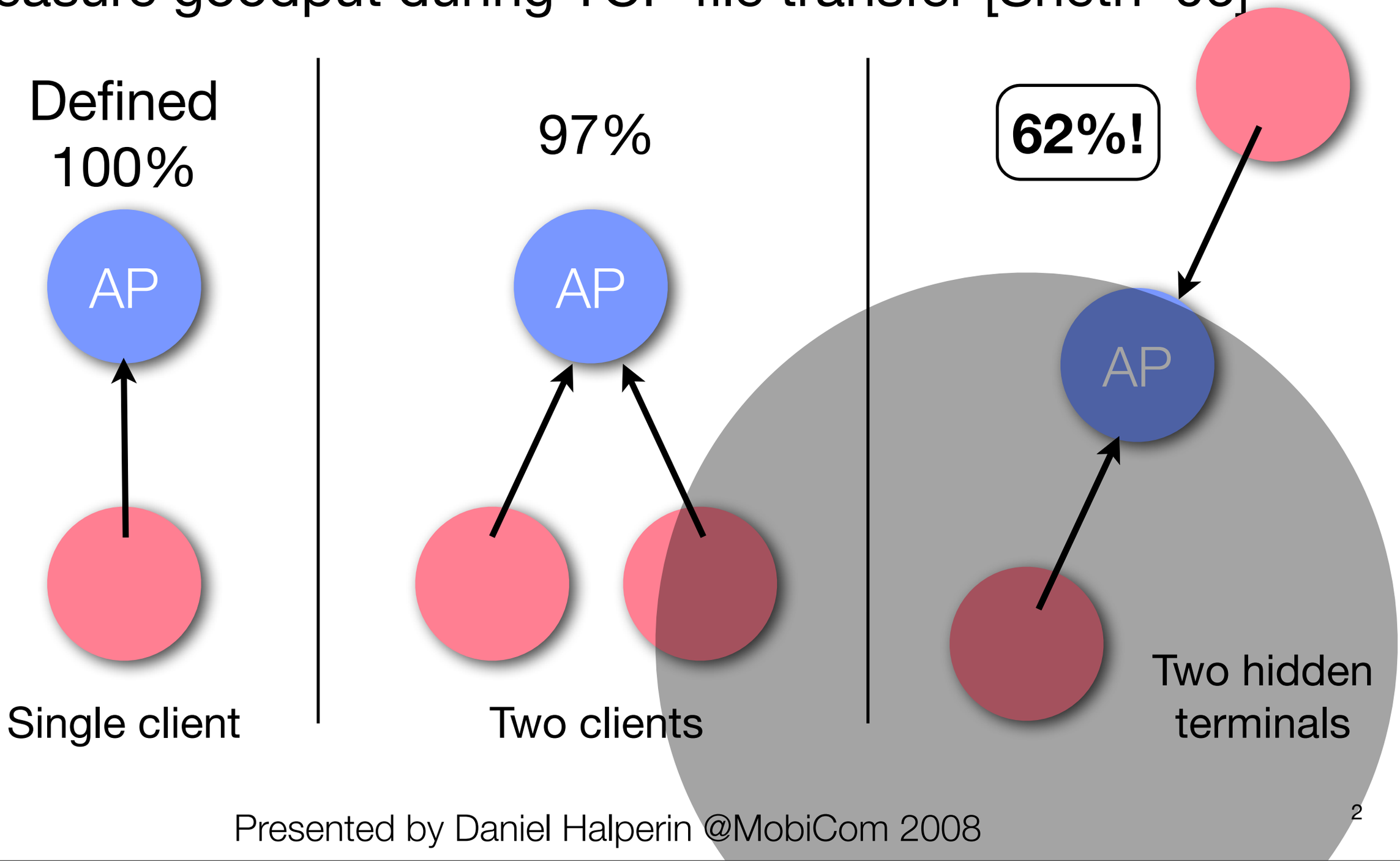
Taking the sting out of carrier sense: Interference cancellation for wireless LANs

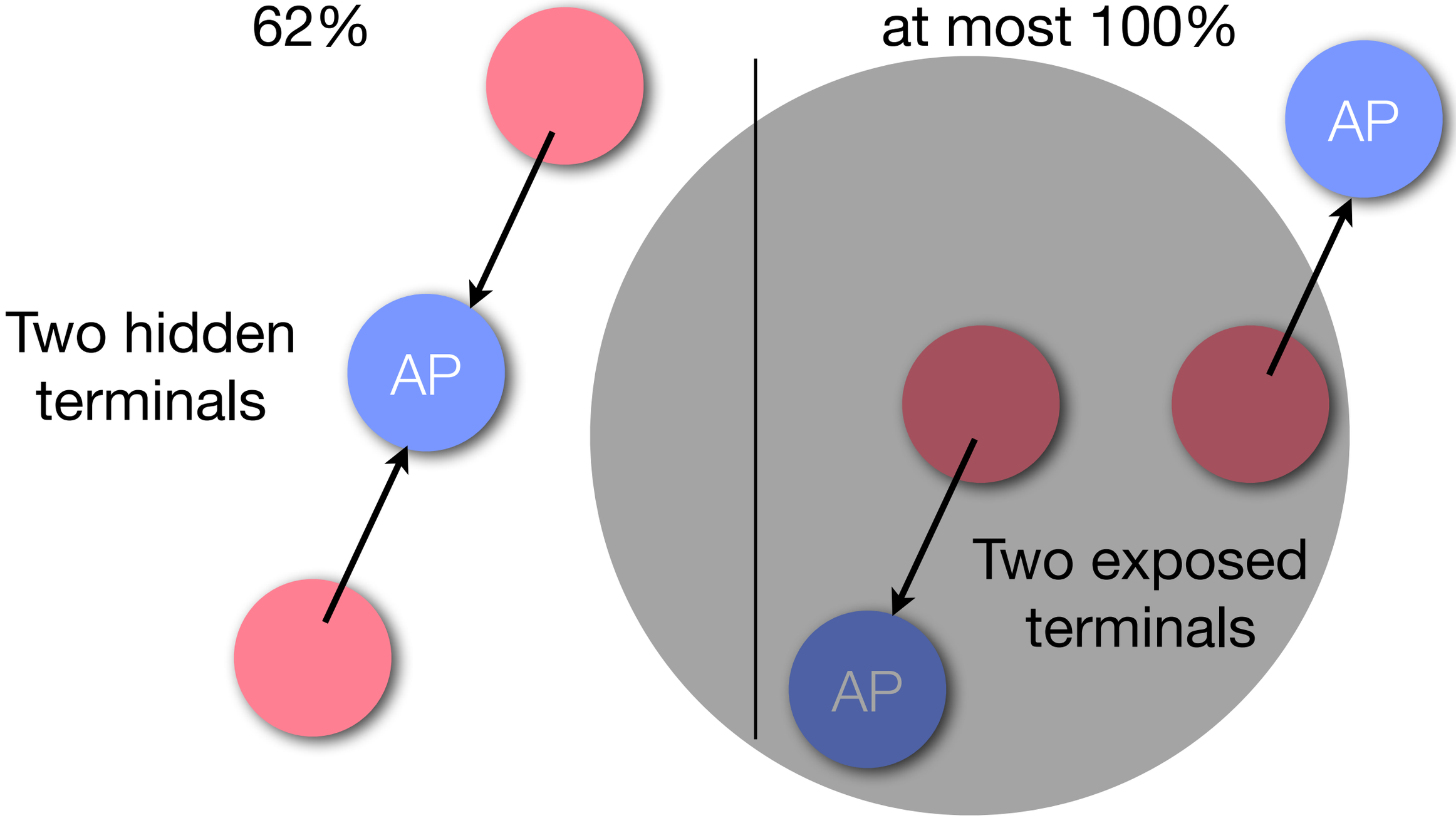
Daniel Halperin, Thomas Anderson, David Wetherall
University of Washington and Intel Research Seattle
MobiCom 2008

Carrier sense doesn't avoid collisions

Measure goodput during TCP file transfer [Sheth '06]



Carrier sense prevents spatial reuse



Interference cancellation as an alternative

- Class of communication techniques designed to overcome interference
- Known to increase capacity in multiuser networks
- Existing practical work in context of **cellular networks**
  - Centralized control over hardware, power, rate; synchronized transmitters
- **WiFi**-like networks are **chaotic** - bursty, unmanaged, unlicensed

Our contributions

- We design a **practical algorithm** for interference cancellation adapted for wireless LANs

- Prototype **implementation** and experimental evaluation in an 11 node ZigBee software radio testbed

  - Data-dependent averaging to model interfering signal

- Cancellation reduces the penalties of carrier sense

  - In our testbed, reduces hidden terminal loss from 14% to 7% and increases median delivery by 1.8x

In this talk

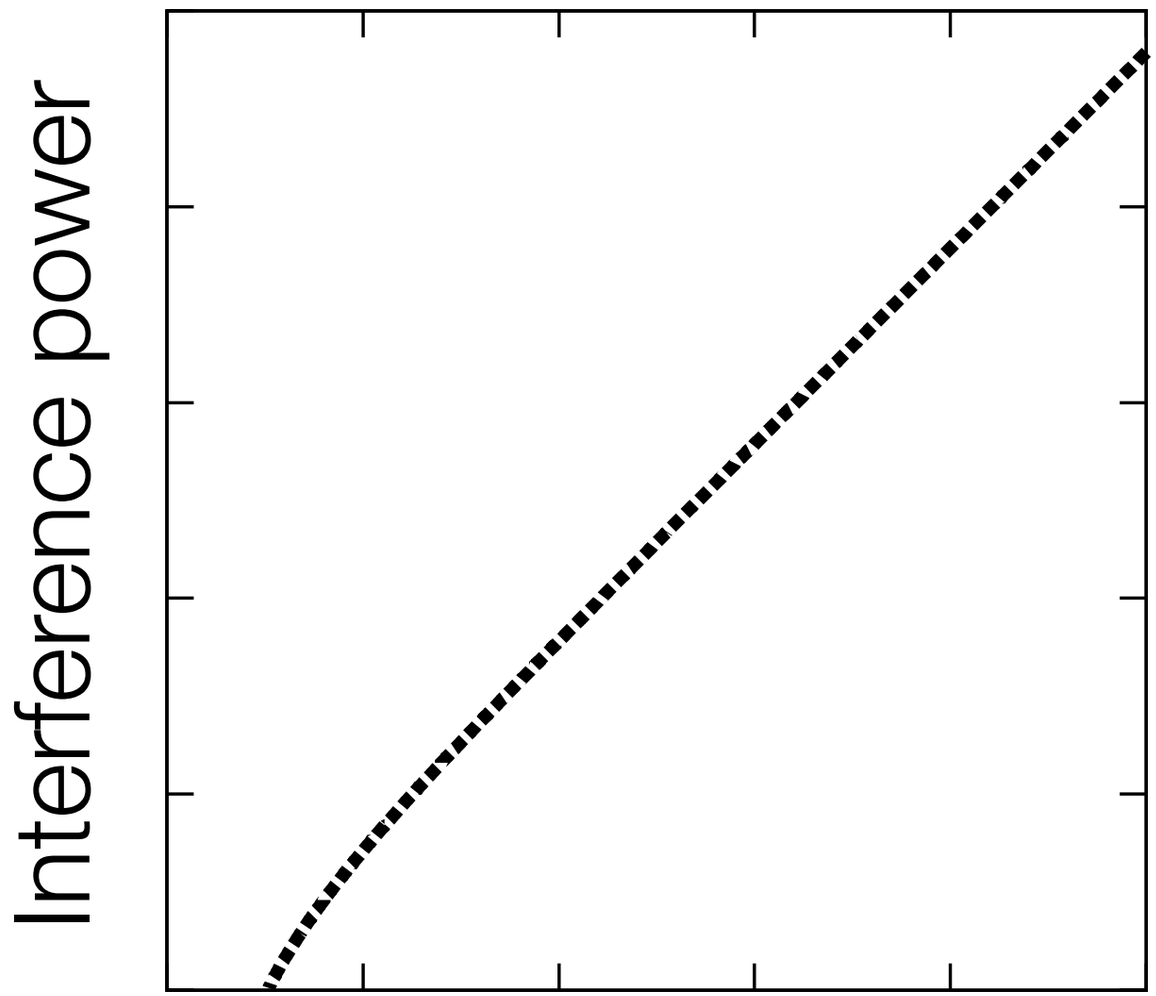
- Motivation for interference cancellation
- Interference cancellation: what and how
- Prototype implementation and software radio evaluation
- Next steps

Receiving during a collision (the SINR model)

$$\frac{\text{Signal}}{\text{Noise} + \sum \text{Interference}}$$

- When relative power of desired signal is large enough, signal received

- Line shows threshold between **reliable** and **lossy** links



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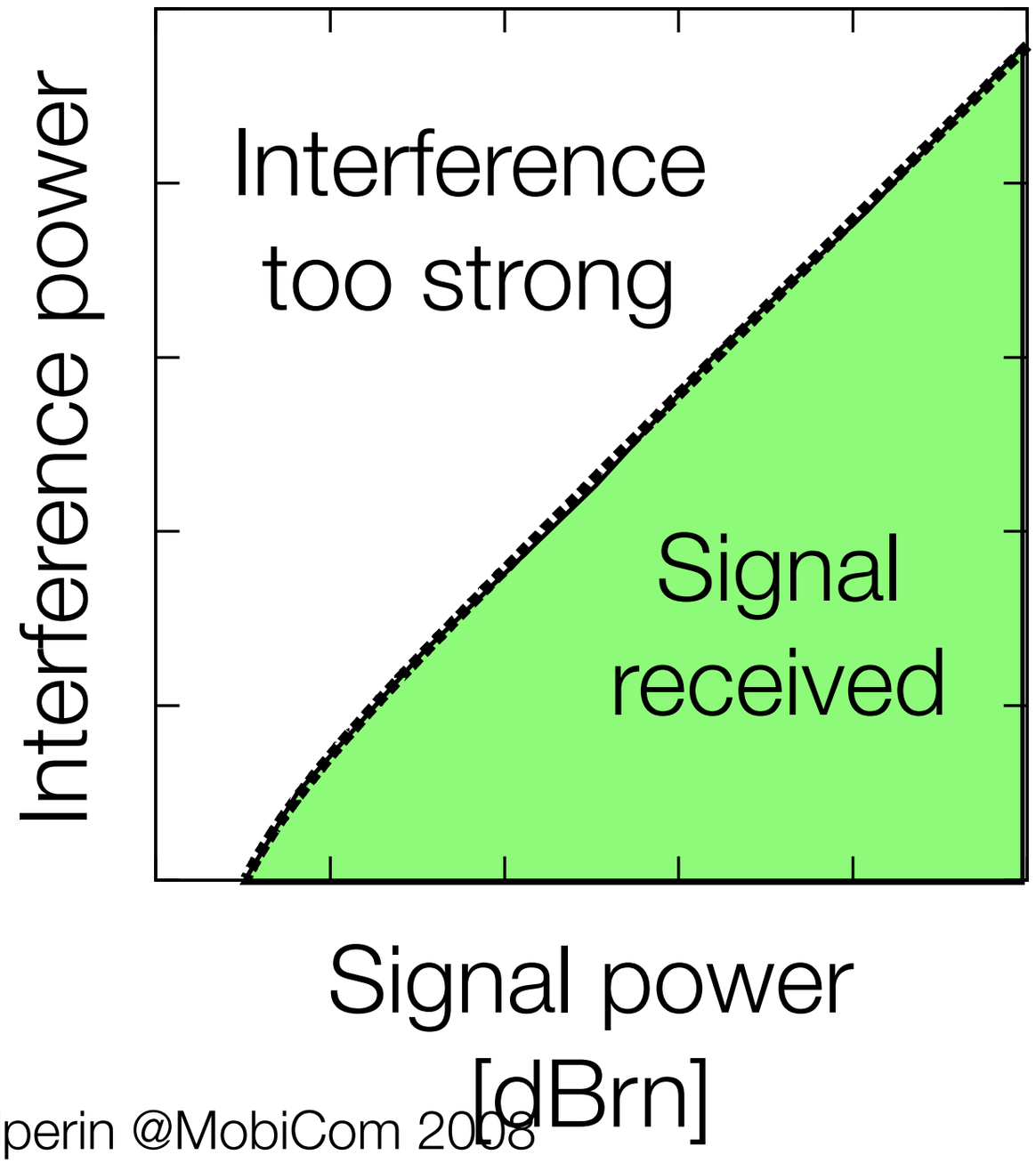

The SINR model is overly simplistic

- SINR treats interference and noise as **equally** detrimental

- Noise is **random**, but interference has **structure** intended to communicate data

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Key idea: exploit structure of interference to overcome its effects

