Efficient Interference Graph Estimation via Concurrent Flooding

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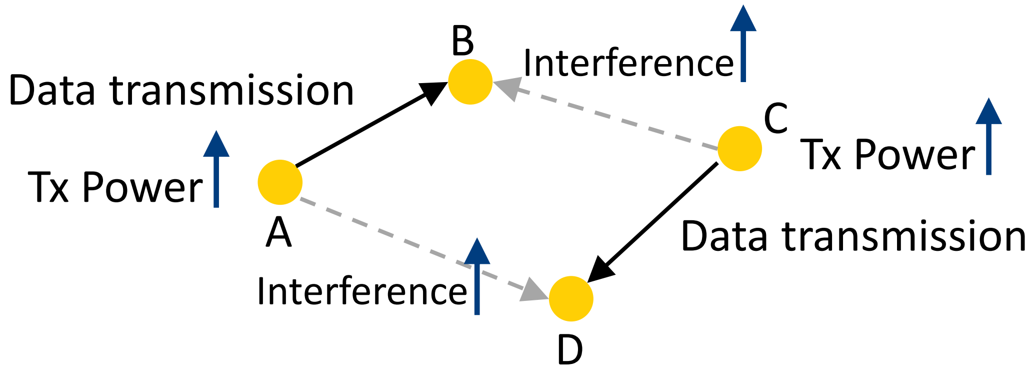
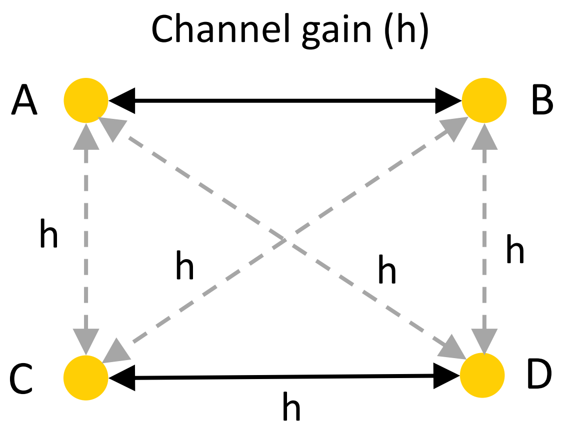
Motivation: Why Interference Graph is Important in Wireless Sensor Network?

Spatial Concurrency Scenario in a Wireless Sensor Network



Interference Graph (IG)



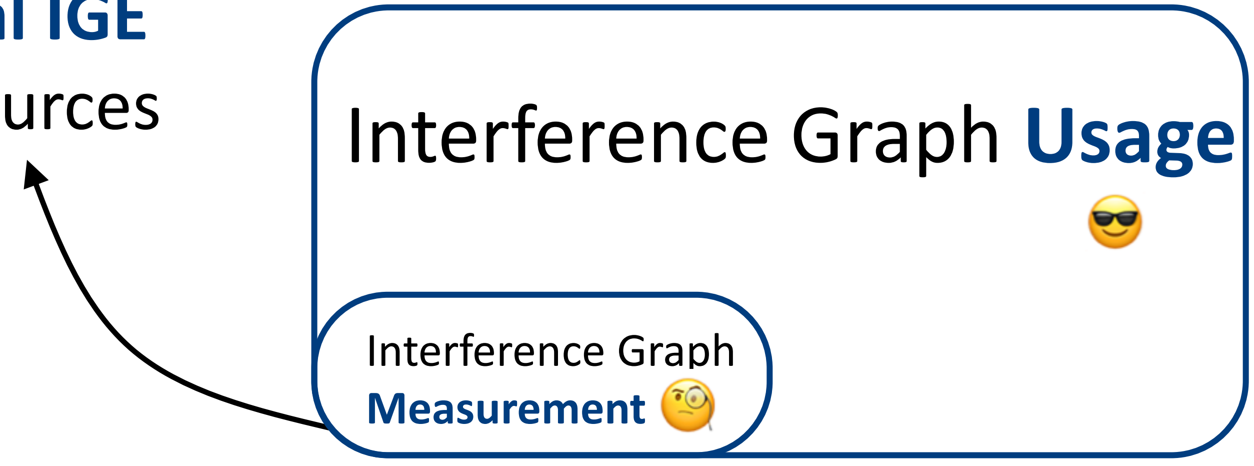
If A and C send at the same time, what tx powers should they use?

