Medium Access and Interference Cancellation: Protocol and Evaluation

Abishek Sankararaman and François Baccelli

Introduction

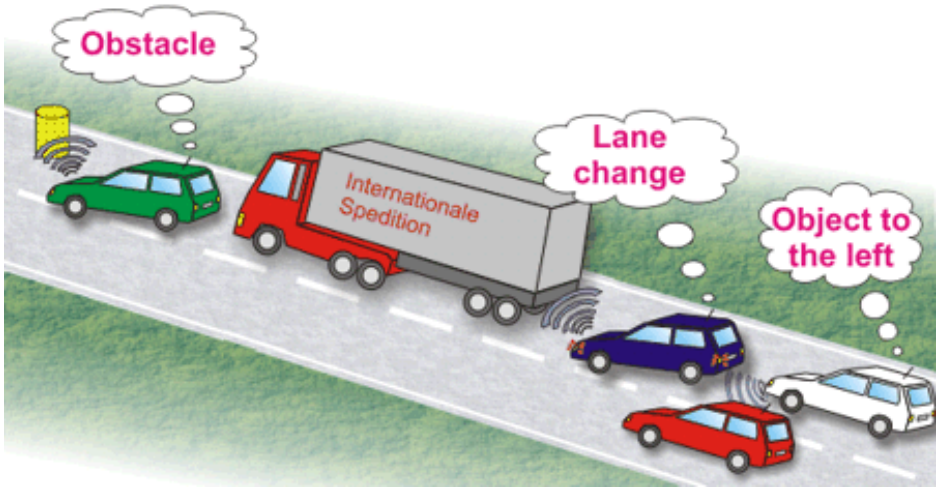
- Focus: Medium Access problem in Ad-hoc networks.

- Aim: Propose simple implementable protocols by incorporating observations and results from Information Theory.

Motivation

- Some key features of emerging wireless networks
  - Dense
  - Decentralized Control

D2D Communication



Vehicular Communication (802.11p)

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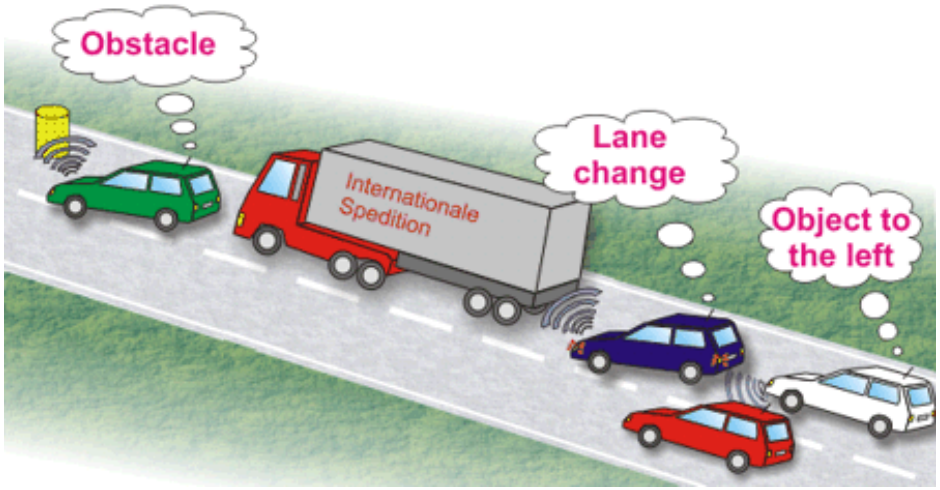

Vehicular Communication (802.11p)

Managing Interference is a key challenge - primarily handled through Medium Access Control algorithms in ad-hoc networks.

Popular Medium Access Solution

- CSMA (Carrier Sense Multiple Access) - 802.11 standards
- ‘Interference as Noise’ (IAN) paradigm.