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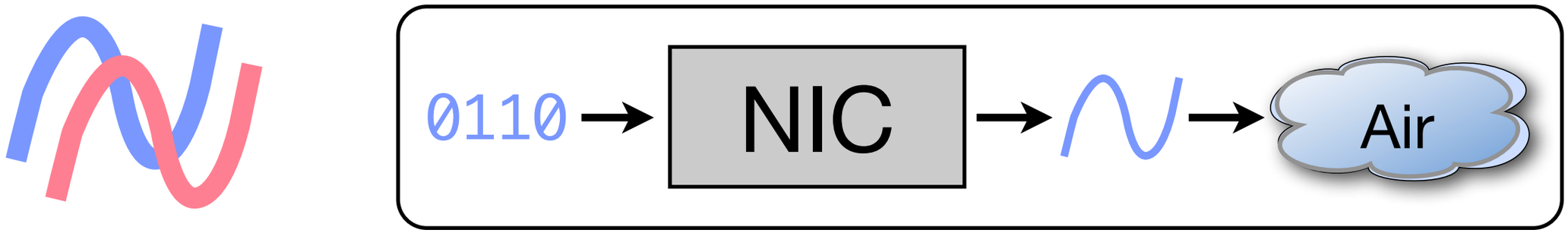

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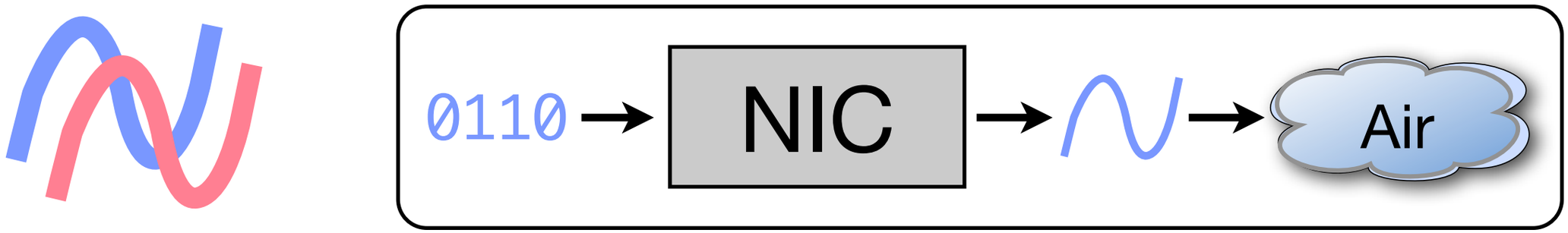

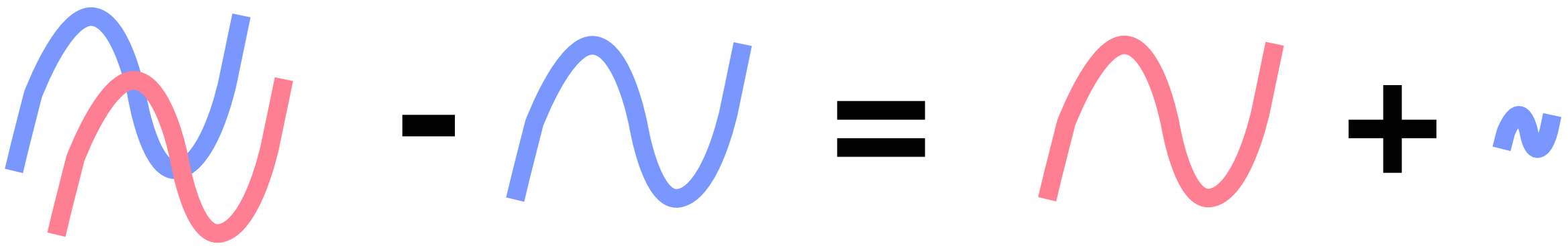

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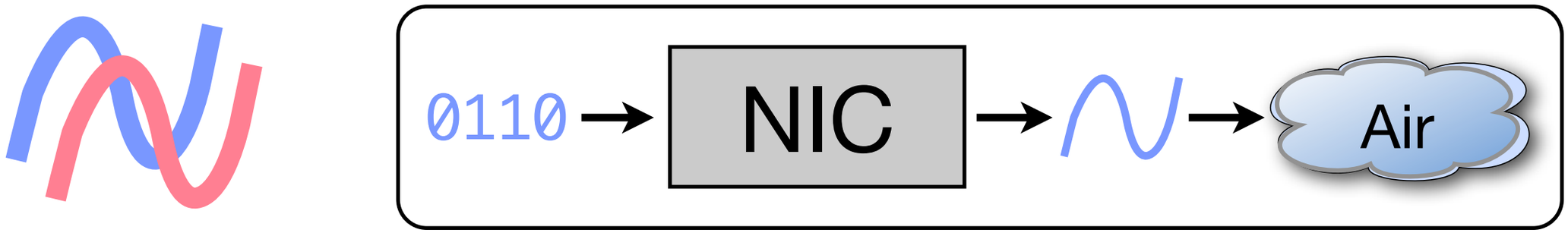
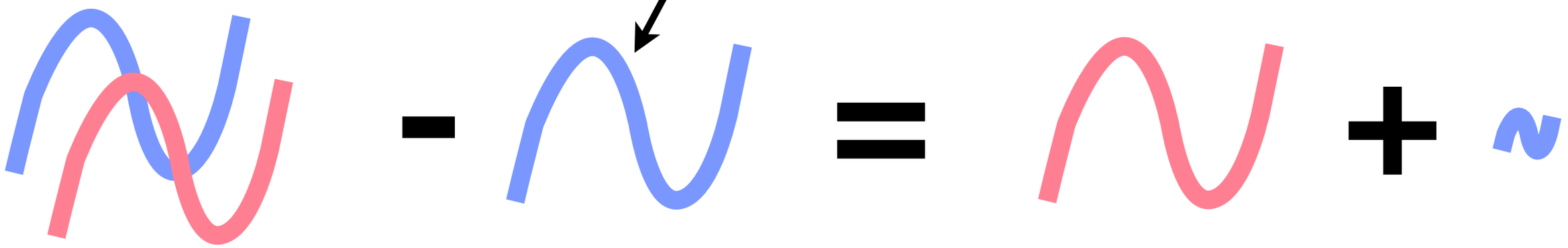


Approximate model



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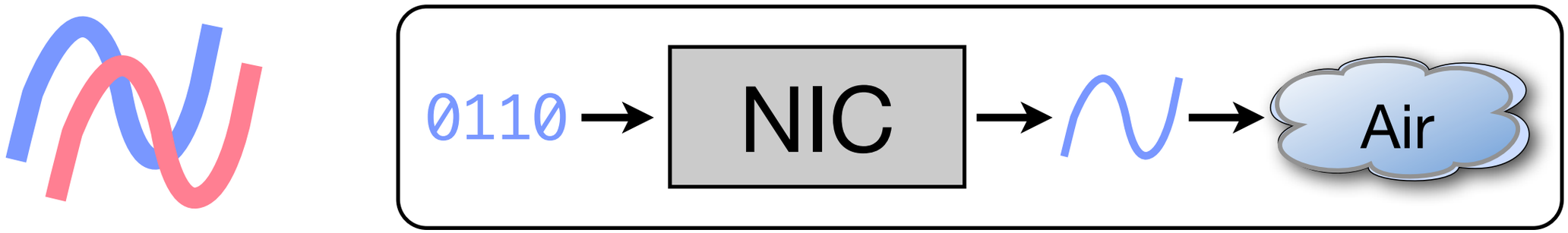
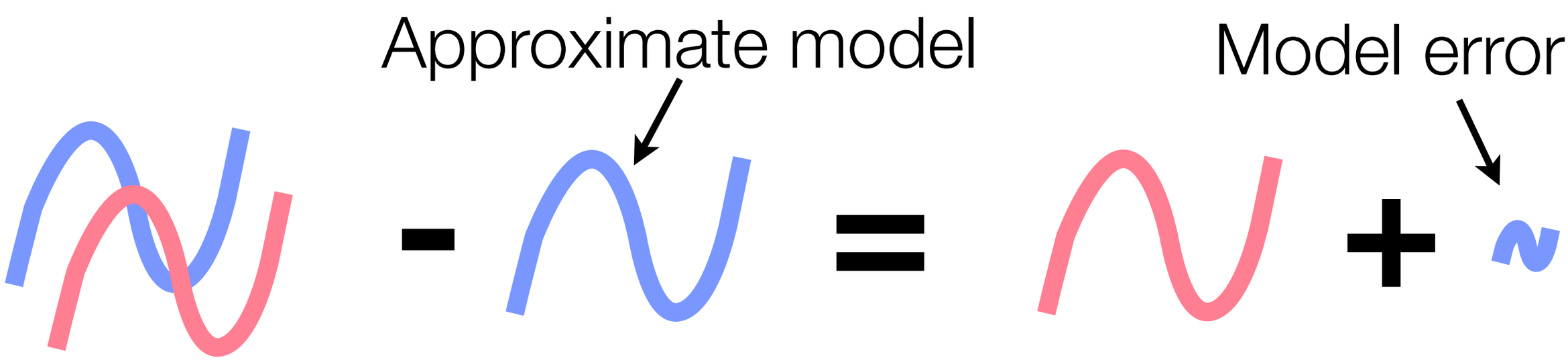
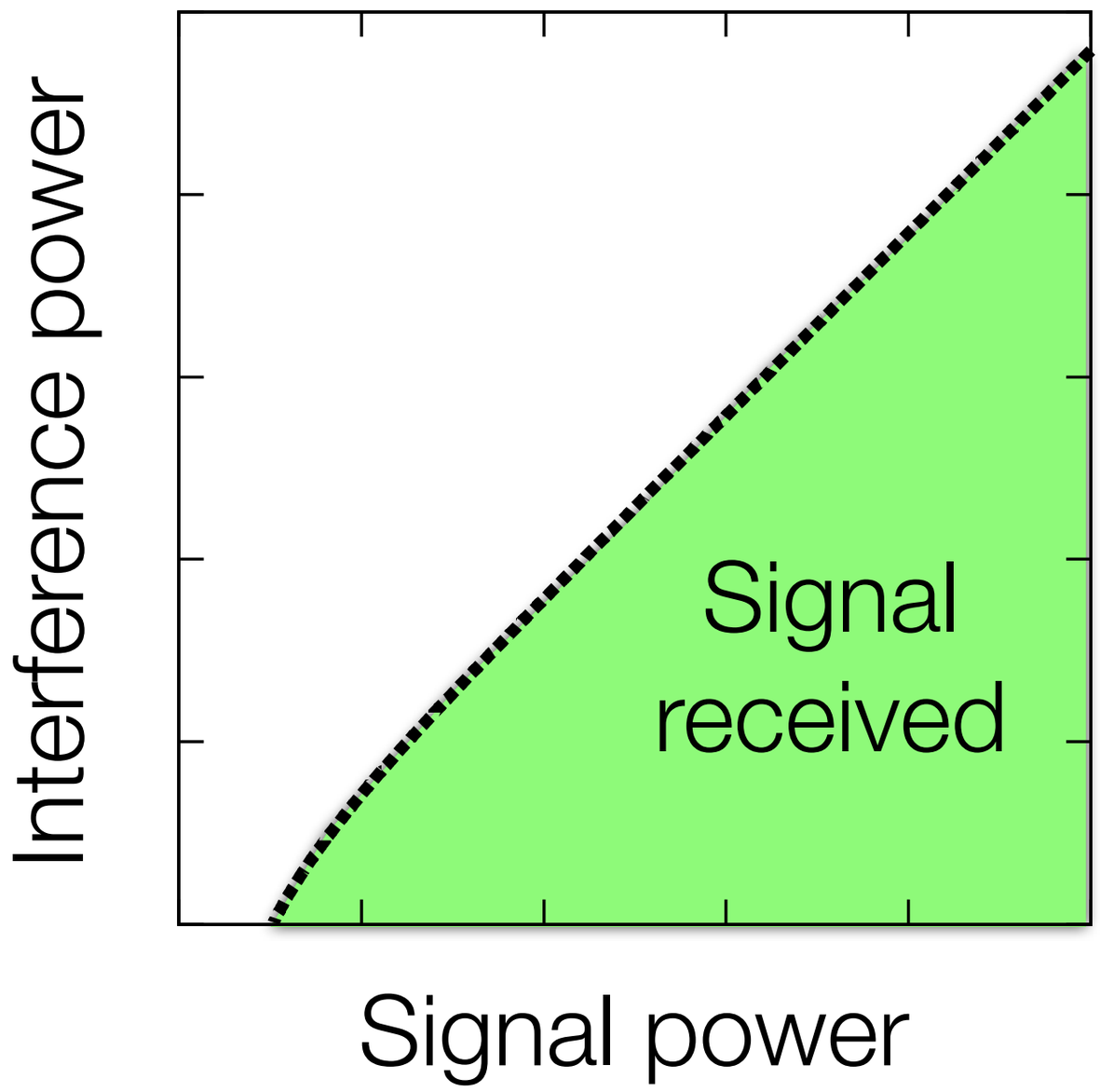




Implementing interference cancellation

- We adapted and implemented **successive interference cancellation (SIC)**

- Strong interferer decoded, modeled, and then canceled



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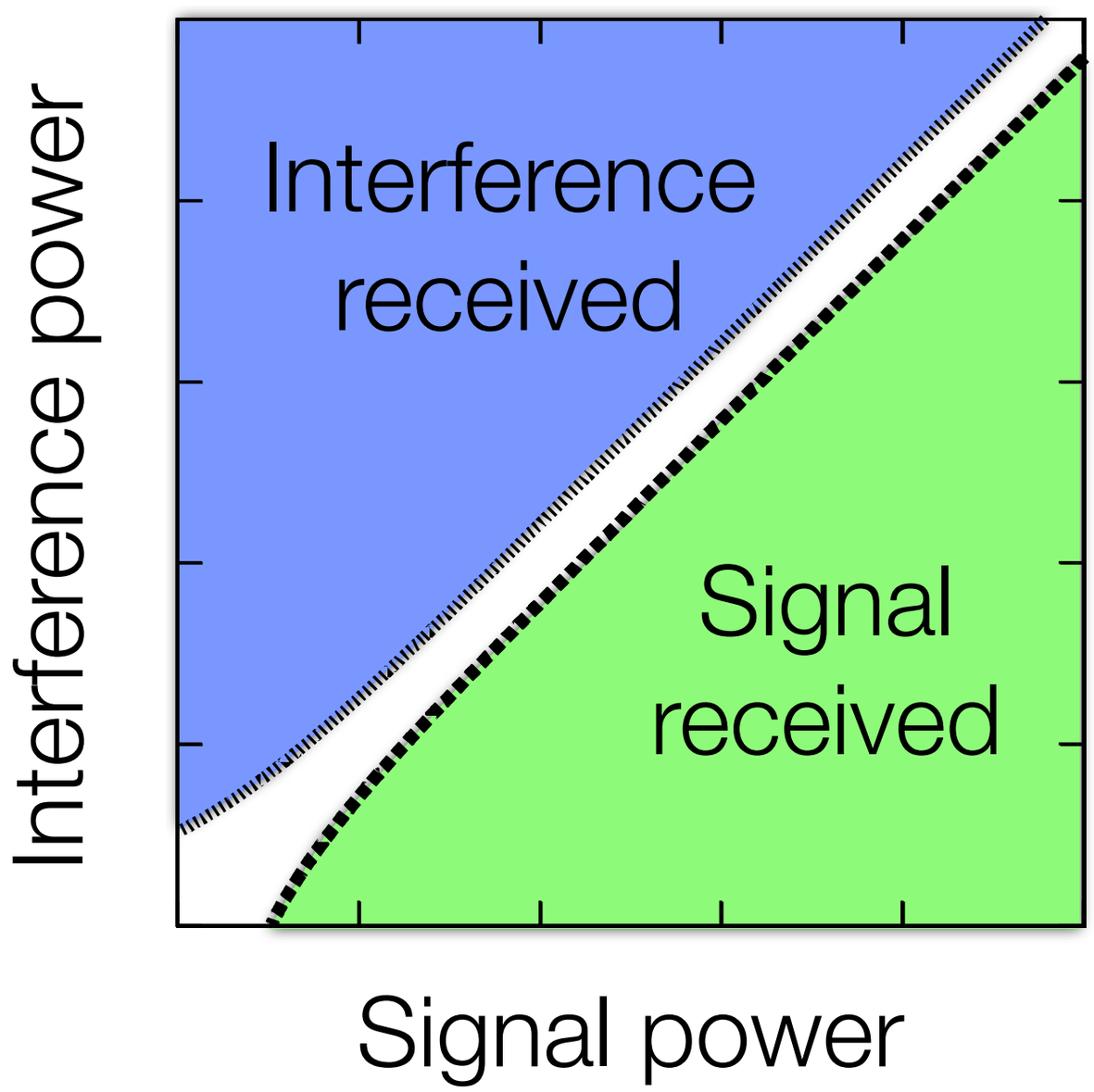

