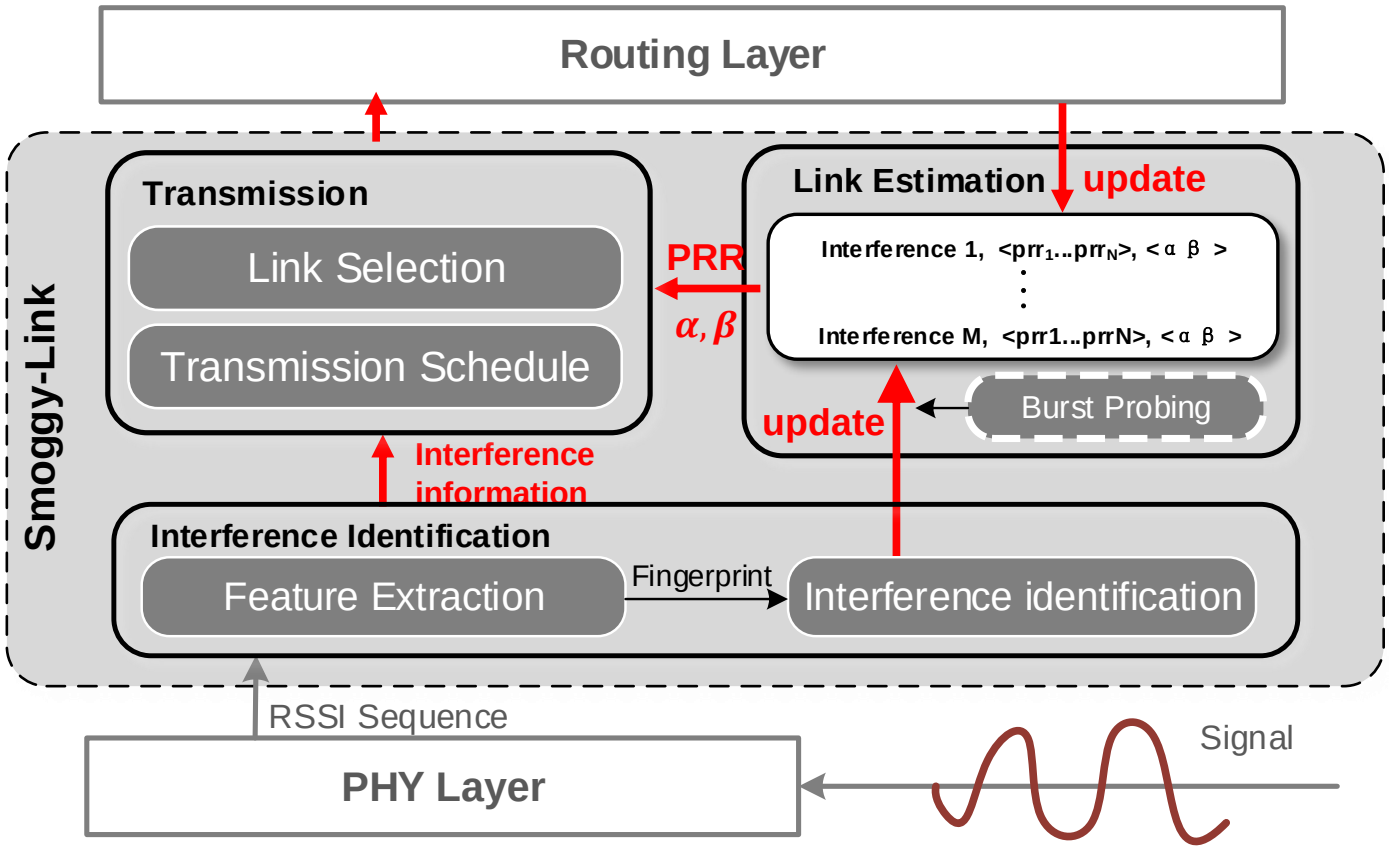


In one white/black period



- ✓ Limiting the length of data period in the current white/black period
- ✓ Adjusting the arrive time of the ACK