Resource Allocation

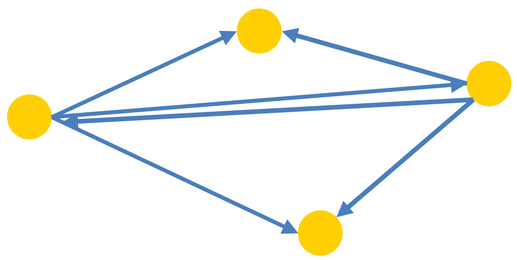
Challenges for Interference Graph Estimation (IGE) in Wireless Sensor Networks

High measurement cost of traditional IGE

- Occupy extra time/frequency resources
- Delay data transmission



The current state of art of Interference Graph



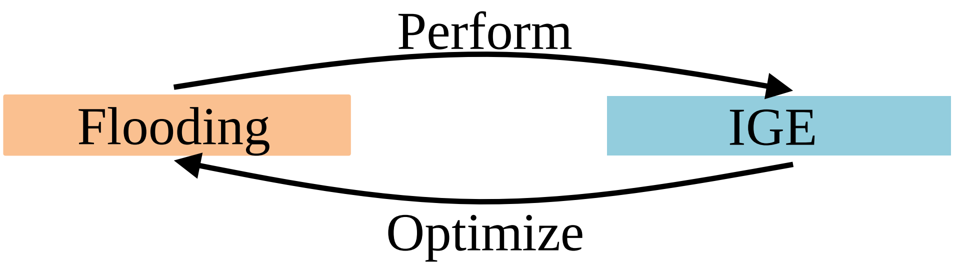
Network scale: N , Link scale: $O(N^2)$

⇒ **Traditional measurement cost:** $\boldsymbol{O(N)}$ **slots**

$\boldsymbol{O(N)}$ slots are too long for wireless sensor networks!

Our approach: IGE Married with Flooding

Marry IGE with flooding without extra time/frequency resources



How could we achieve this?

Key idea: Use power as a new dimension for measurement.

Outline

Motivations, Challenges & Introduction

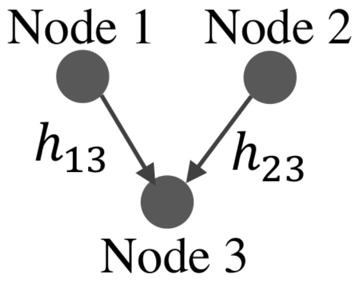
Interference Graph Estimation (IGE)

I. Power Linearity
II. Full-rank Constraint

Practical IGE Scheme

Real-world Experiment

Core Insight by an Example



$$\begin{array}{l} \text{Slot 1} \\ \text{Slot 2} \end{array} \underbrace{\begin{bmatrix} 1mW & 2mW \\ 1mW & 1mW \end{bmatrix}}_{\boldsymbol{Tx\ power}} \underbrace{\begin{bmatrix} h_{13} \\ h_{23} \end{bmatrix}}_{\boldsymbol{h_3}} = \underbrace{\begin{bmatrix} 3\mu W \\ 2\mu W \end{bmatrix}}_{\boldsymbol{Rx\ power}}$$