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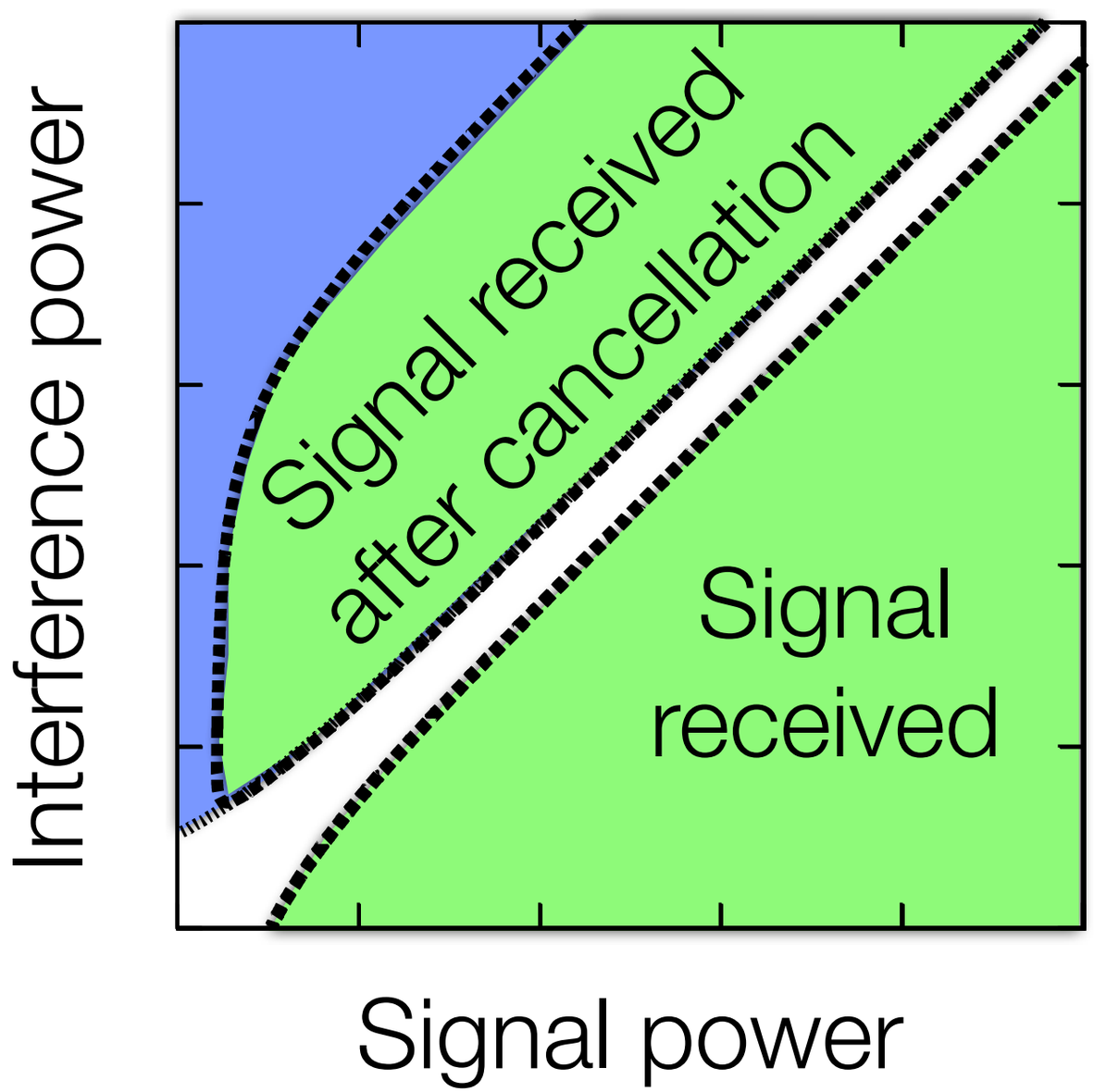


Prototype implementation and evaluation

Presented by Daniel Halperin @MobiCom 2008

Interference cancellation for IEEE 802.15.4

- Prototype implementation of successive interference cancellation for 2.4 GHz ZigBee PHY on software radios
  - Low power, low rate wireless networking using O-QPSK with 8x direct sequence spread spectrum
  - Similar to slowest rates of WiFi and good for SIC
  - 2M chips/s and 2.5 MHz spectral mask

➡ **Real PHY** that fits well with USRP limitations

Key challenges in implementing cancellation

- Synchronizing receivers with packets during collisions

- Modeling and approximating interference

- Implications for traditional MACs (e.g., synchronous ACKs)

How to model an interfering signal?

- **Key step** in interference cancellation is approximating and subtracting interference

- Any **error** in the model increases the noise floor and makes post-cancellation **performance worse**

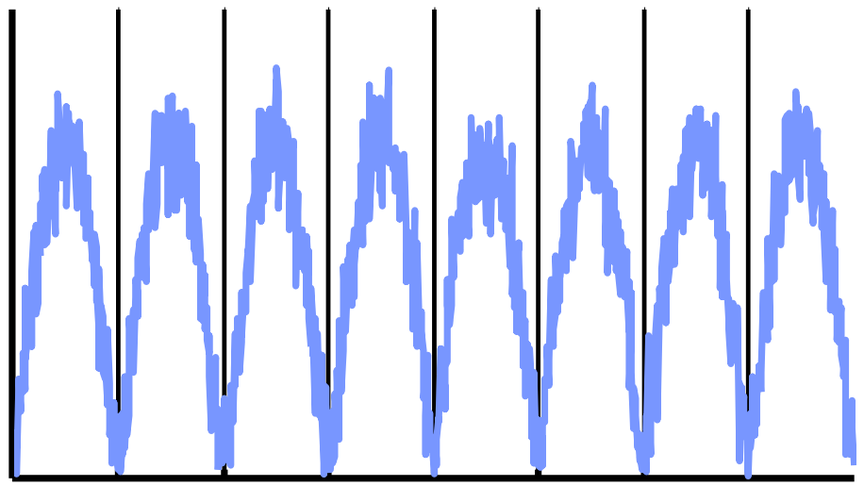
- Model specific environment features - simple but limited

- Channel filter computation is complex and misses non-linearities

Our solution:
Data-dependent models by averaging

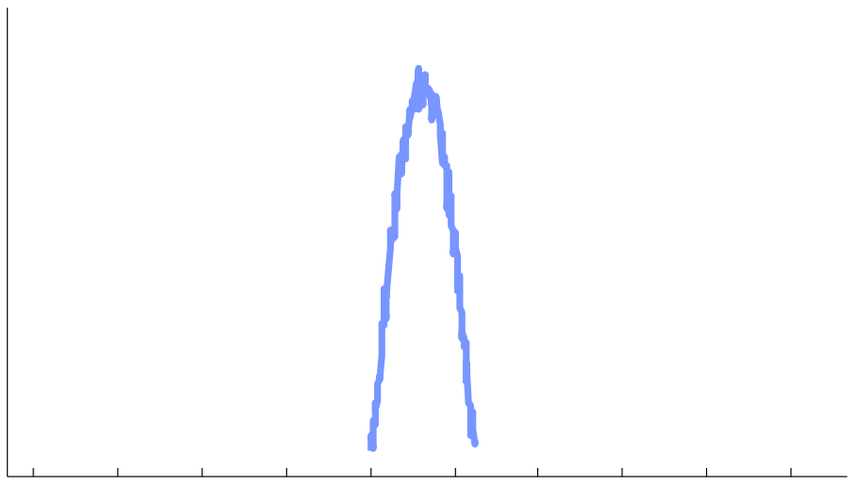
- Symbols blended in time by filters and channel; received at time *i* depends on *i-1*, *i*, *i+1*

- Build an RF template for each bit pattern by averaging received waveforms



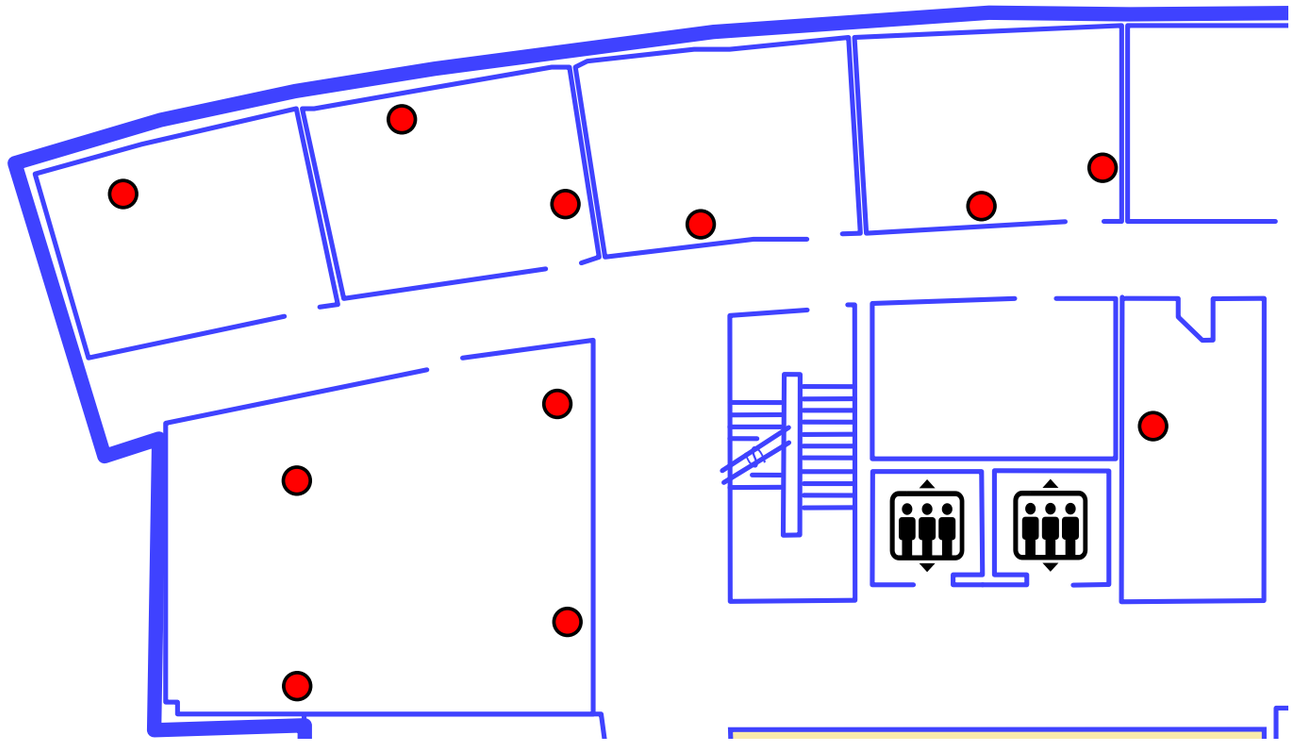
- Uncorrelated noise, interference will average out

- We use 3 consecutive symbols (6 bits; 64 models)



Experimental setup

- Deployed an 11-node wireless testbed in UW CSE



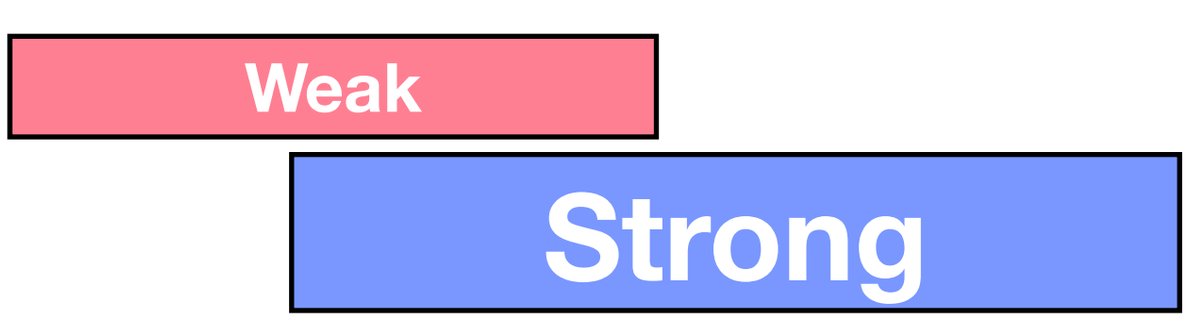
- Non-LOS, co-channel WiFi APs, node pairs range from perfect communication to completely hidden

Experimental methodology

- Implemented three ZigBee receivers
  - Two conventional single-packet receivers
  - Successive interference cancellation
- Generate random two-packet collisions for all pairs of senders while logging digitized, raw RF at other 9 nodes
- Replay logs to each receiver to allow direct comparison

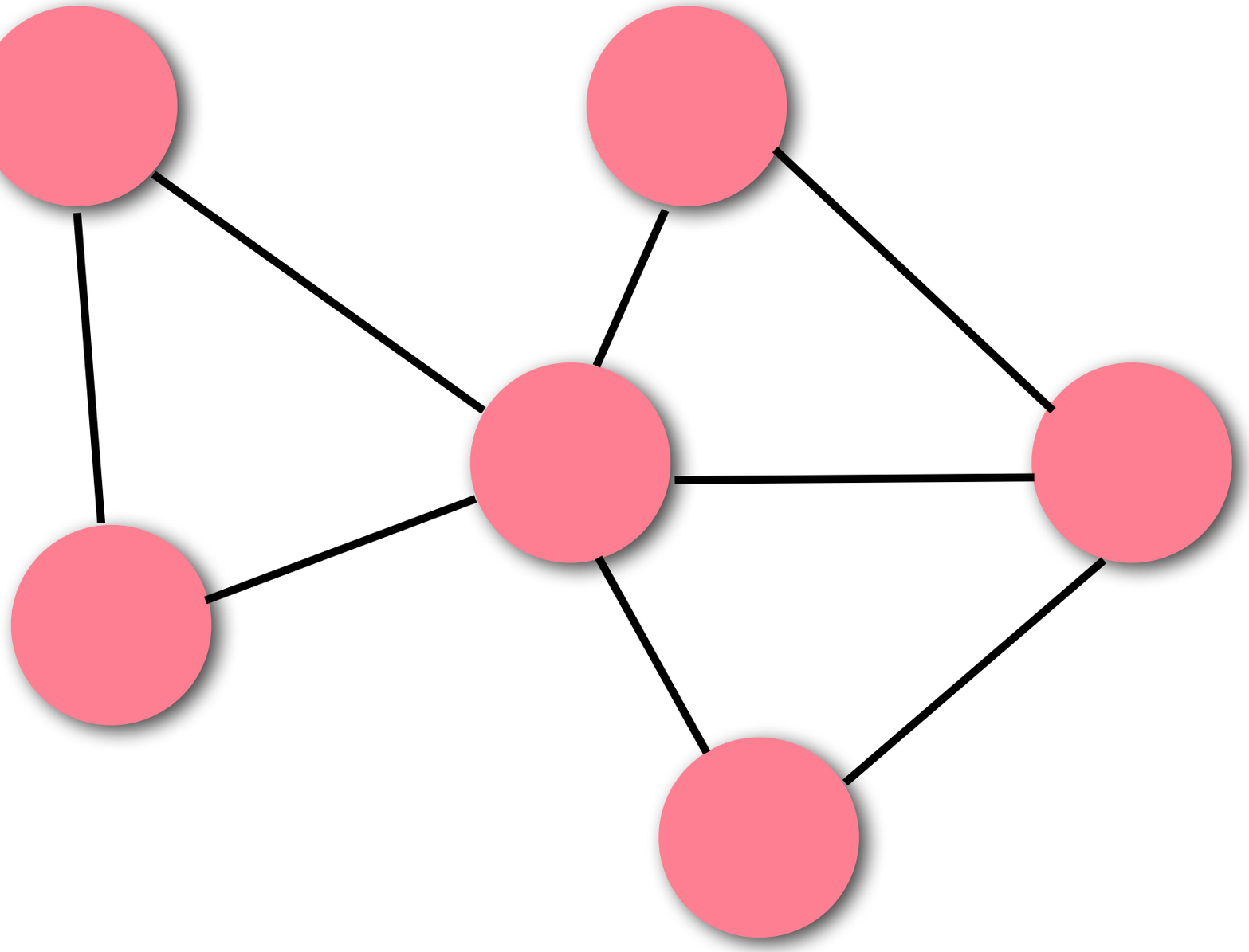
Baseline receiver implementation

- By locking onto one transmission, a receiver can miss a second, stronger packet



- Observed commercial hardware of both types
- We compare successive cancellation against both