Putting Them Together



Evaluation

- **Implementation:**
  - TelosB
  - TinyOS 2.1.1

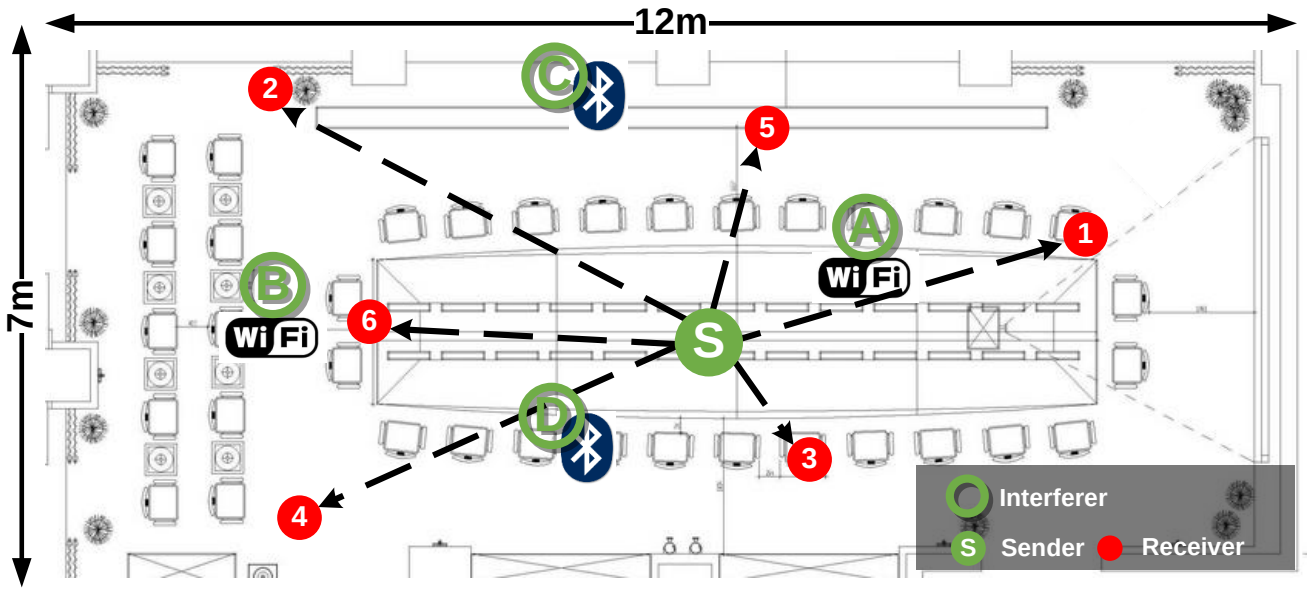
- **Interference**
  - WiFi: Smartphone, iperf
  - Bluetooth: Smartphone

- **Compared schemes**

Smogy-Link: the proposed design in this paper.
Beacon+CSMA off: transmission method with CSMA enabled using beacon-based link estimation.
Beacon+CSMA on: transmission method with CSMA enabled using beacon-based link estimation.
Beacon+WISE[1]: transmission method using beacon-based link estimation and using WISE for interference avoidance.