Key Assumptions

1) Power linearity

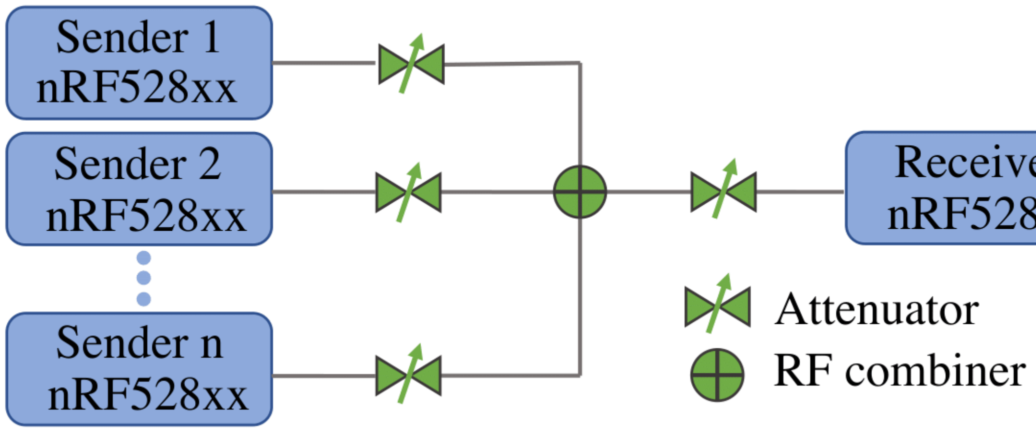
2) Full-rank Tx power matrix

Power Linearity Break Down

Linearity = Proportionality + Additivity

$$p_{i\to j}^{rx} = h_{ij}\, p_i^{tx} \quad \text{(proportionality)}$$

$$p_i^{rx} = \sum_j p_{j\to i}^{rx} \quad \text{(additivity)}$$

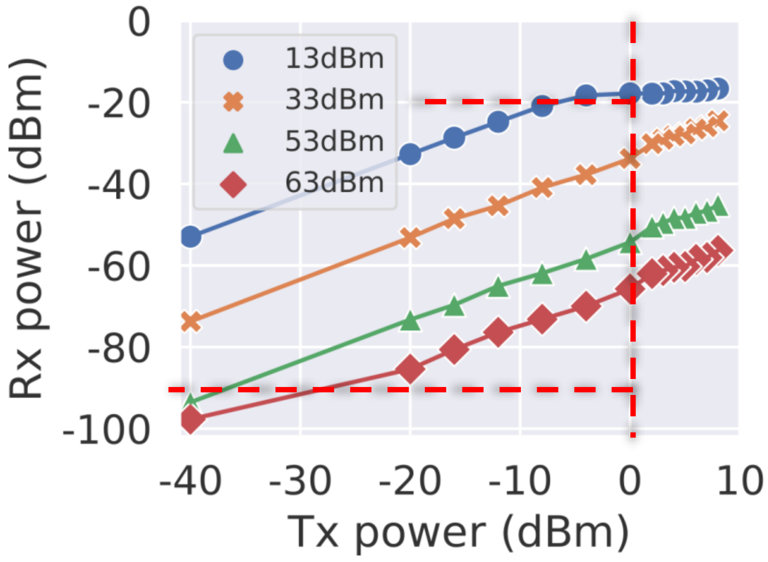


Proportionality between Tx and Rx Powers

Experimental Setup

Proportionality between Tx and Rx Powers

Experimental Result

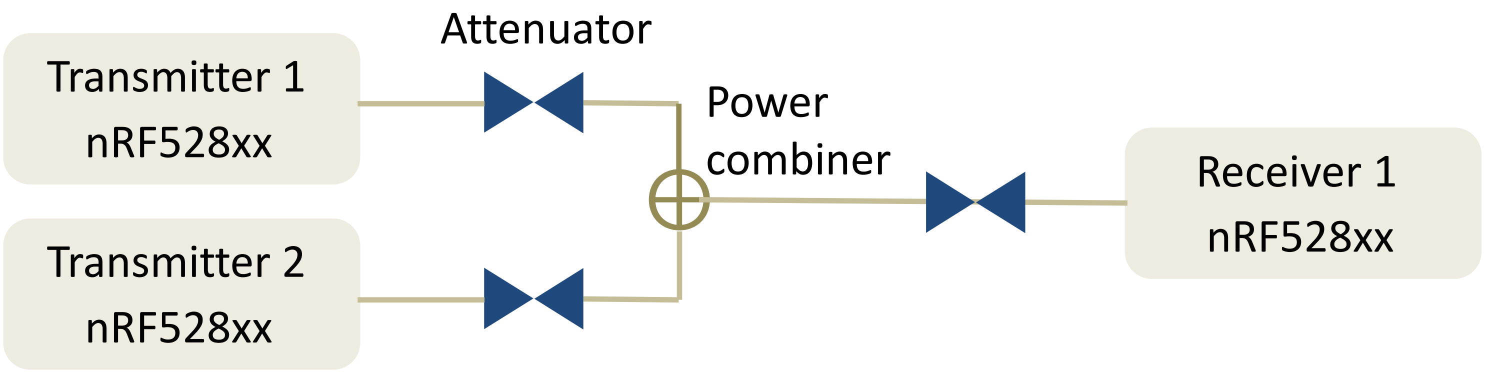


Linear region:

1) Rx power $\in [-20, -90]$ dBm
2) Tx power $\leq$ 0 dBm

Additivity of Received Powers

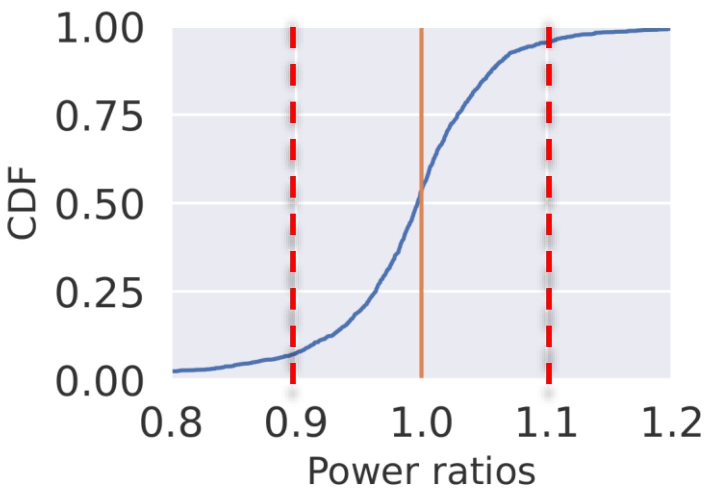
Experimental Setup

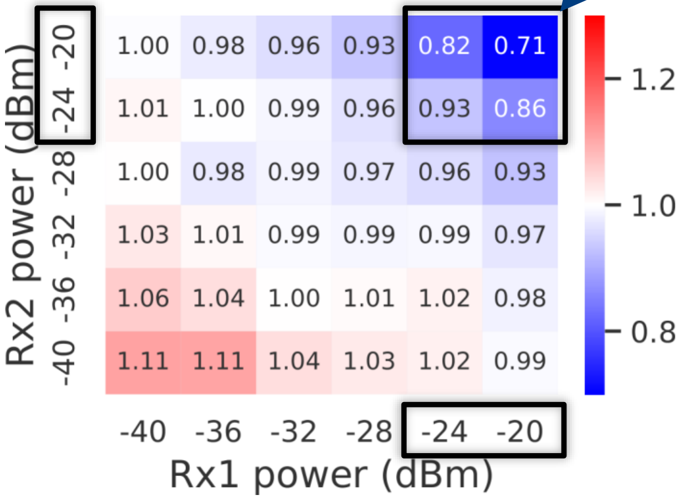


Additivity of Received Powers

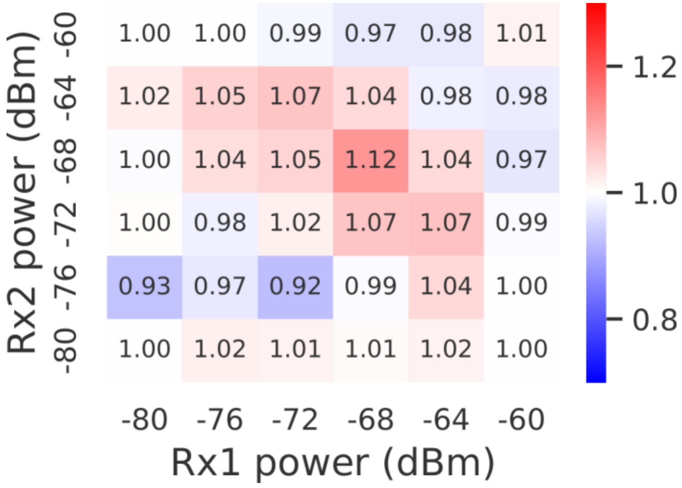
Experimental Result

$$\text{Power ratio} = \frac{\text{Actual rx power}}{\sum individual \text{ rx powers}}$$





The rx power is saturated



88% of power ratios fall within 0.9 and 1.1

Power ratios decrease as rx powers increase

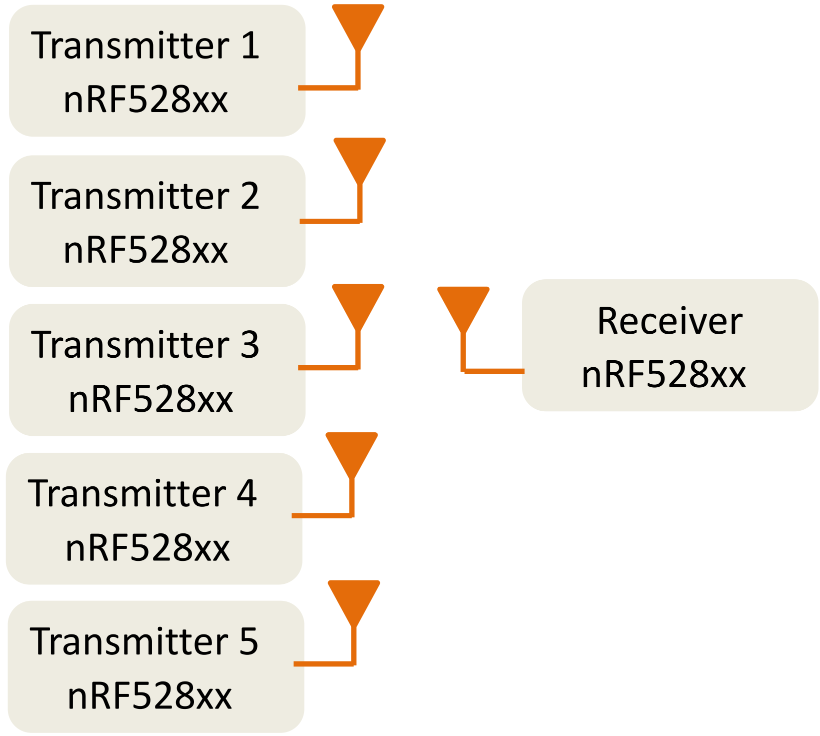
Similar additivity except for rx power greater than -24 dBm

Full-rank Constraint

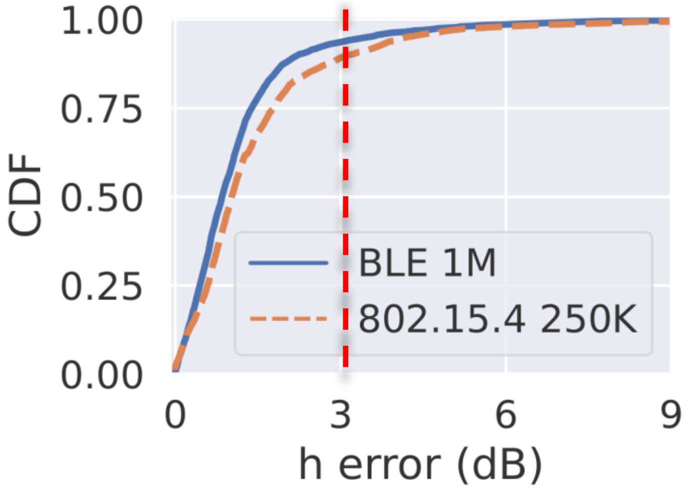
$$\left\{ \begin{aligned} \boldsymbol{P}^{tx} \cdot h_i &= p_i^{rx} \\ \underbrace{rank(\boldsymbol{P}^{tx}) = \#\text{Senders}}_{\text{Full-rank constraint}} \end{aligned} \right\} \Rightarrow h_i = (\boldsymbol{P}^{tx})^{-1} \cdot p_i^{rx}$$