Experiment analysis



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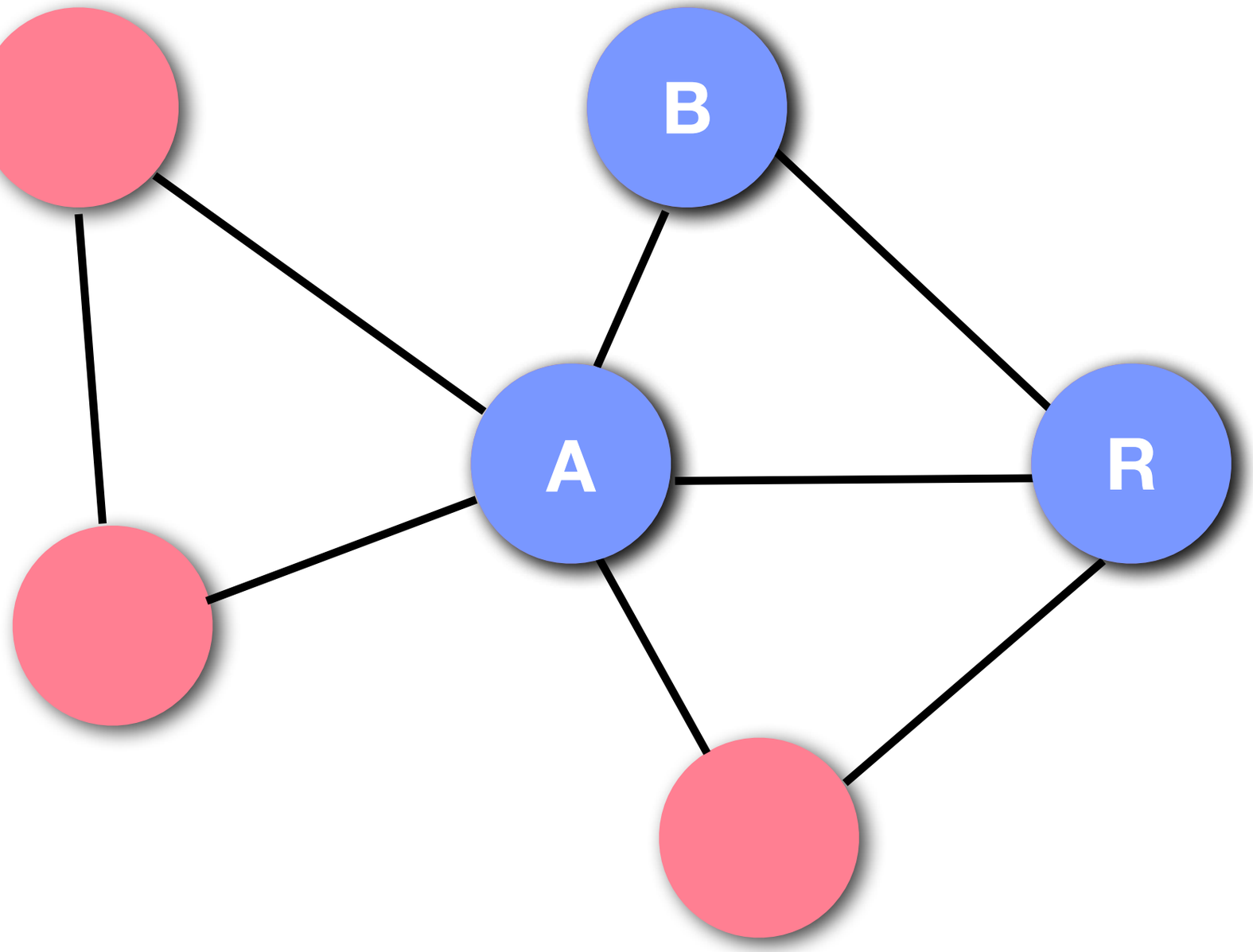
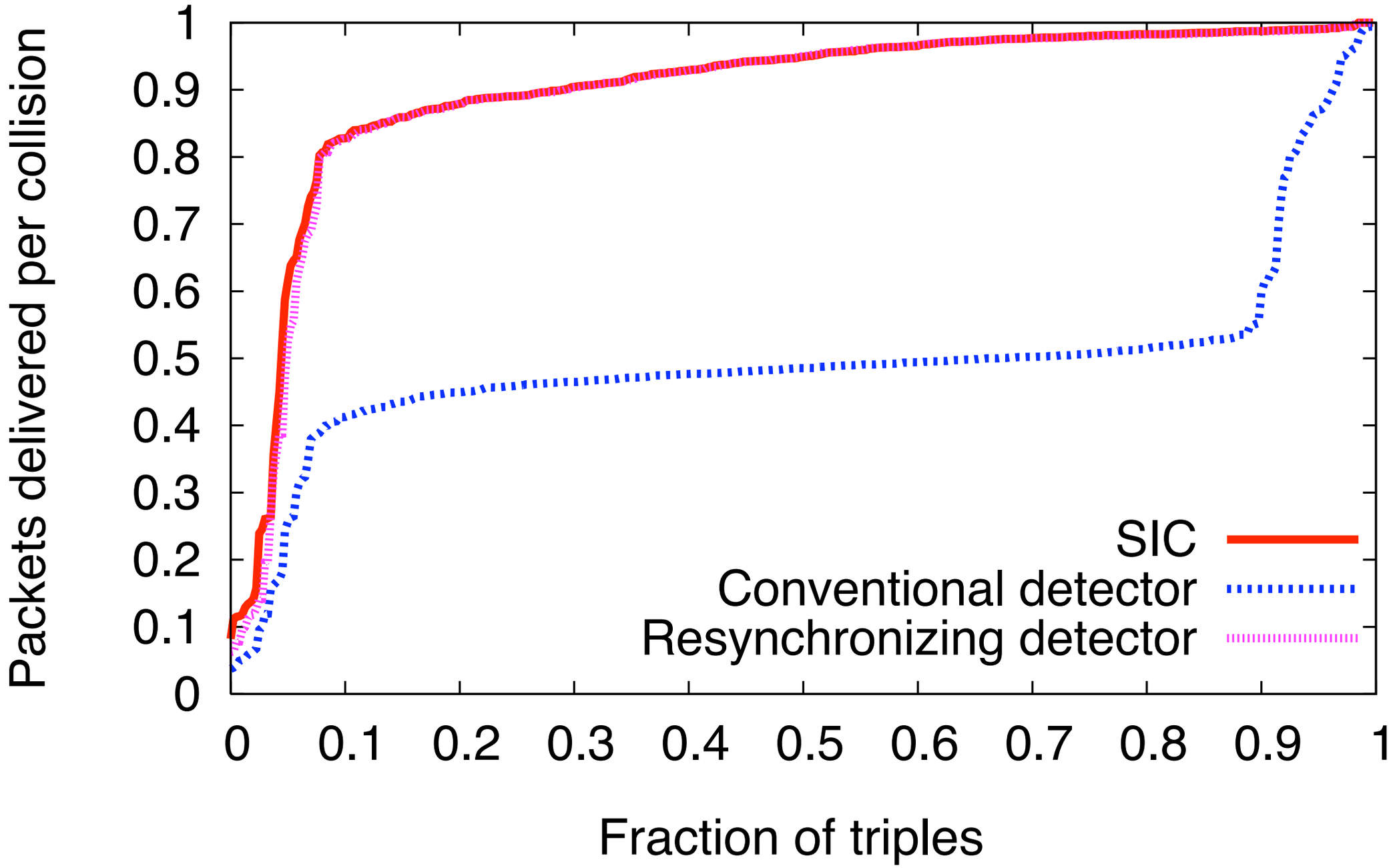


For the stronger transmitter (lower loss link)



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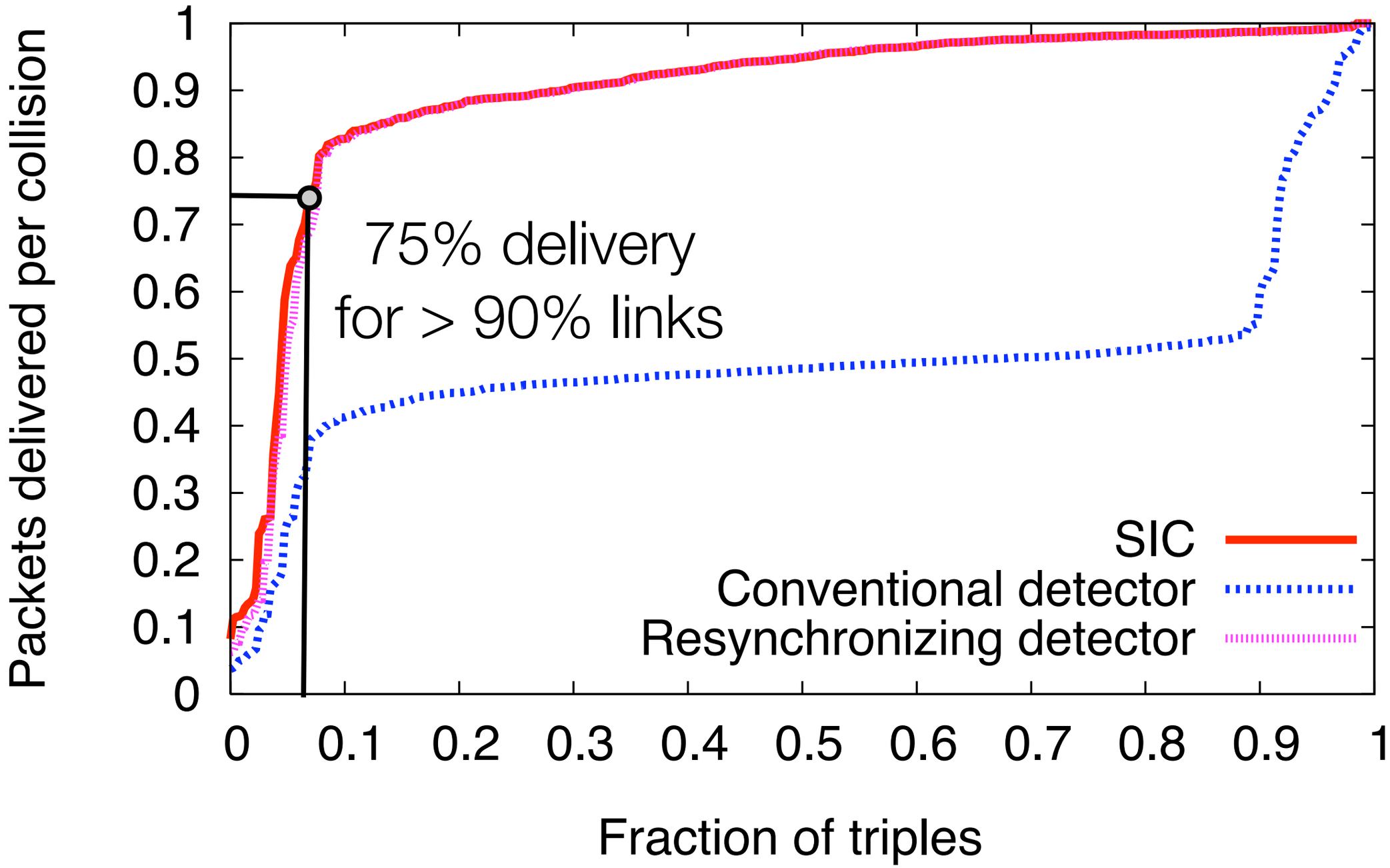

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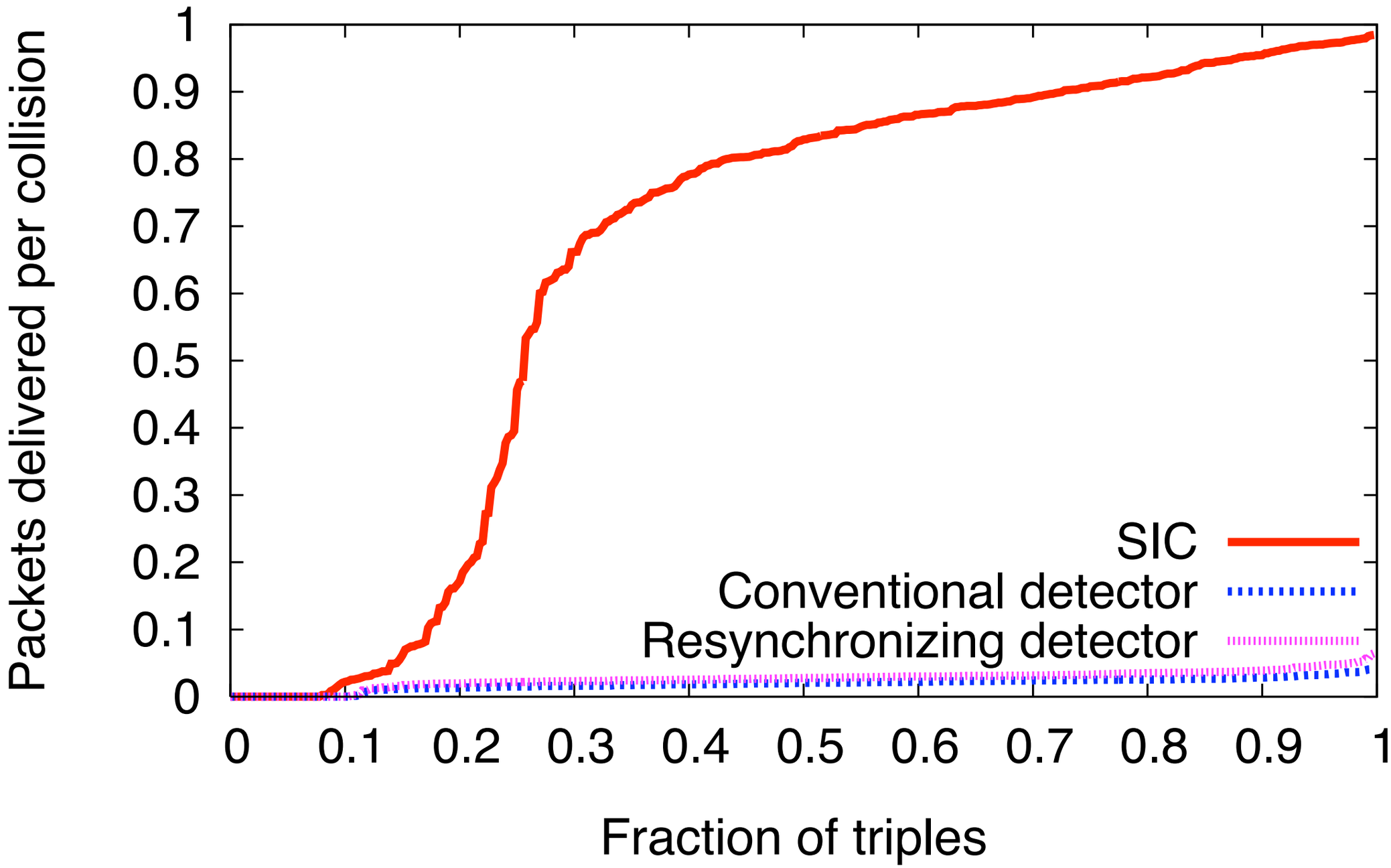