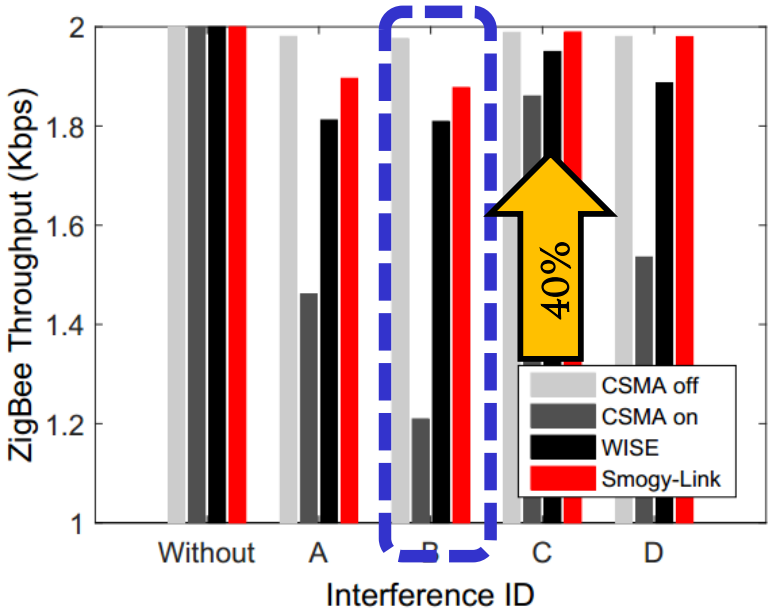
[1] Beyond Co-existence: Exploiting WiFi White Space for ZigBee Performance Assurance. ICNP 2010