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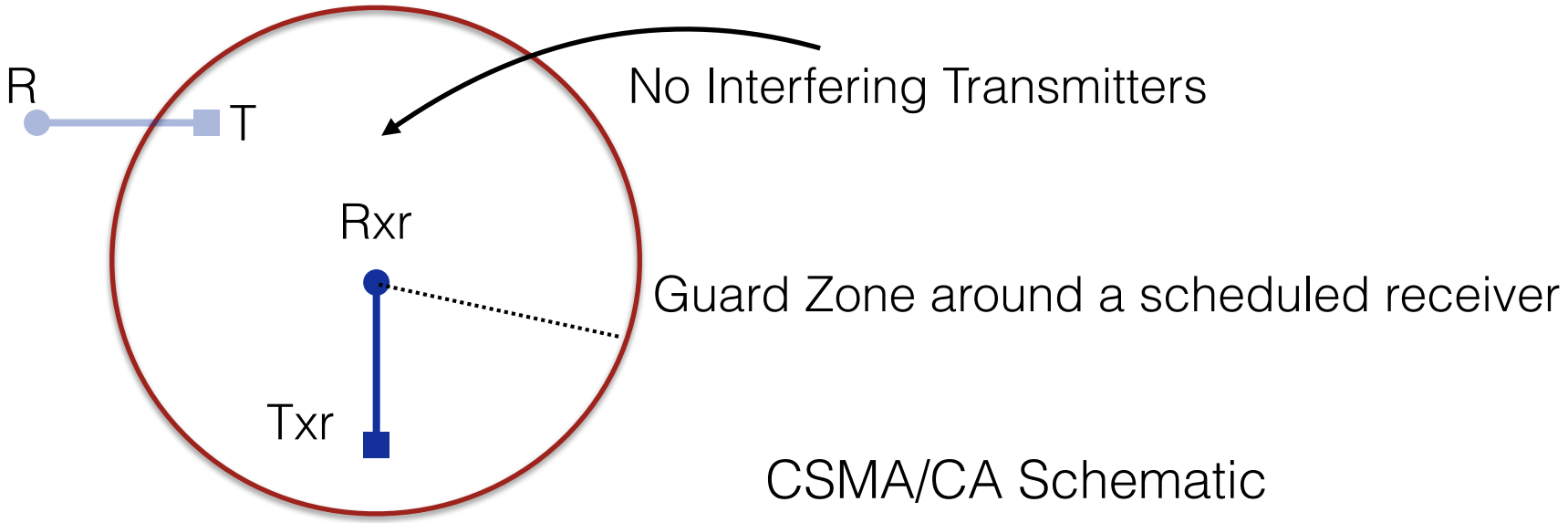
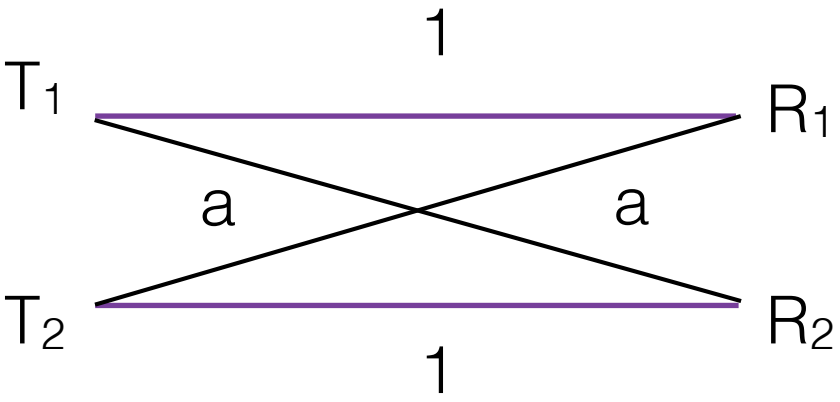


CSMA/CA Schematic

- Simple Distributed Implementation (RTS/CTS)

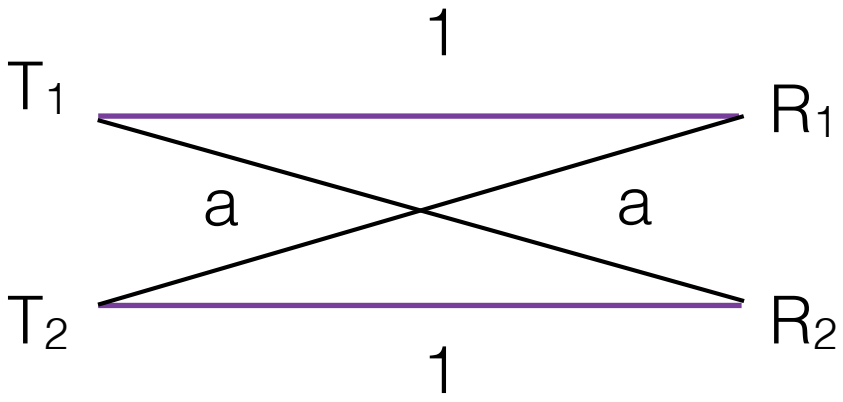
Ad-hoc Network - Interference Channel



2 user interference channel

- Capacity and achievability is unknown in general.