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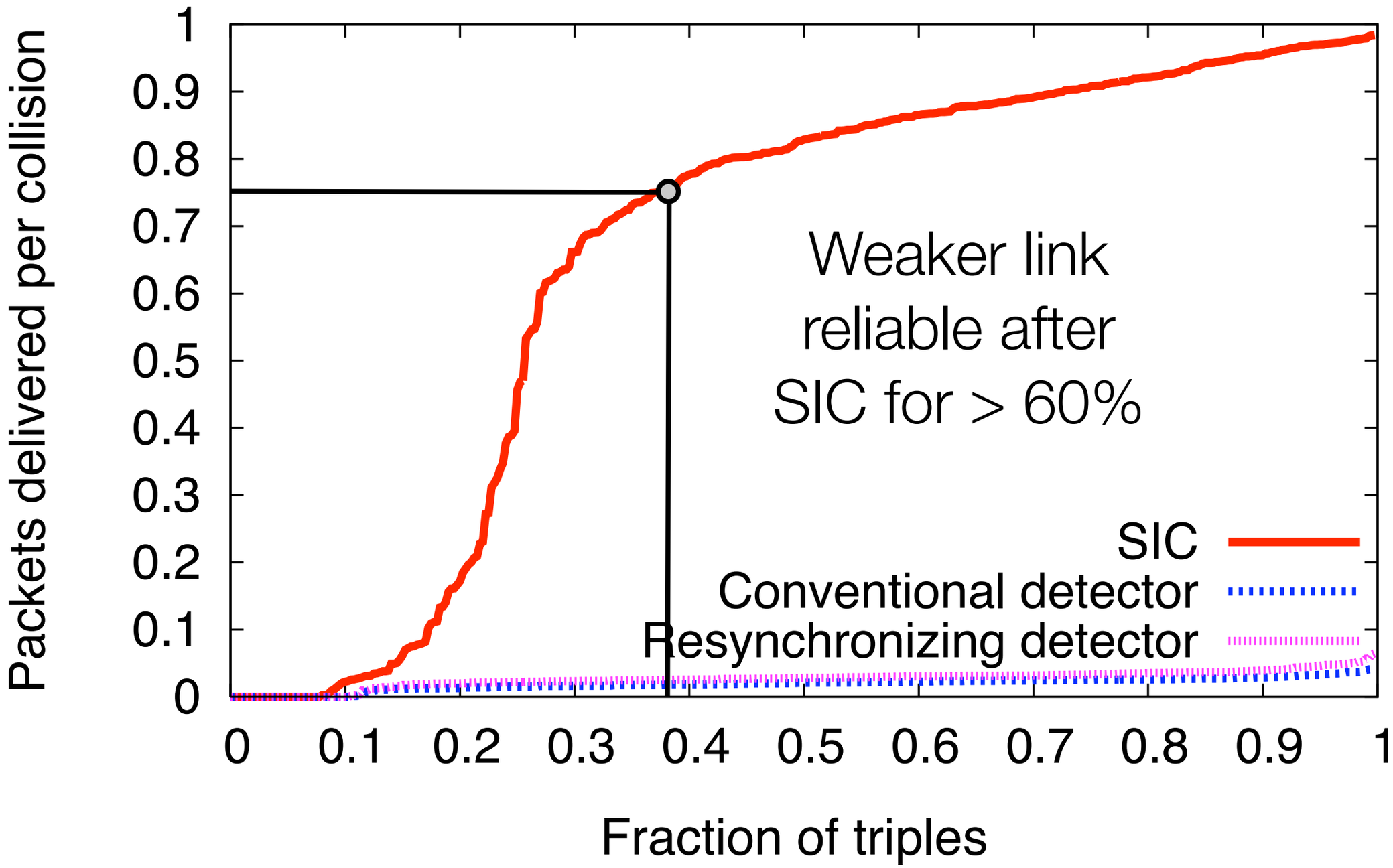
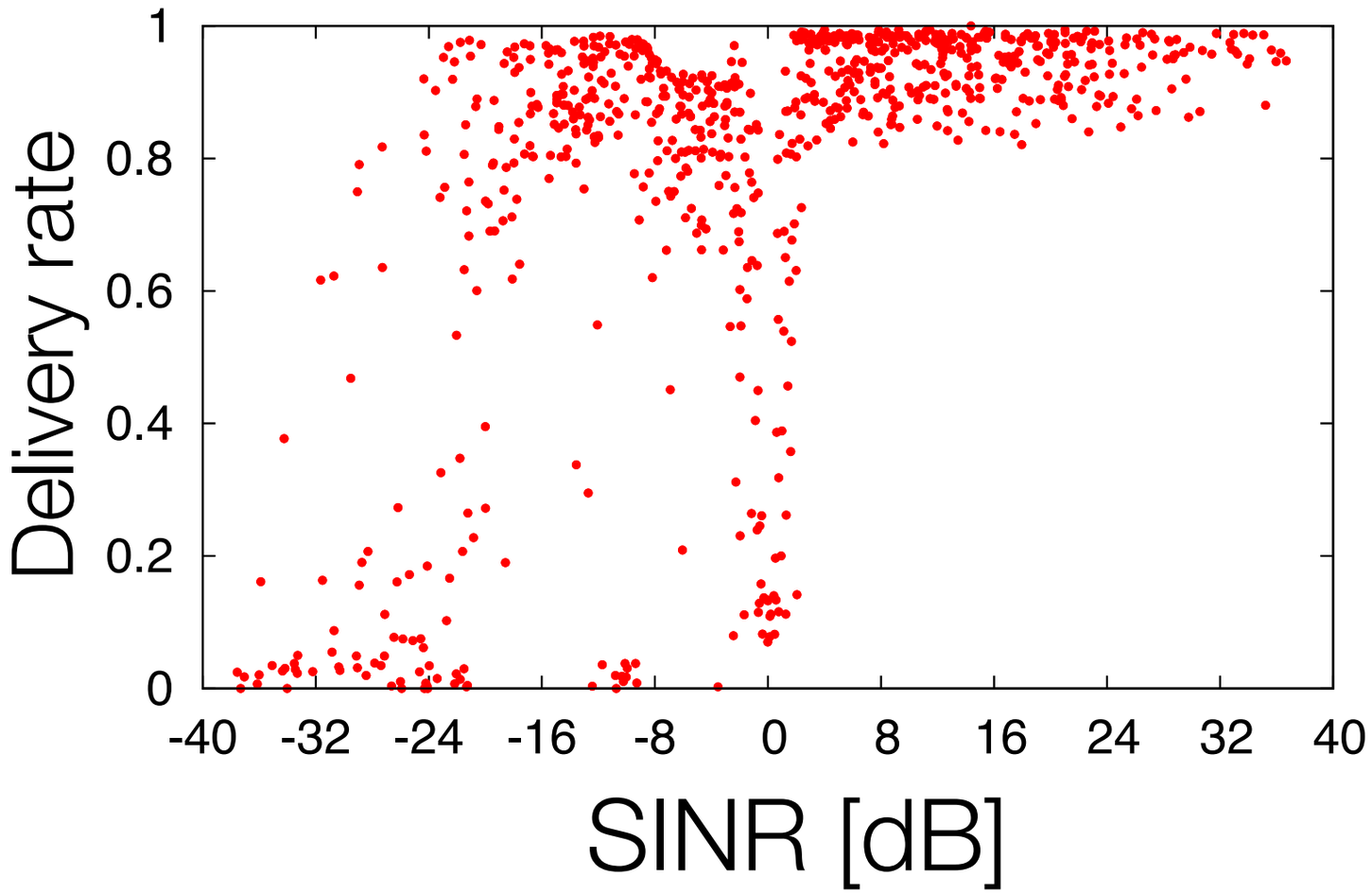
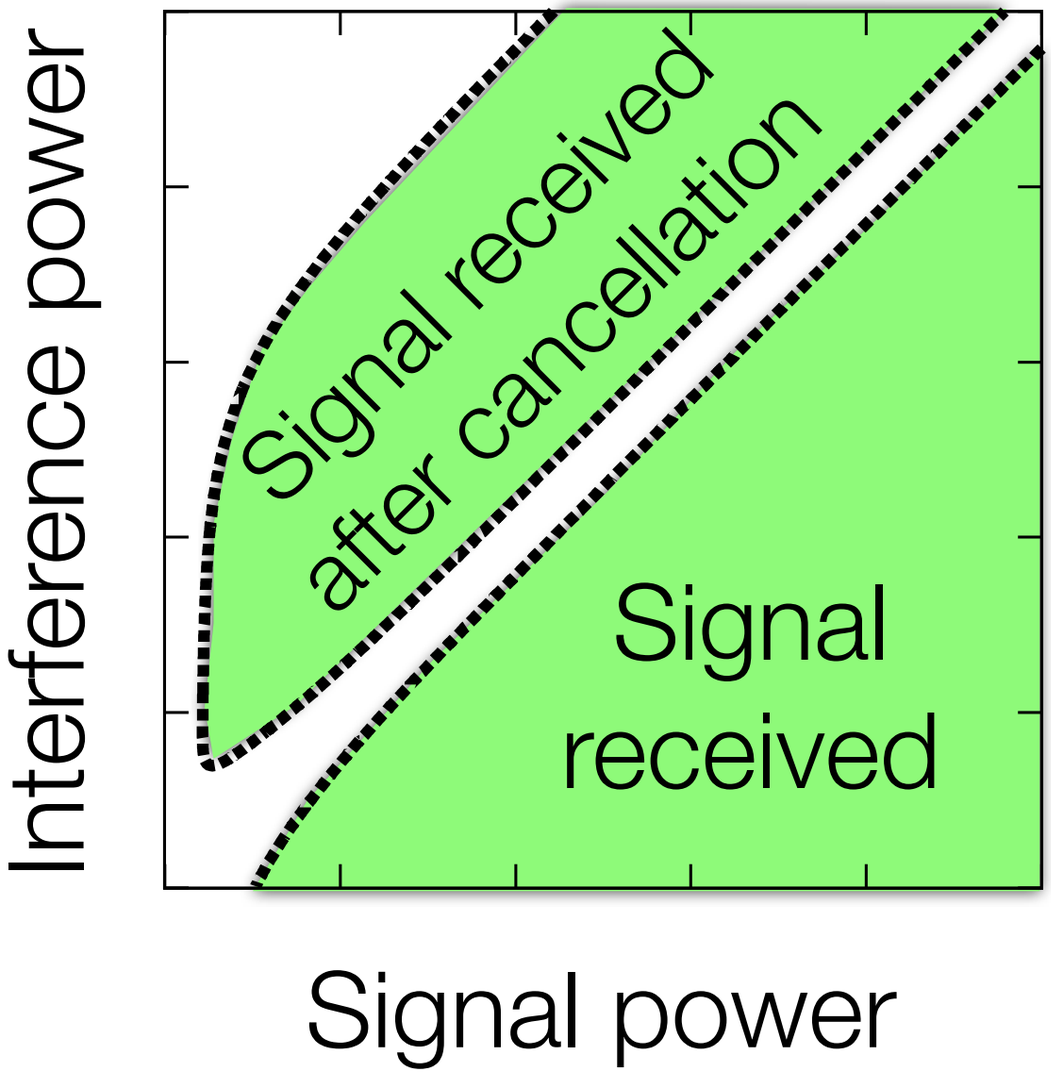


Delivery vs SINR (interference cancellation)

SINR [dB] ≅ Signal power [dB] - Interference power [dB]





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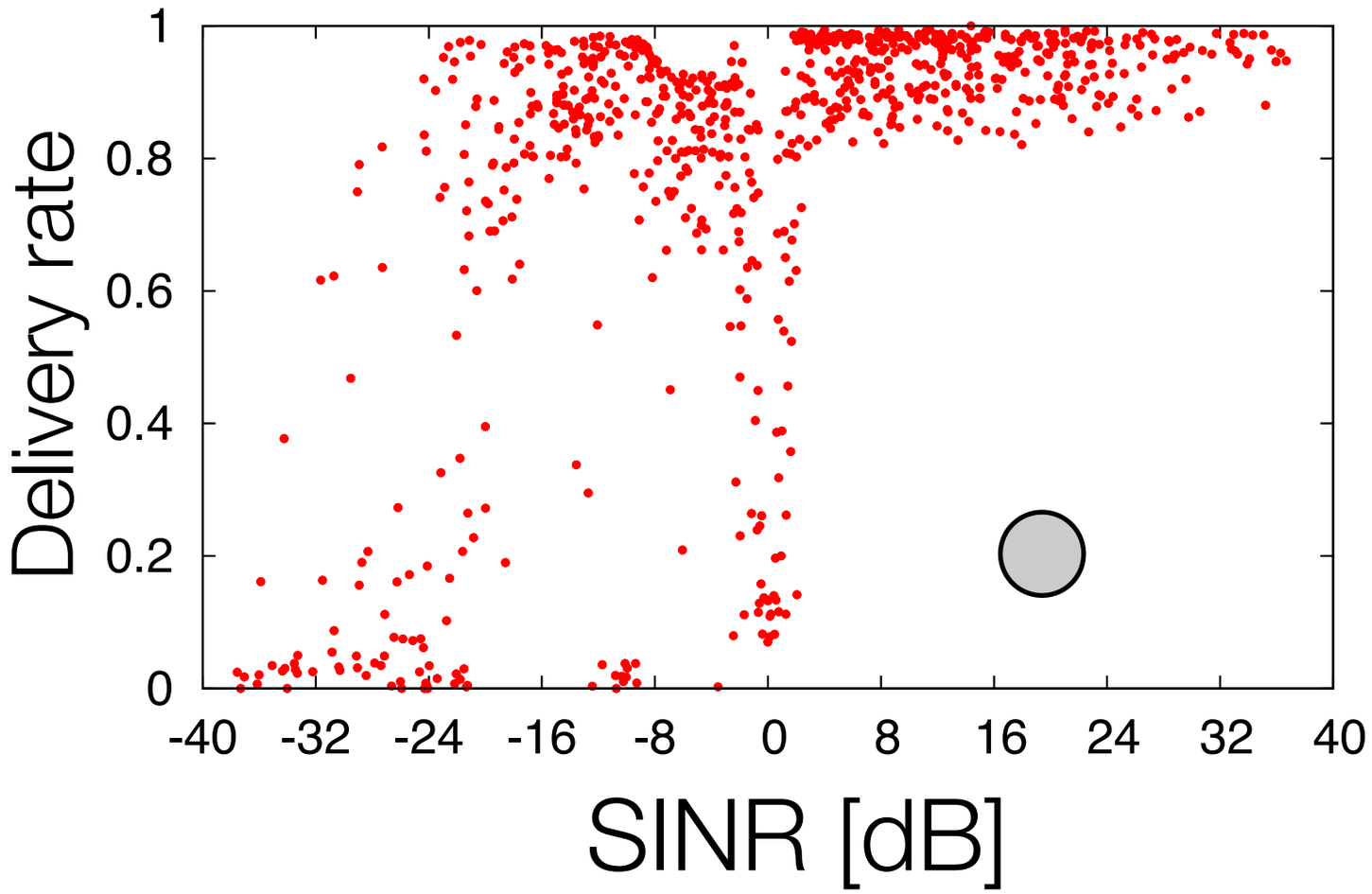

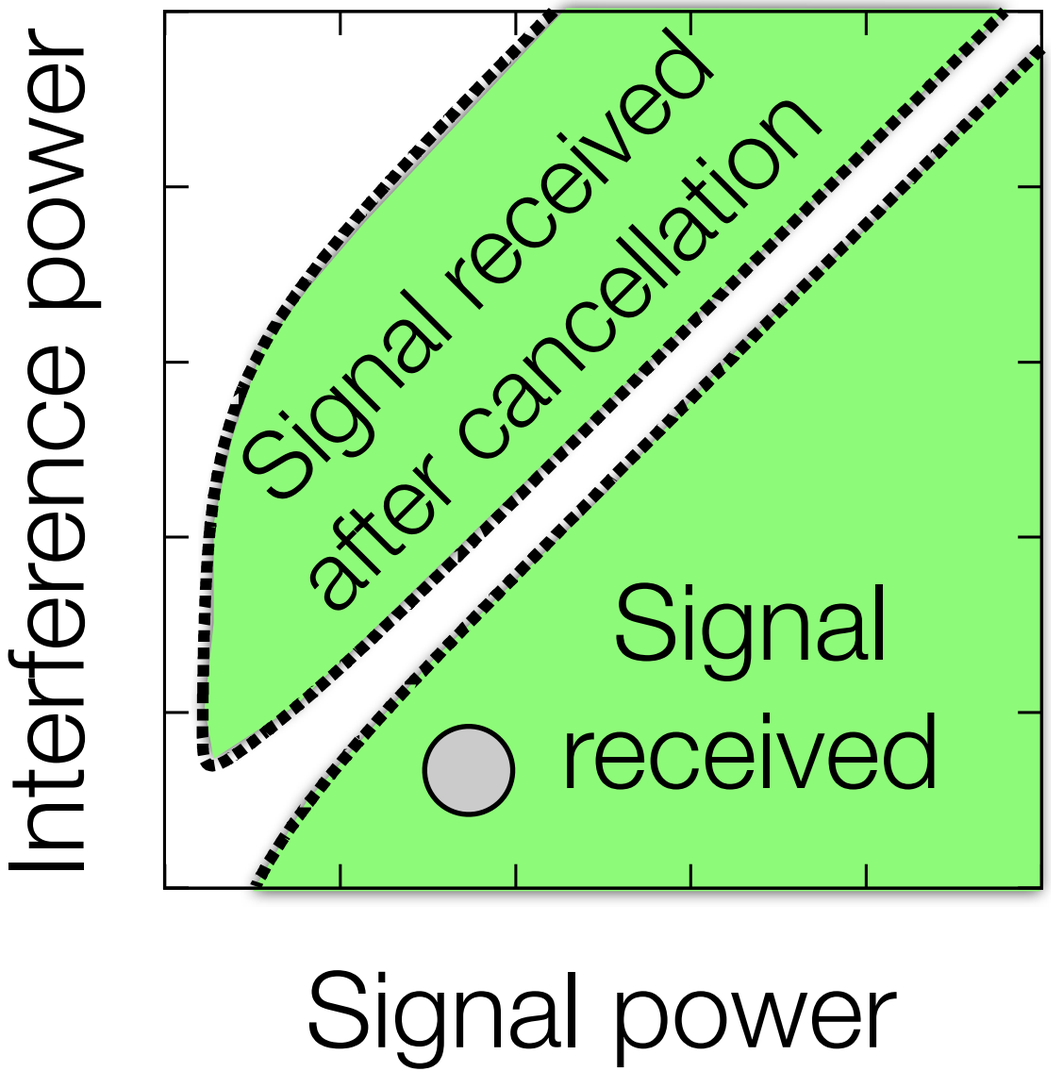

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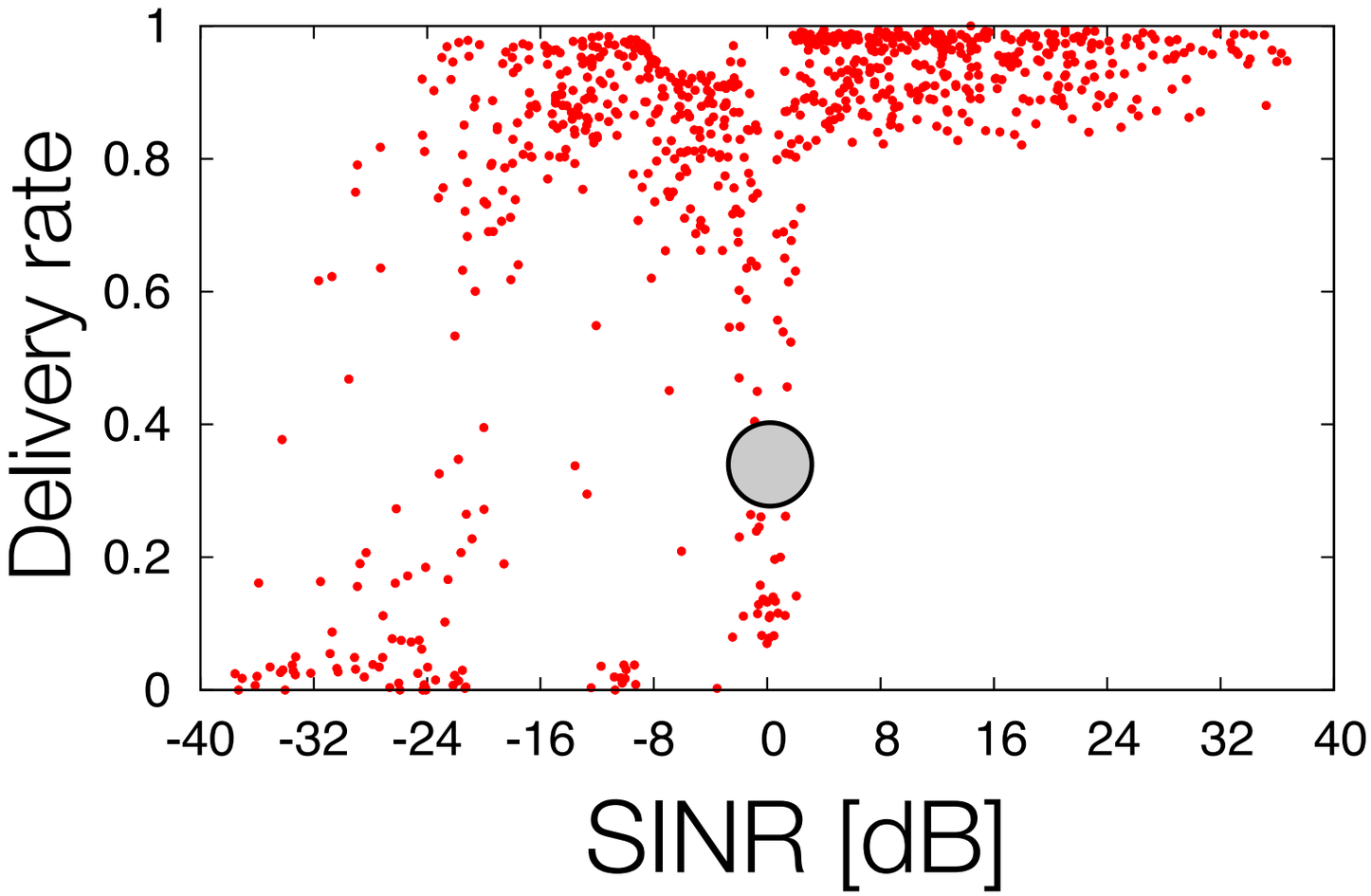