Feasibility of IGE under controlled environment

Experimental Setup



Experimental Result



More than 90% of the h error is under 3dB

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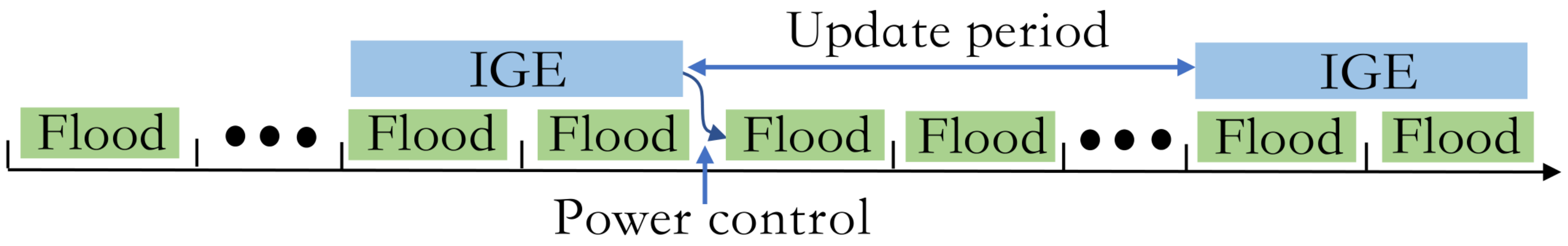
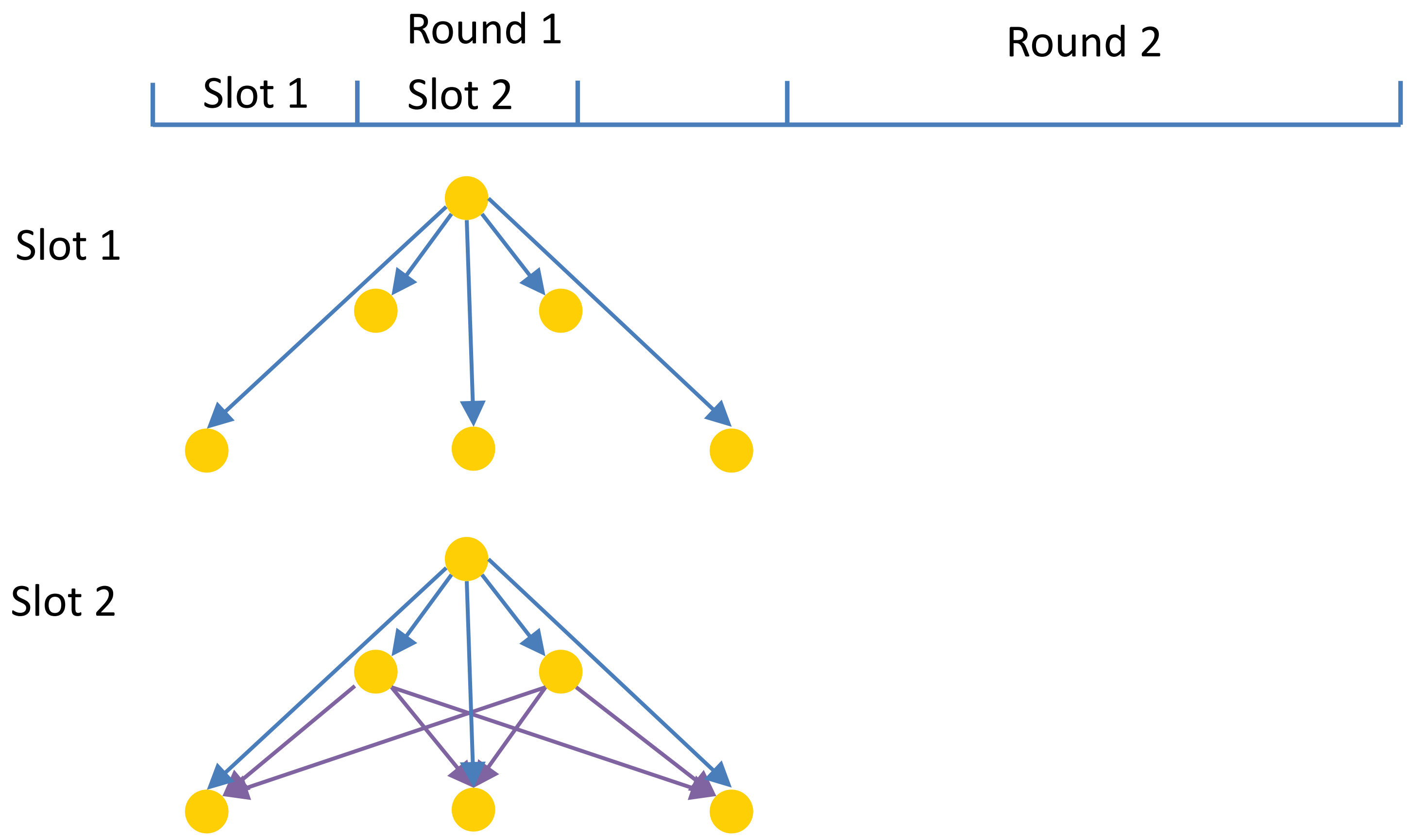
Real-world Experiment