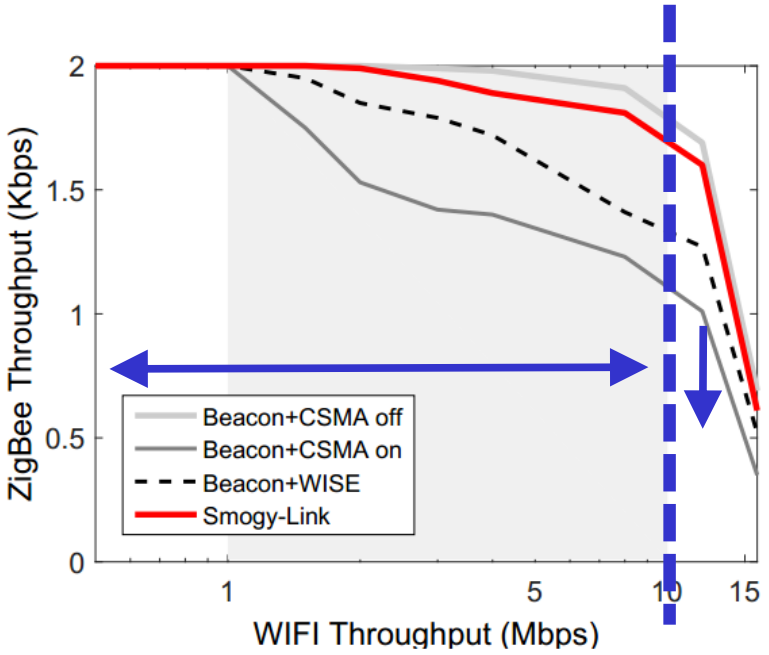
Network Performance



- **Performance**
  - Throughput
  - Retransmission

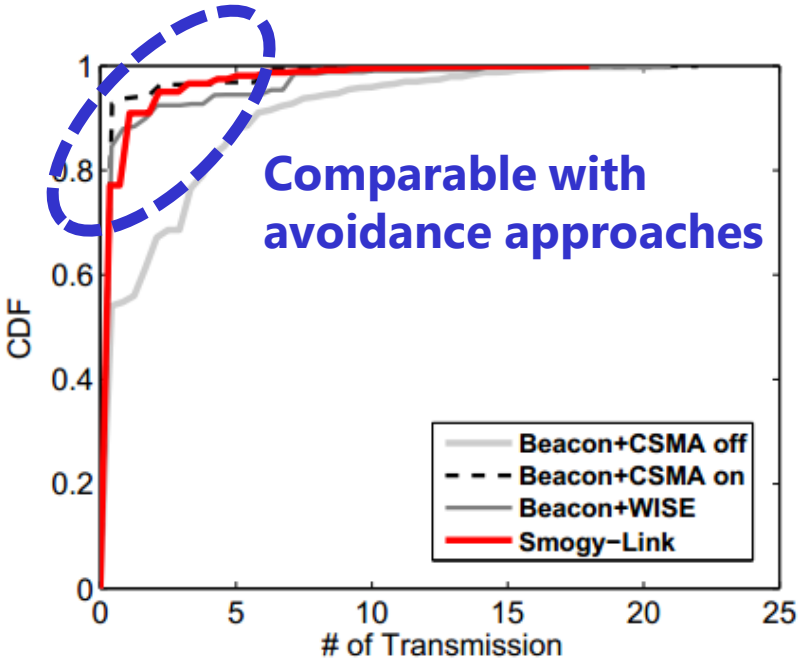
Throughput

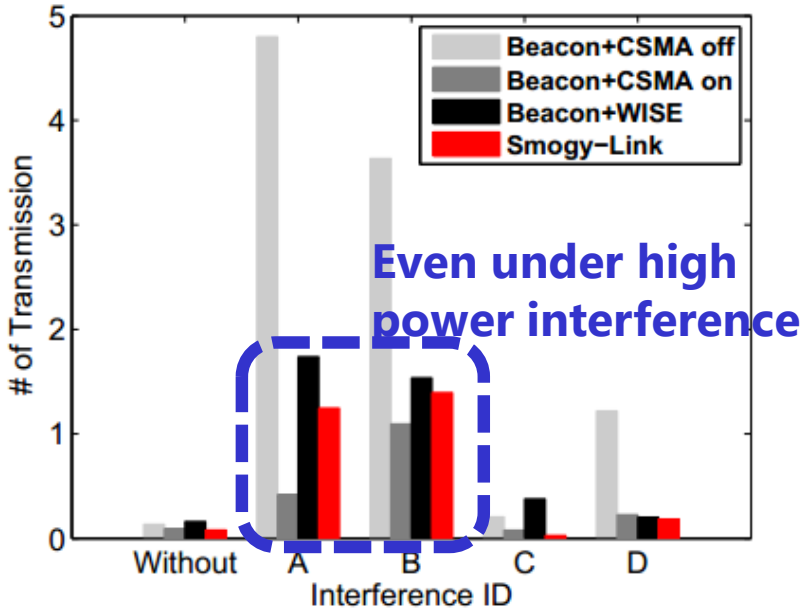




- **Throughput of Smogy-Link only decreases slightly even under high power interference**
- **Smogy-Link achieves high throughput when WiFi data rate ≤10Mbps**