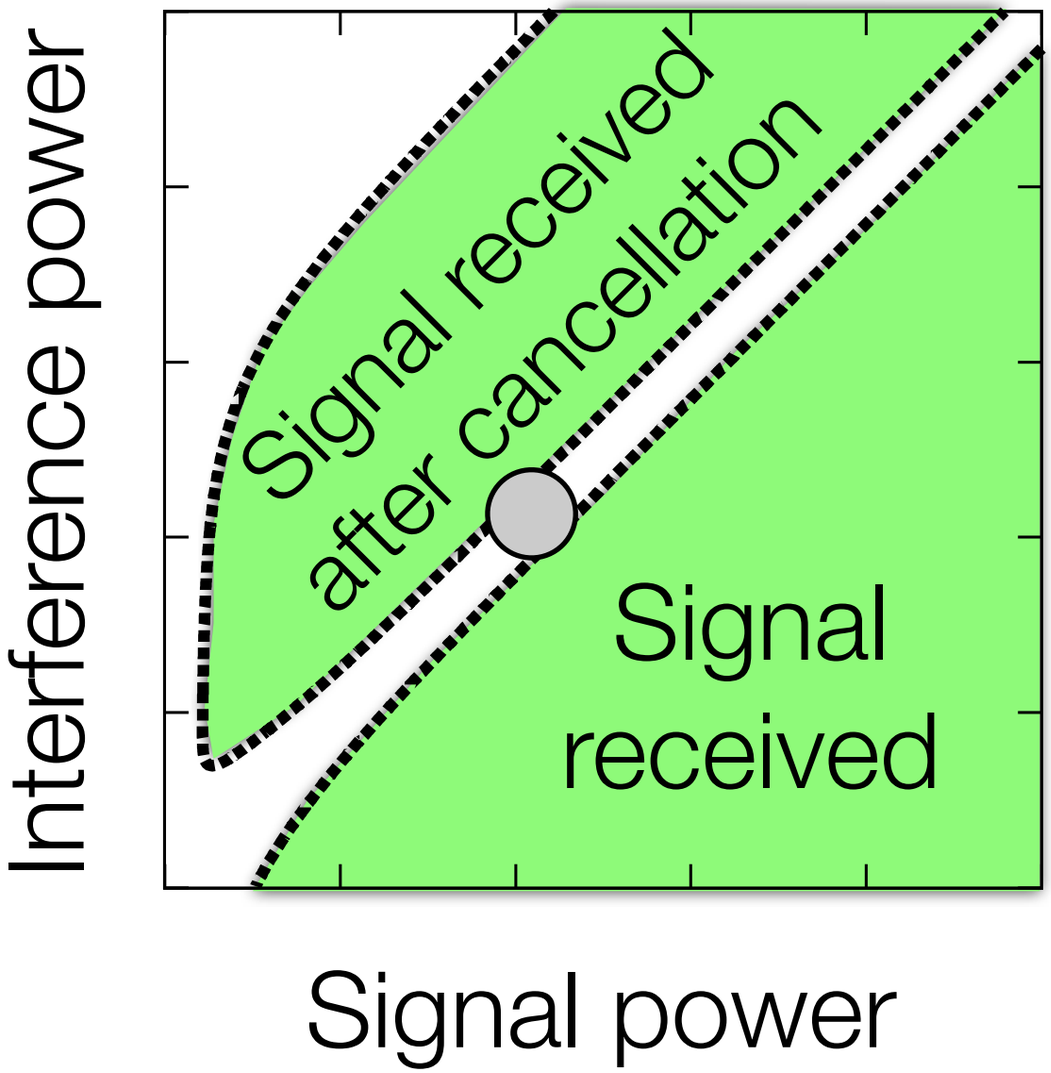

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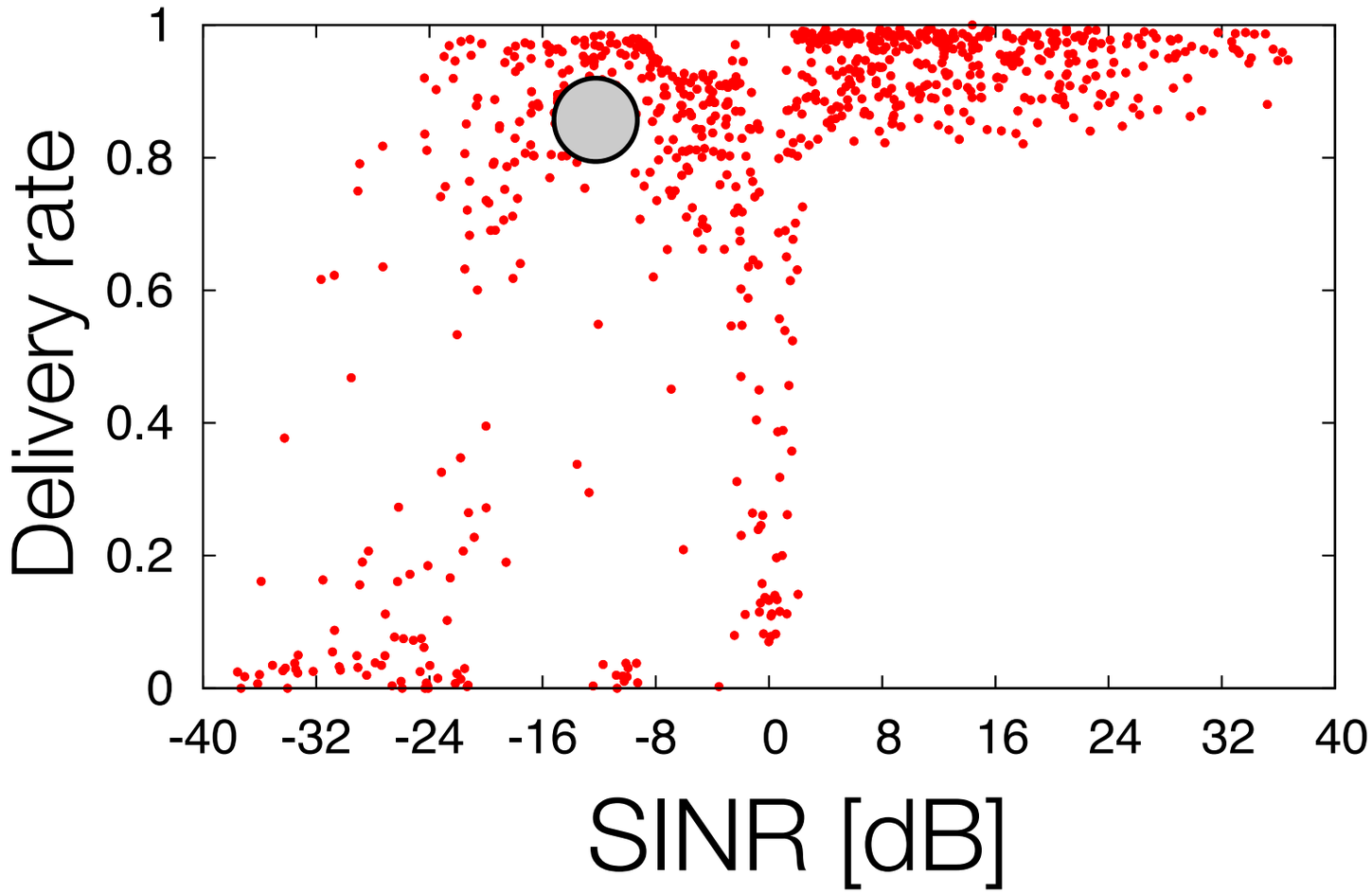