Practical IGE Scheme over Flooding

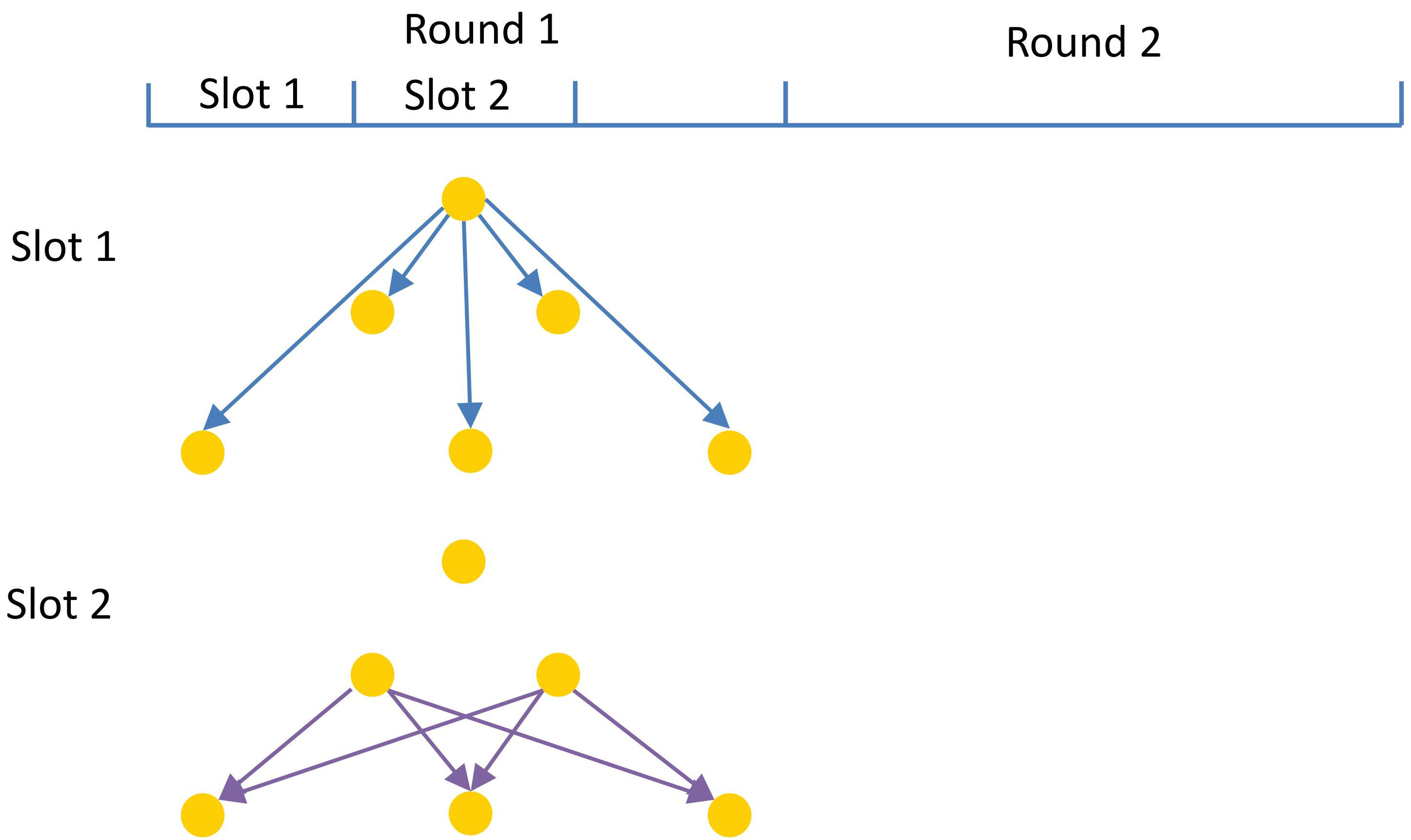


- **IGE** period + **Update** period
- **Power control**: allocate tx powers

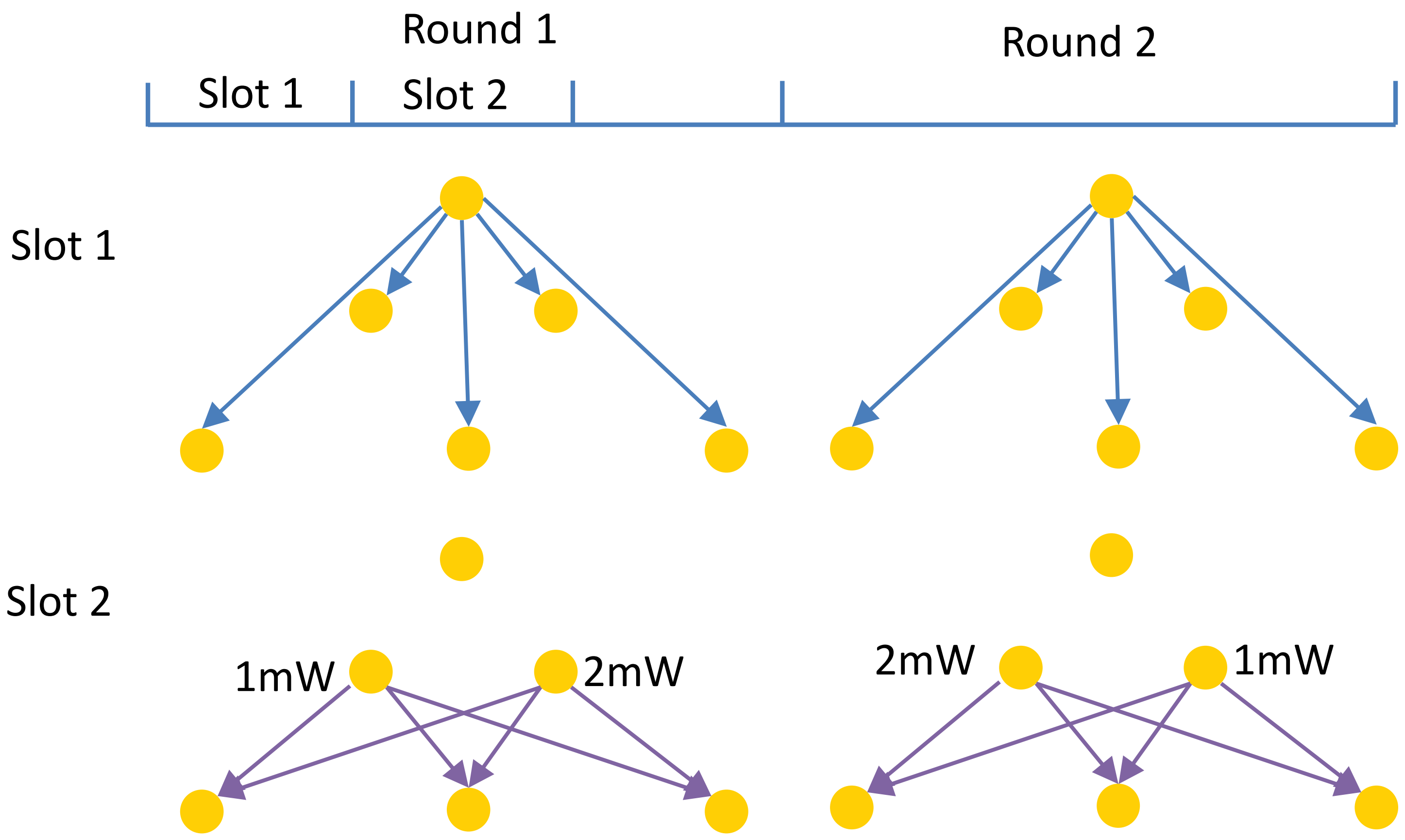
Example of IGE in a Two Hop Flooding Network



Example of IGE in a Two Hop Flooding Network



Example of IGE in a Two Hop Flooding Network



$$\begin{bmatrix} 1mw & 2mw \\ 2mw & 1mw \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} = \begin{bmatrix} p_1^{rx} \\ p_2^{rx} \end{bmatrix}$$