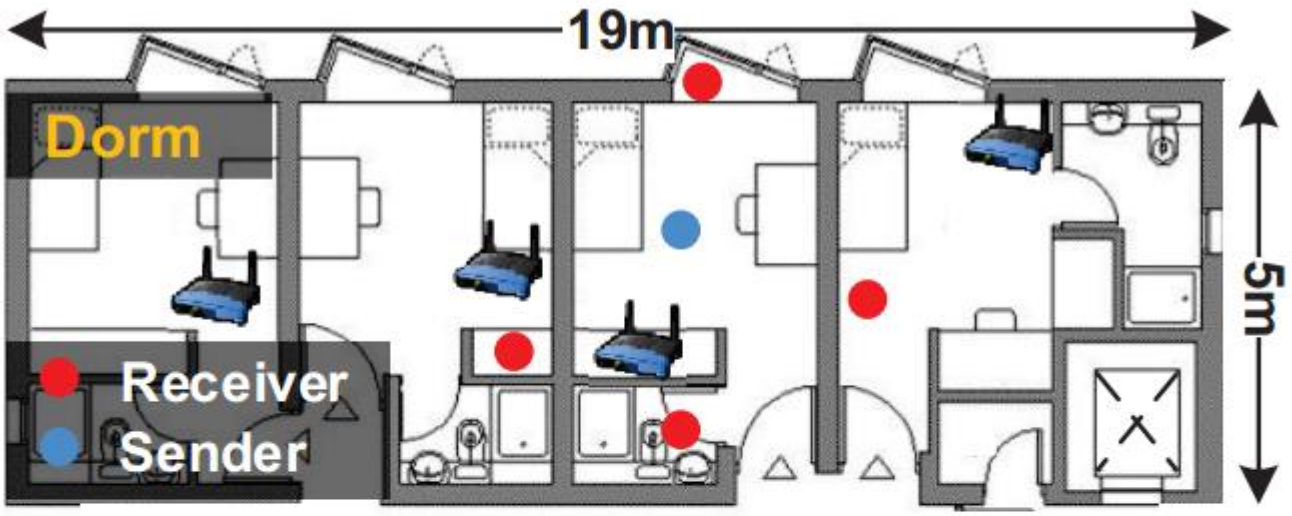
Retransmission

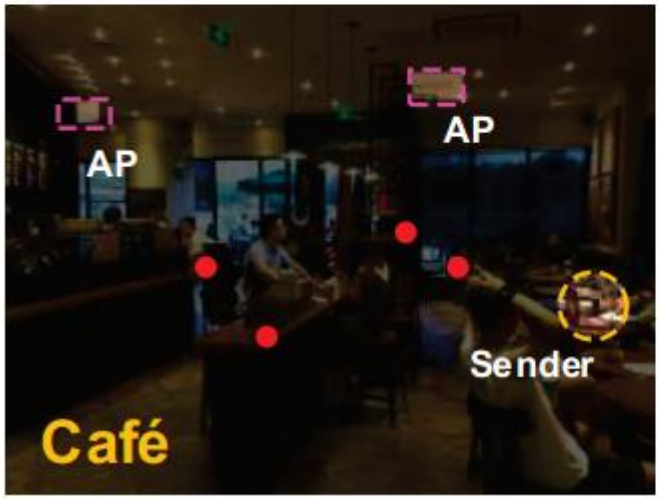


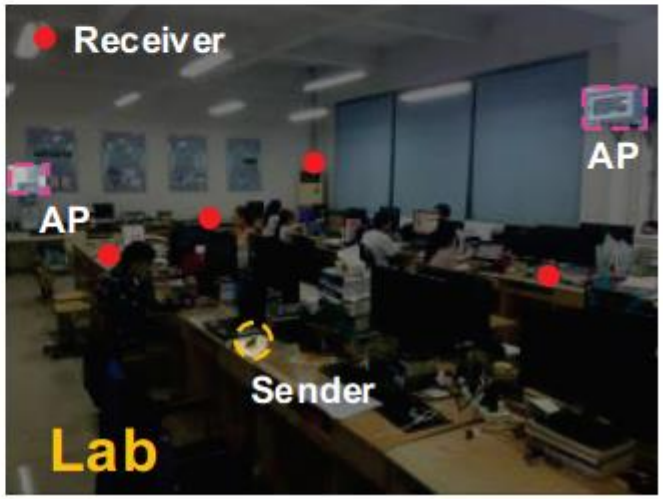


- **Retransmission count of Smoggy-Link is comparable with that of interference avoidance approaches.**
- **Retransmission count is controlled under 2 even under harsh interference.**