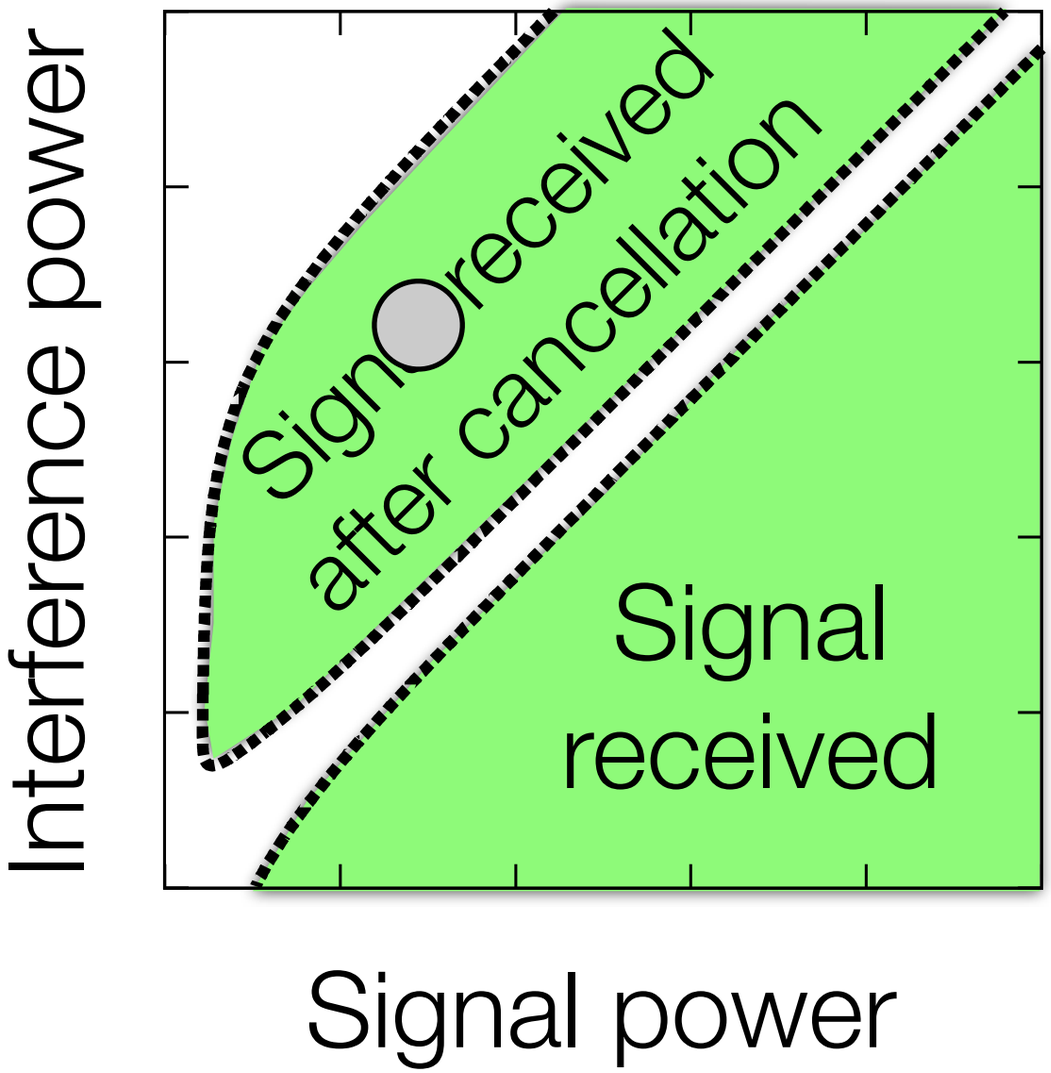

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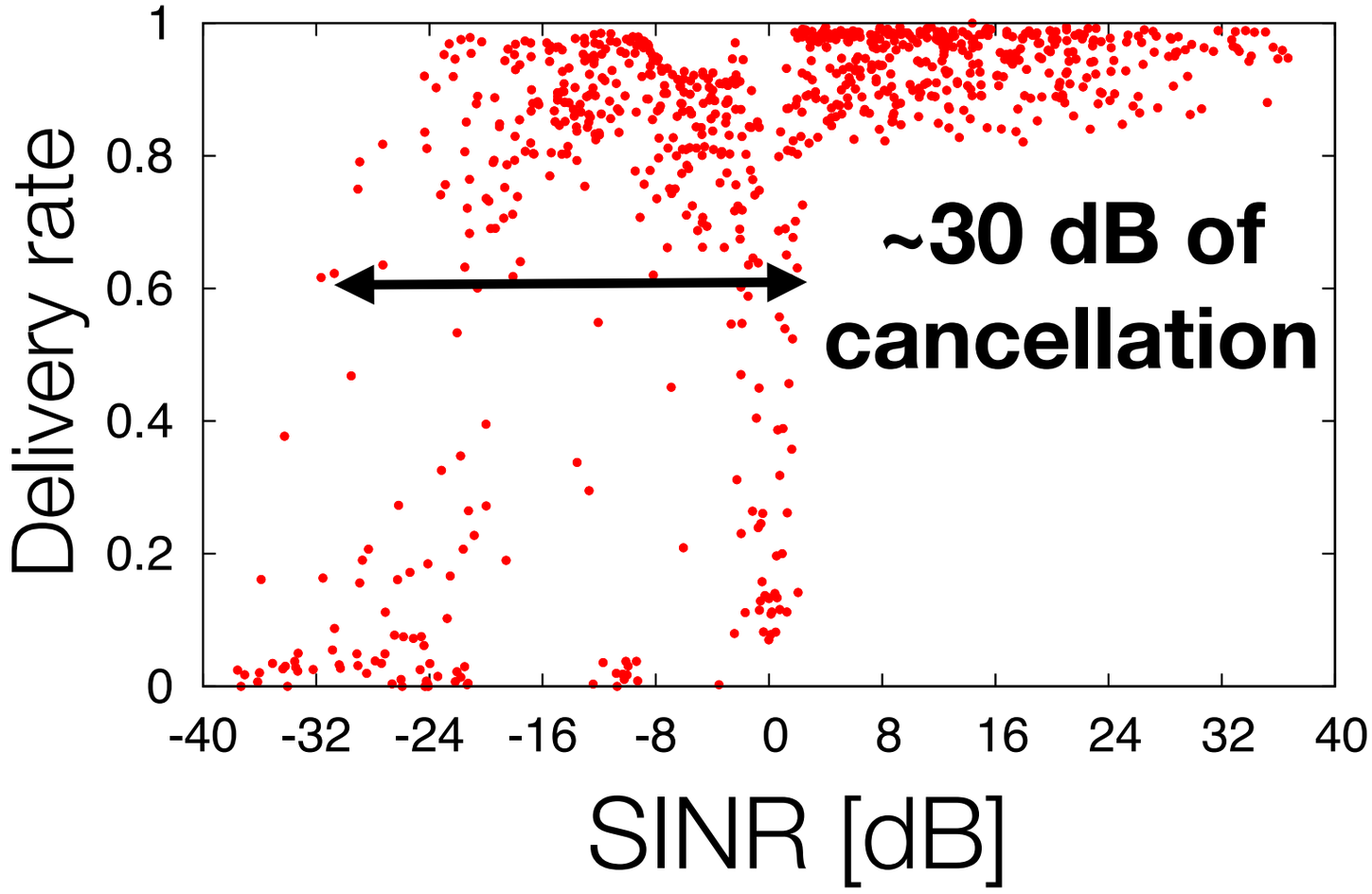
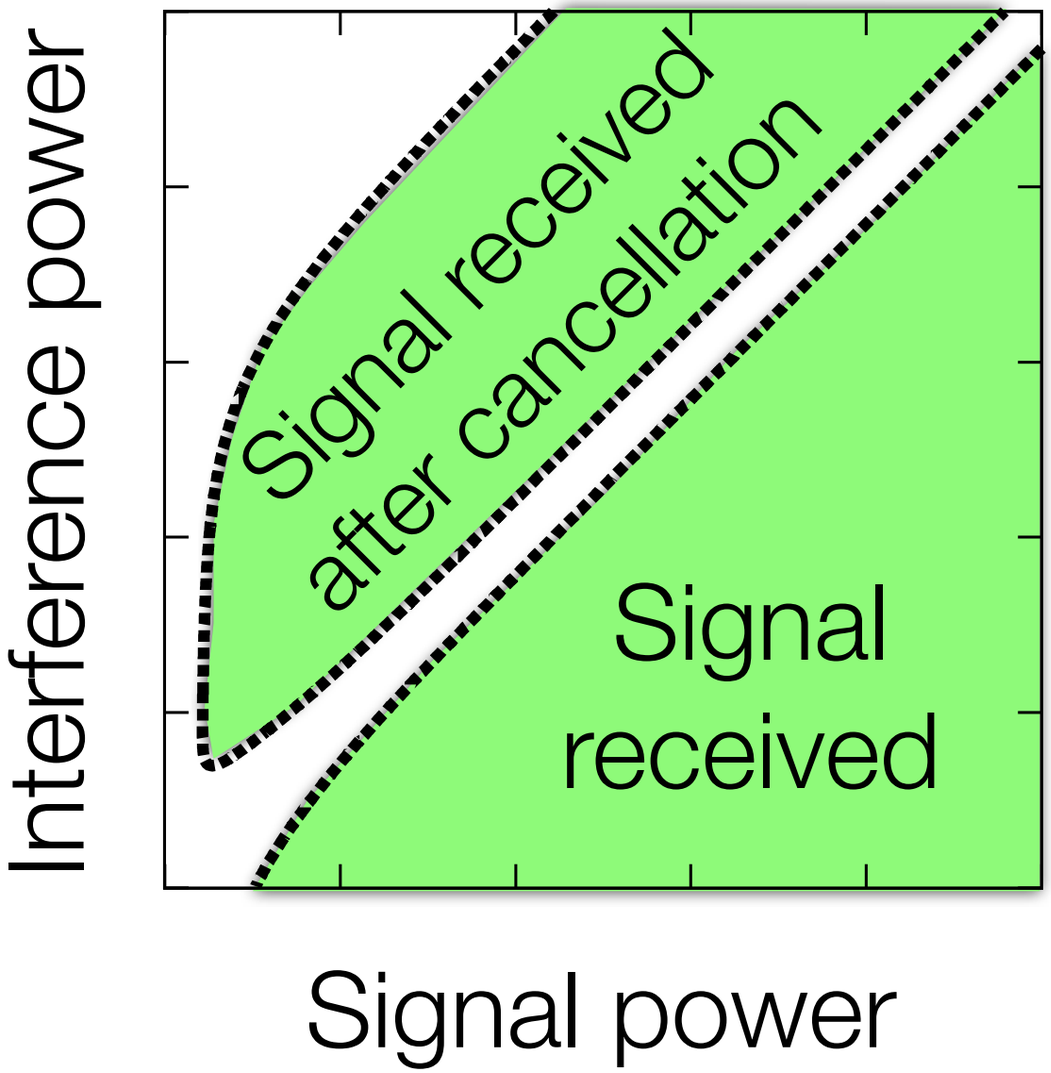
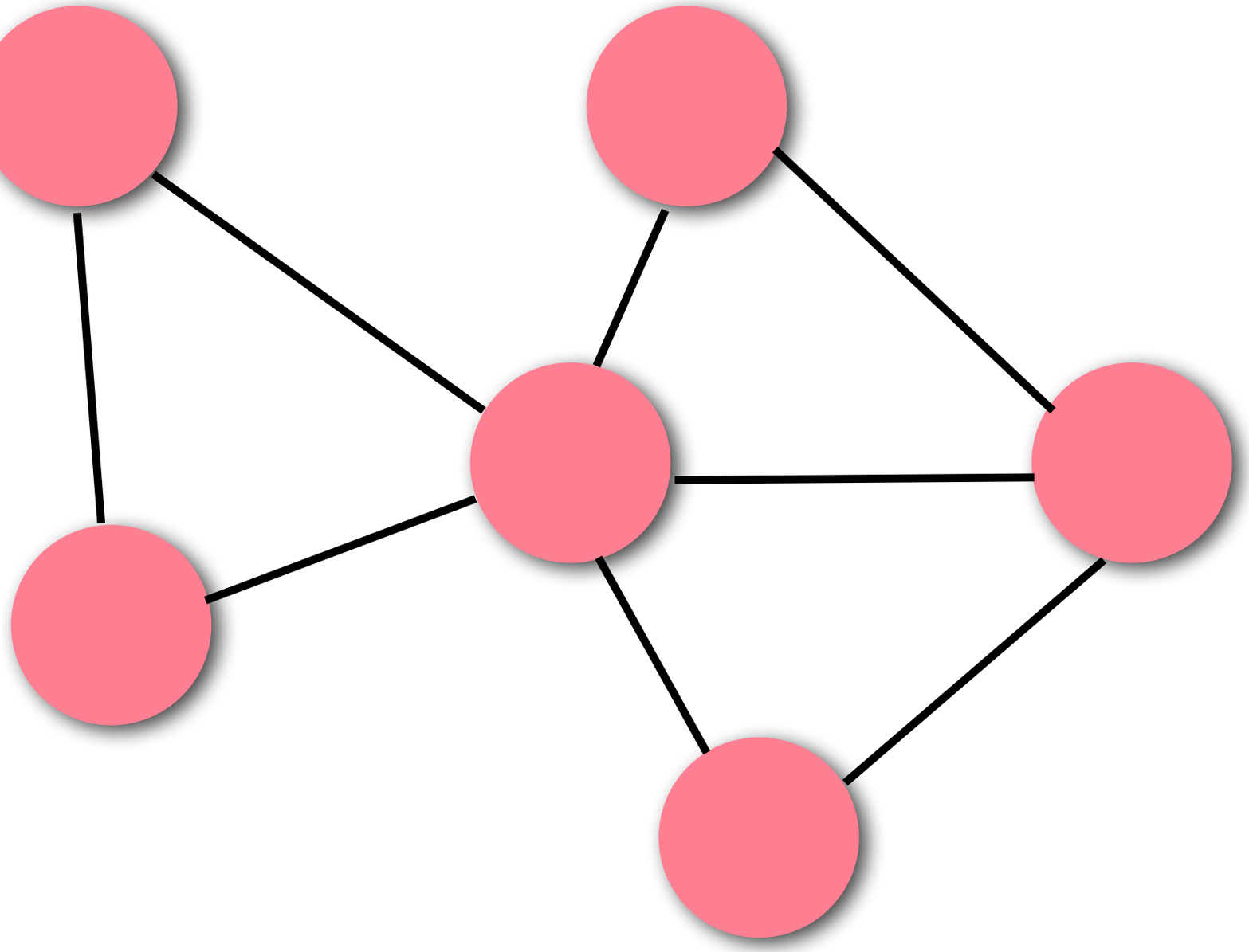




Experiment analysis



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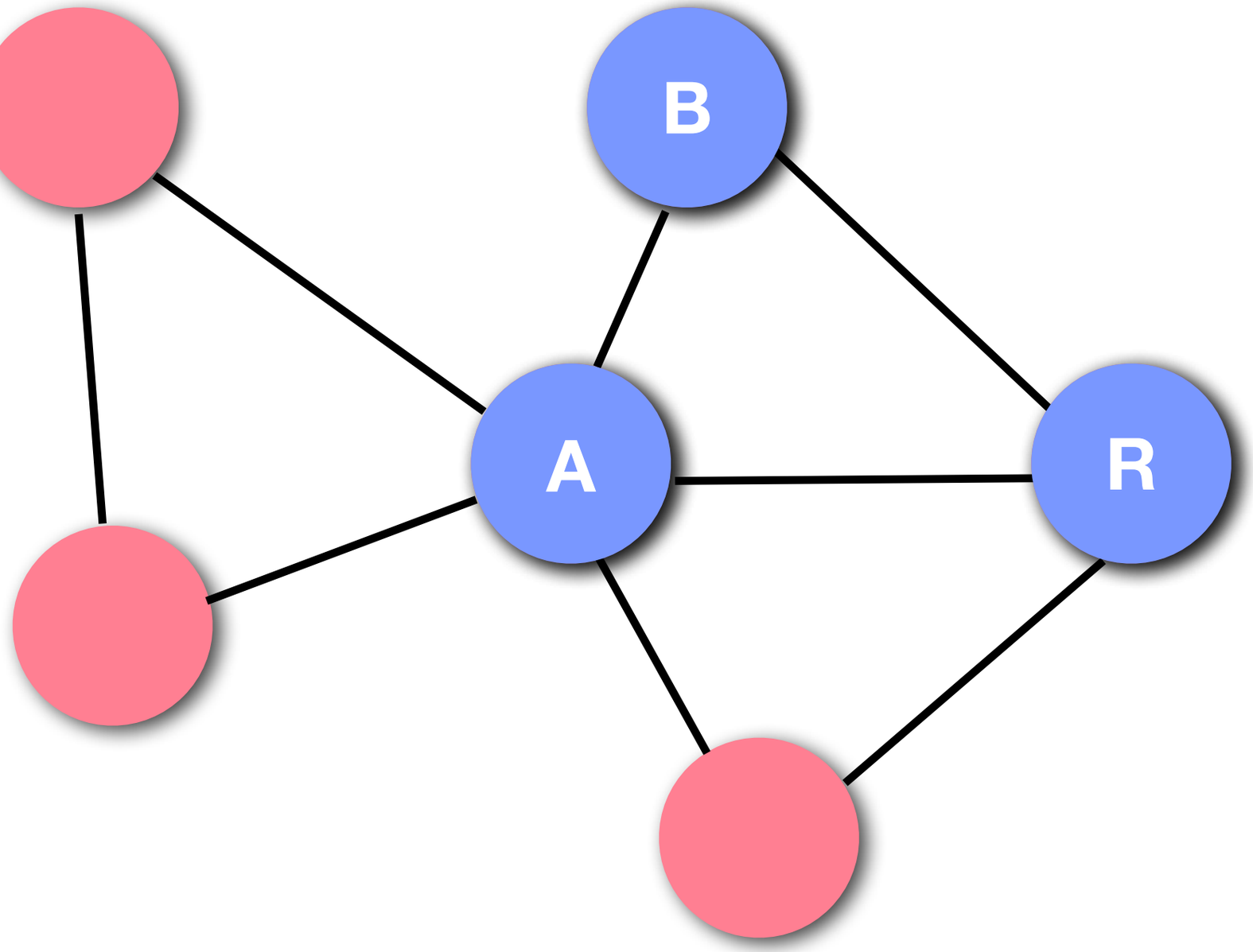

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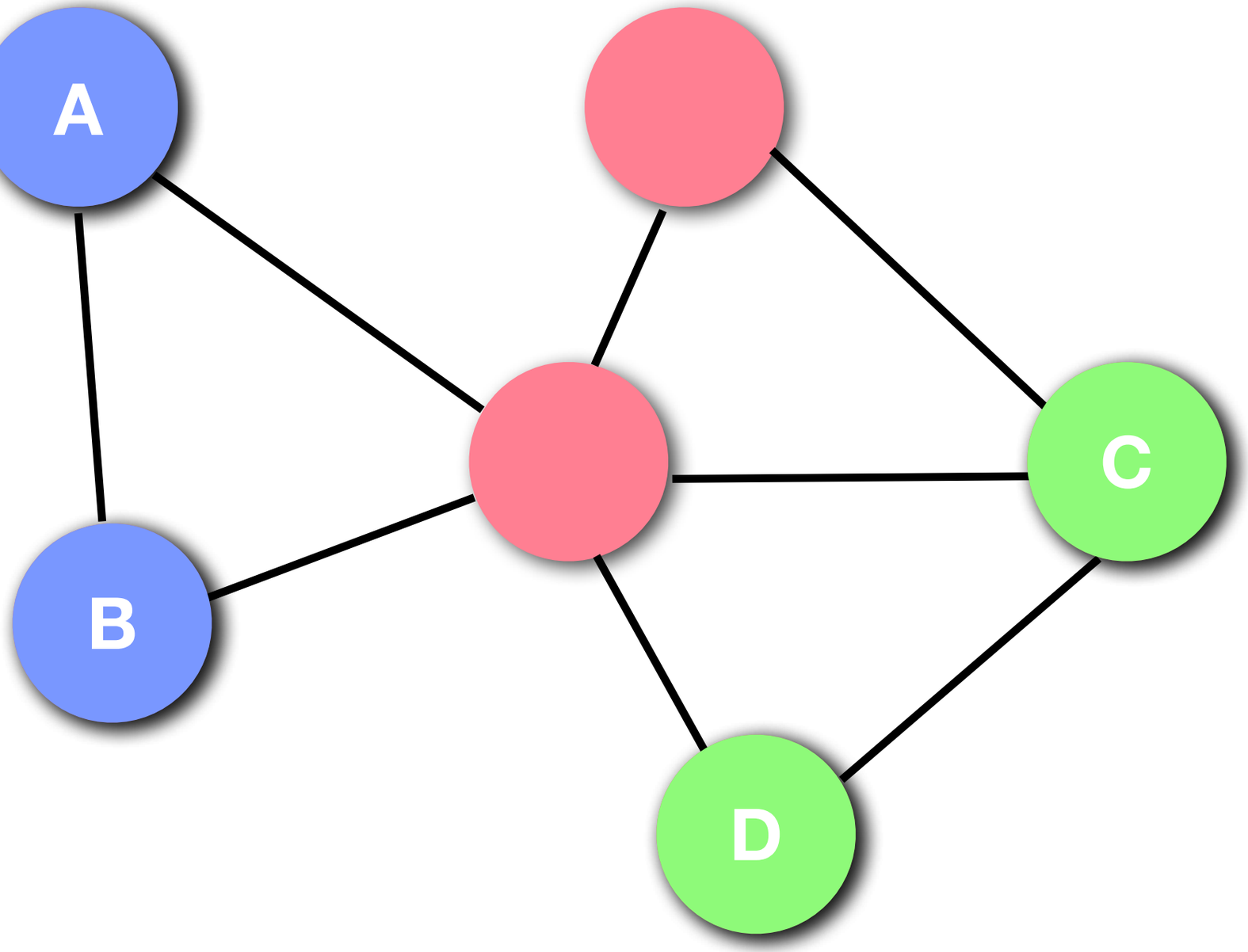
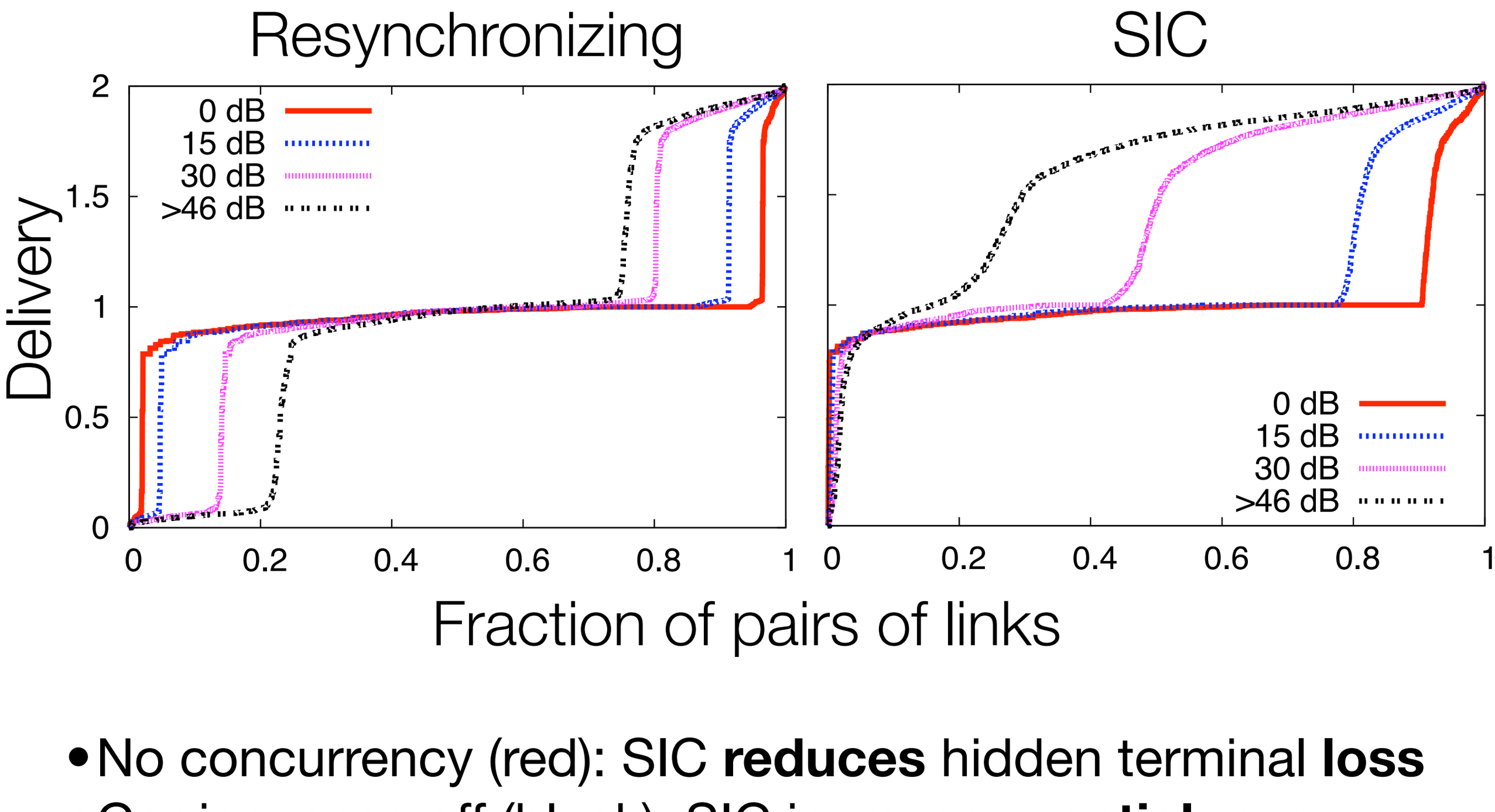