Full-rank

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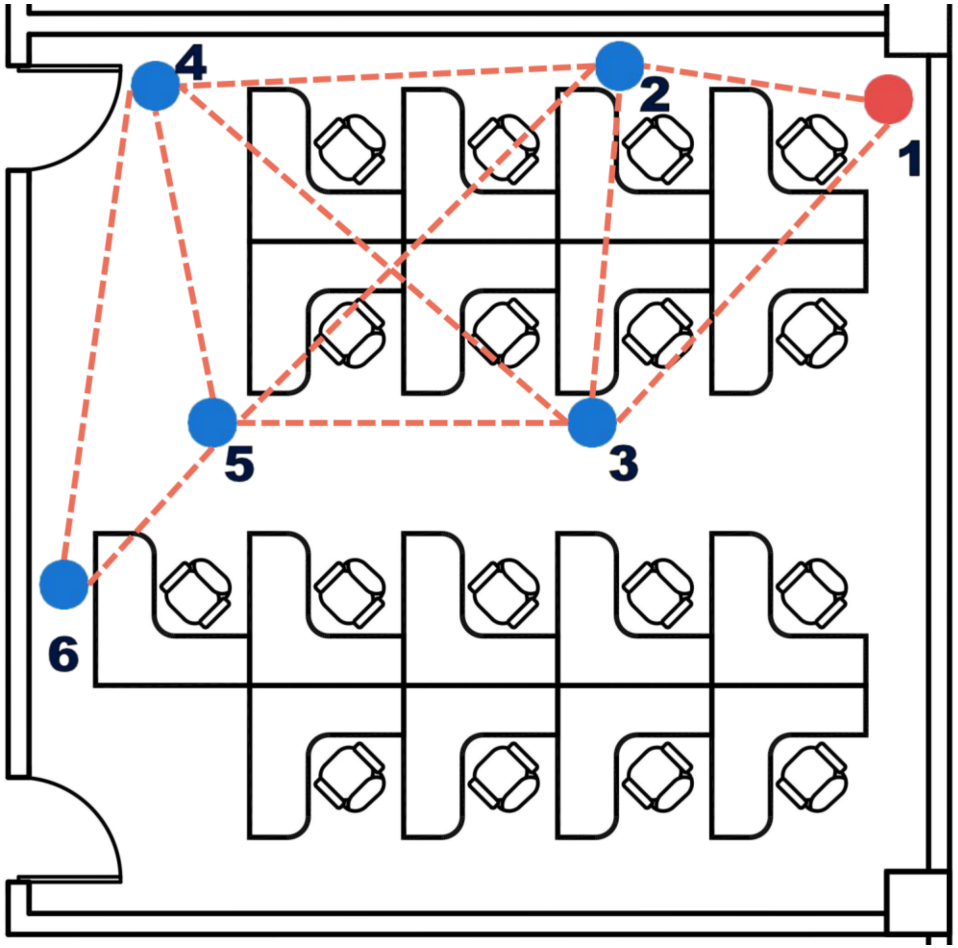
Testbed Setup

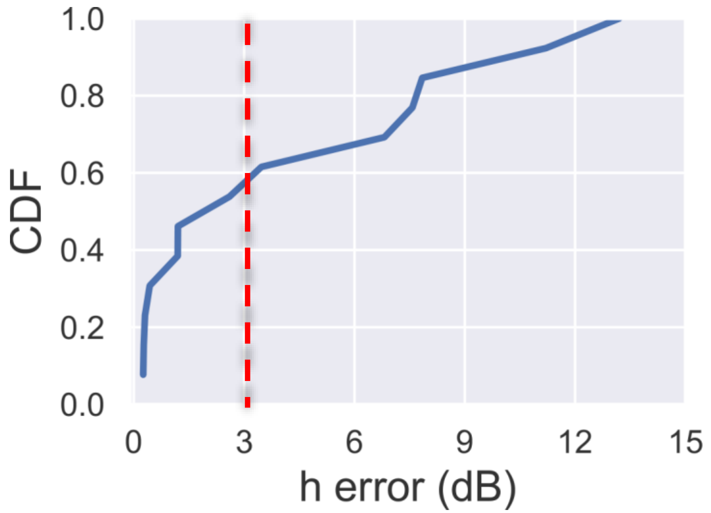


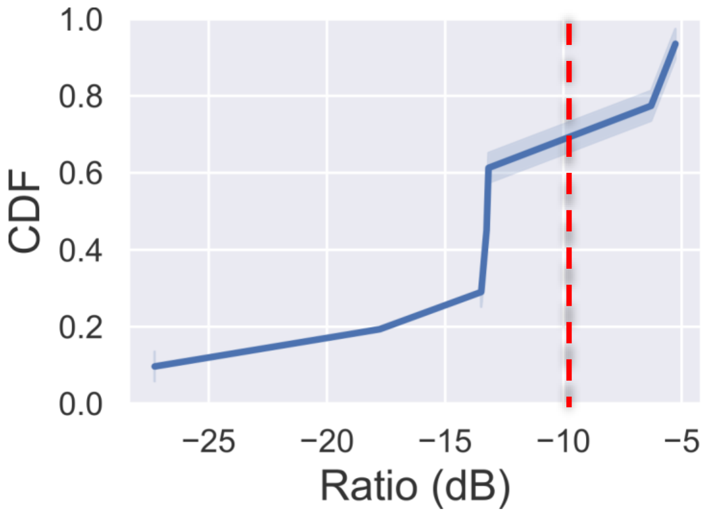
Initiator node

Normal nodes

Accuracy of IGE on our testbed

$$ratio = 10 \cdot lg\left(\frac{h_{error \geq 3dB}}{h_{max}}\right)$$





60% of channel gain errors $\leq 3\ dB$

70 % of the ratio $\leq -10\ dB$ (at least 10 times smaller than the max channel gain)

IGE in real world underperforms controlled experiments, but is still feasible, where large errors usually occur with small channels.

Key takeaways

- We integrate interference graph estimation (IGE) into data transmission using the same frequency-time resources.
- We demonstrate the feasibility of IGE over COTS Nordic nRF52 series SoCs in both controlled and real-world experiments.
- Concurrent flooding is a perfect carrier for IGE in wireless sensor networks.

Thank You!
Q&A

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