Real World Experiment

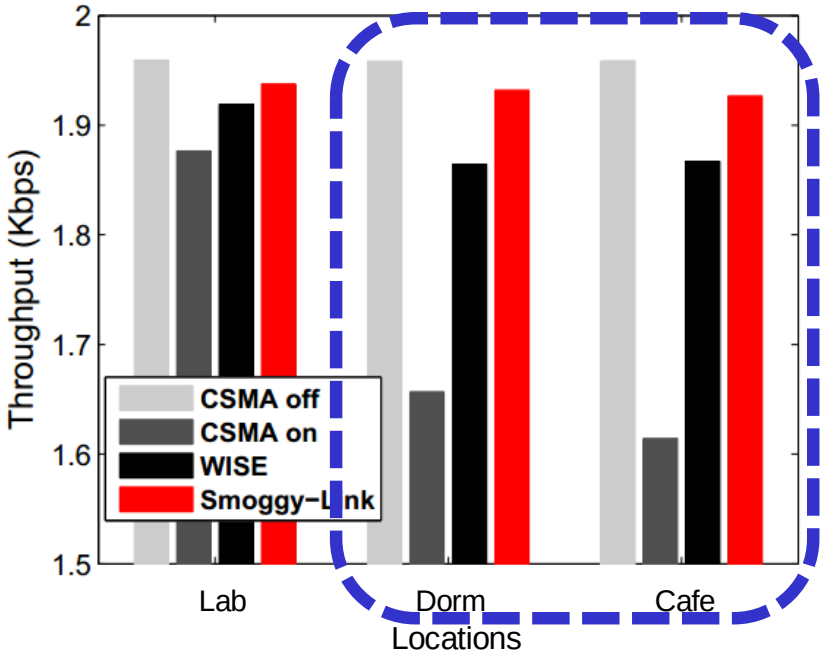




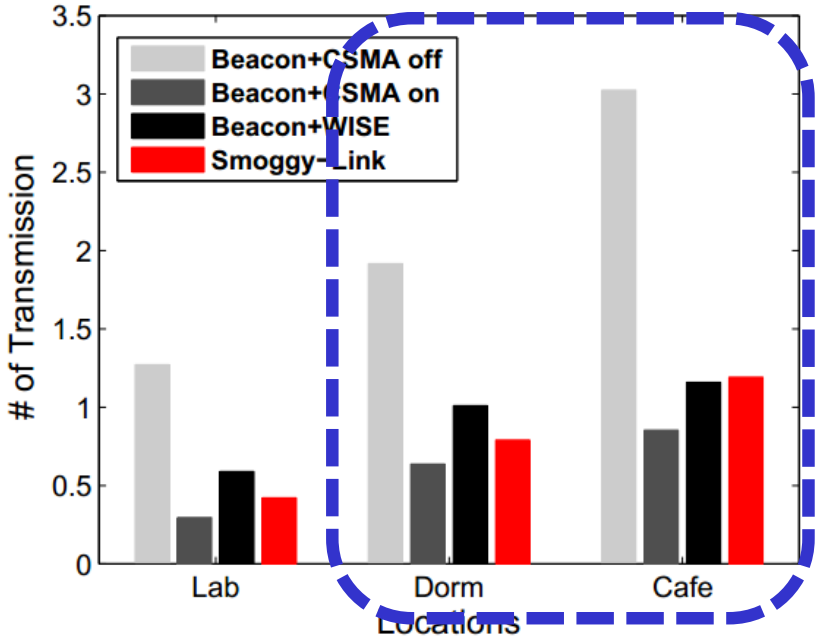


Real World Experiment

Throughput



Retransmission



Smoggy-Link's performance gain is more significant in the cafe and dorm than that in the lab.

Conclusion

We propose Smoggy-Link to exploit potential concurrency for adaptive transmission under interference.

- ✓ Interference identification
- ✓ Link model
- ✓ Link selection and transmission schedule

Real implementation of Smoggy-Link in TinyOS2.1.1

Evaluation in under practical environment

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Update fingerprint table:

If the interference $\boldsymbol{I_m}$ is detected, its fingerprint can be updated using moving average as:

$$\boldsymbol{F_m = \lambda \cdot F_m + (1 - \lambda) \cdot F_{det}}$$

where $\lambda = 0.9$

Update LinkMap:

The PRR of Link $\boldsymbol{L_n}$ under interference $\boldsymbol{I_m}$ can be updated using moving average as:

$$\boldsymbol{prr_{S,L_n}^{I_m} = \lambda \cdot prr_{S,L_n}^{I_m} + (1 - \theta) \cdot prr_{S,L_n}^{I_{m-new}}}$$

where $\theta = 0.9$