Performance varying carrier sense



- No concurrency (red): SIC **reduces** hidden terminal **loss**
- Carrier sense off (black): SIC increases **spatial reuse**

Wrap up

Presented by Daniel Halperin @MobiCom 2008

Cancellation is part of a broader solution

- Can't always cancel and it's worse for higher rates. But capture does happen in real networks

- Challenge is to **maximize spatial reuse** where it works while **minimizing harmful interference**

- Use cancellation in conjunction with MAC
  - Carrier sense with raised threshold
  - Selectively defer to ongoing transmissions [CMAP, Vutukuru '08]

Limitations / Future work

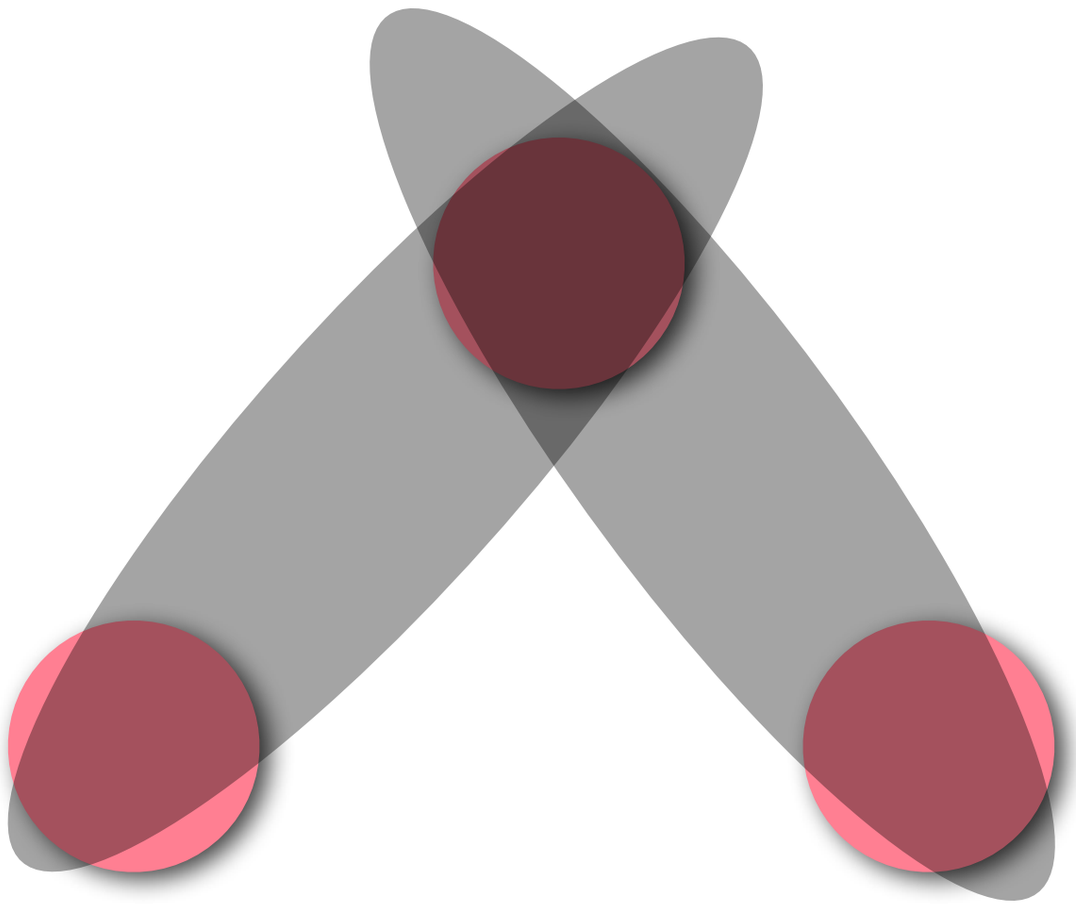
- Prototype (and hence evaluation) is limited by platform
  - Real-time MAC prevented by long processing and communication latency
  - Inhibits evaluation of network-level effects
- Revisiting wireless system design
  - Able to run online, able to handle more traffic patterns
  - Evaluate on variety of workloads with real protocols

Backup slides

Presented by Daniel Halperin @MobiCom 2008

Interference cancellation integrates with future technologies

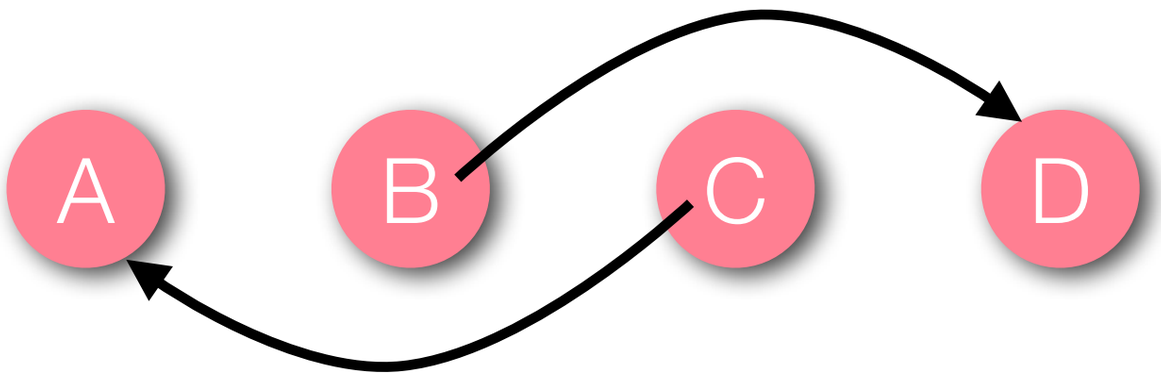
- Multiple streams (MIMO) and beamforming
  - Relies only on superposition principle; still applies



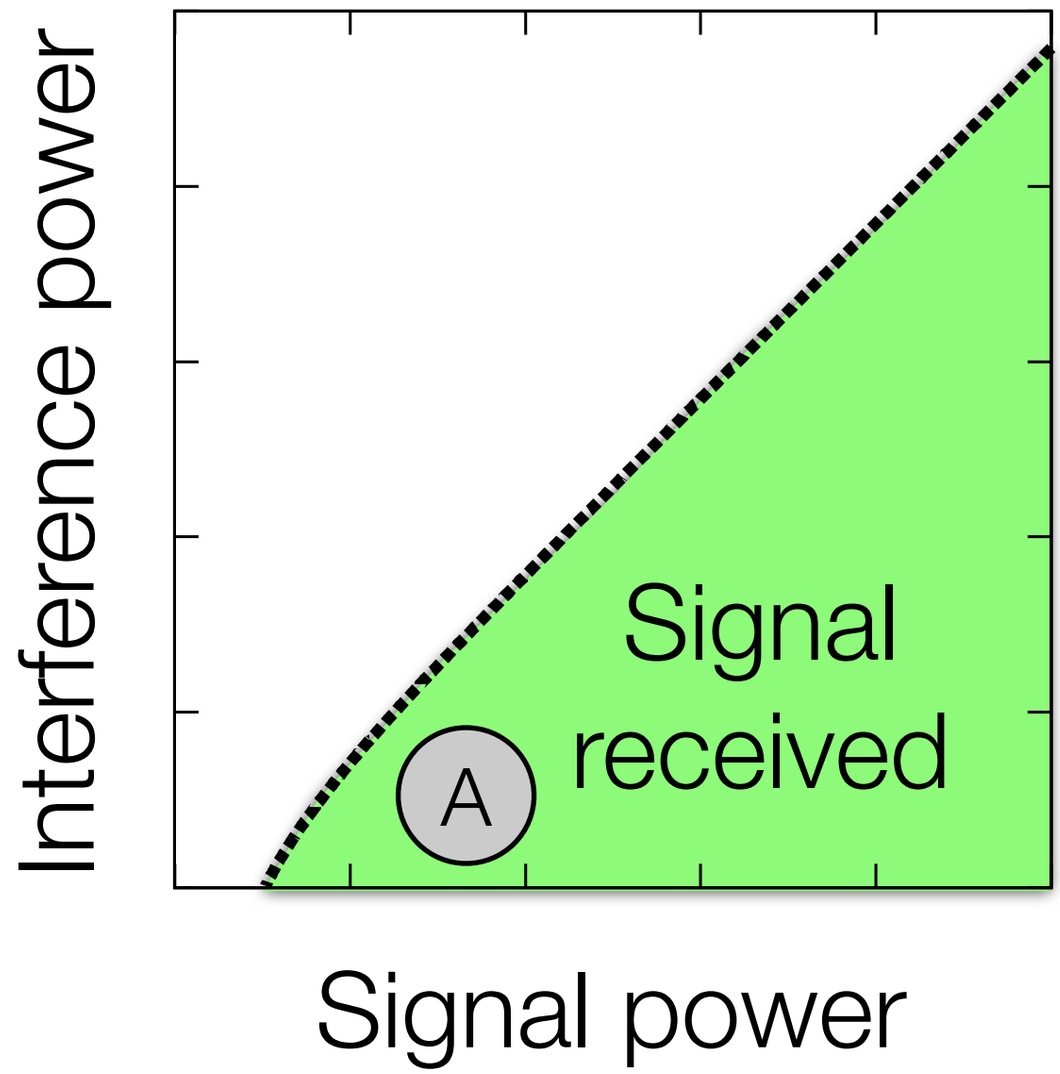
- Adds robustness as carrier sense degrades

Interference cancellation provides gains beyond power control

Inverted links



- If A can receive,
  - C stronger than B at A
  - C *much* stronger at D



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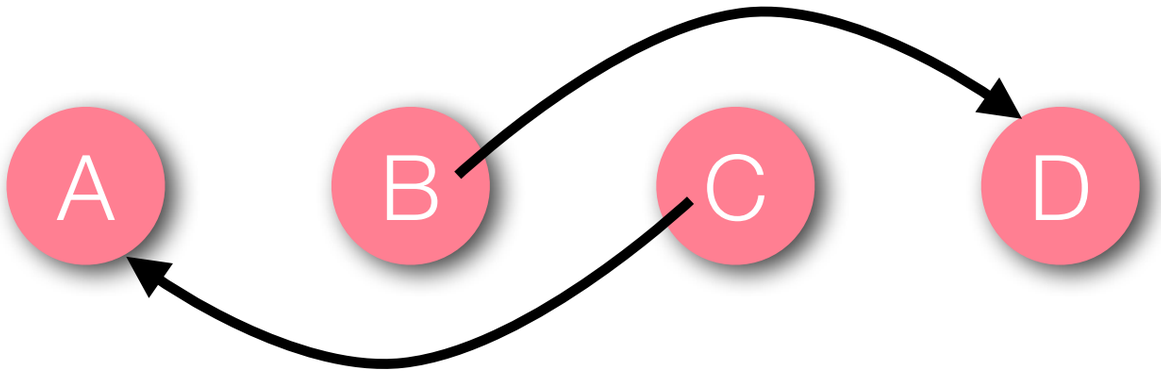

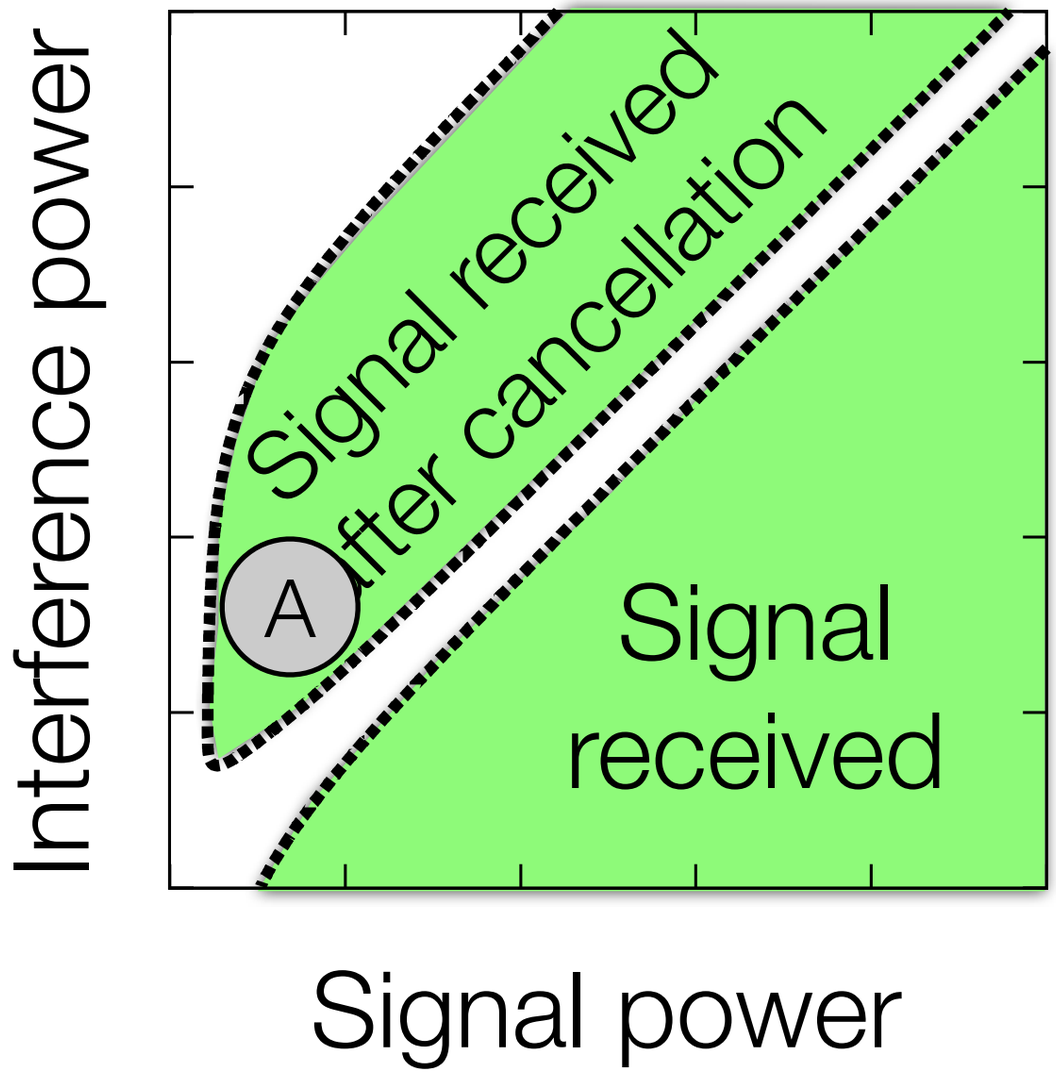

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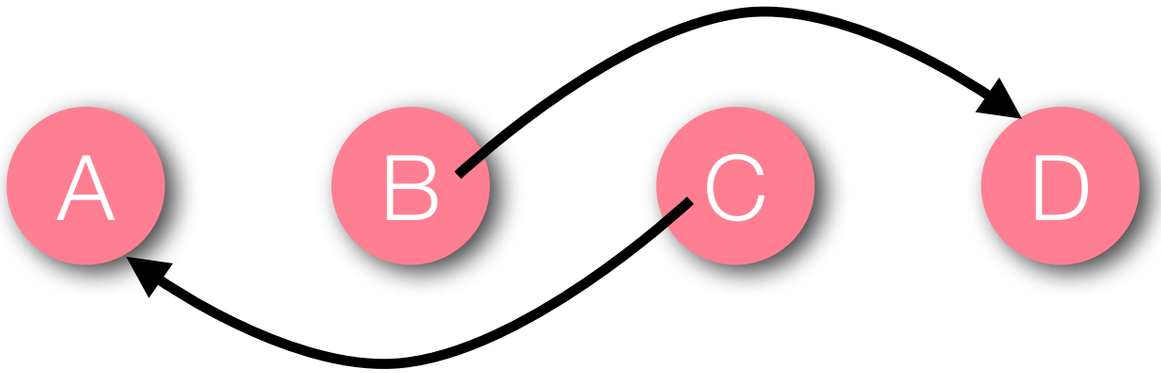

Enable spatial reuse for new link pairs