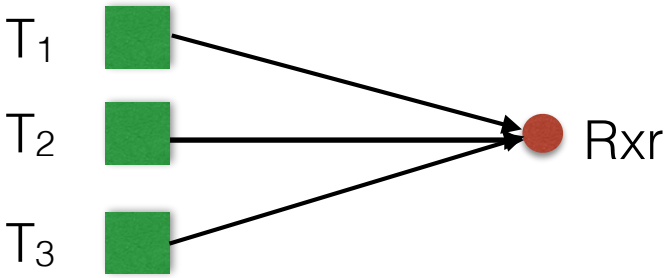
Results from Information Theory



2 user interference channel

- Capacity and achievability is unknown in general.
- $a \to 0$, IAN is optimal.
- $a \to \infty$, SIC (Successive Interference Cancellation) decoding is optimal.
  (Receivers treat the transmitters as a MAC channel).

Successive Interference Cancellation



Gaussian Codebook

Received Powers P_i, Rates R_i

$$C\left(\frac{P_i}{N_0+\sum_{j=i+1}^{3} P_j}\right) \geq R_i \quad , i \in \{1,2,3\}.$$

where $P_i > P_j \ \forall i < j$, $C(x) = \frac{1}{2}\log_2(1+x)$

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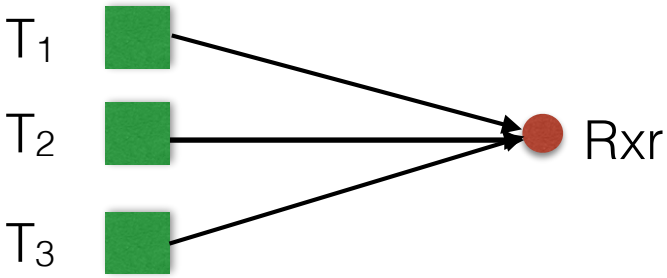

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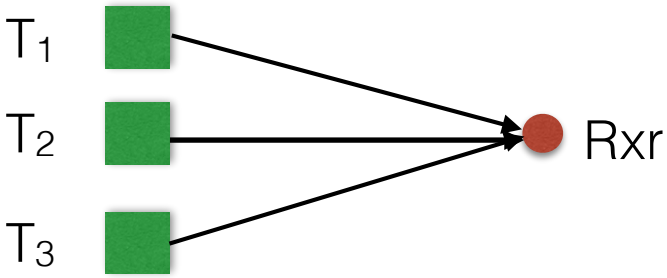
- Separation of Powers needed to ensure decodability !

SIC - Separation of Powers



Received Powers P_i, Symmetric Rate R

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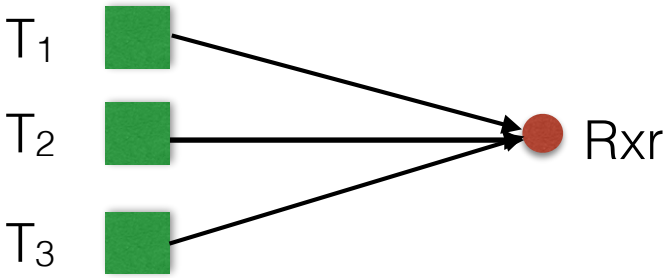

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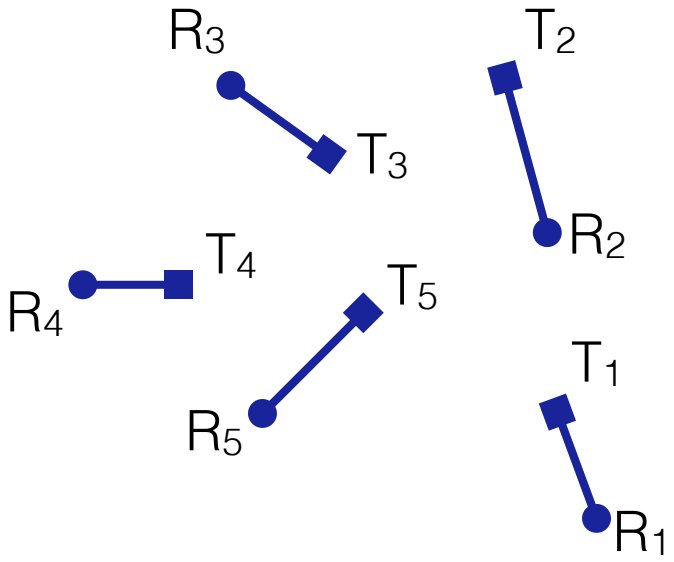
  P_i ***needs to be significantly larger than*** P_{i+1}

Main Idea of an Improved Protocol



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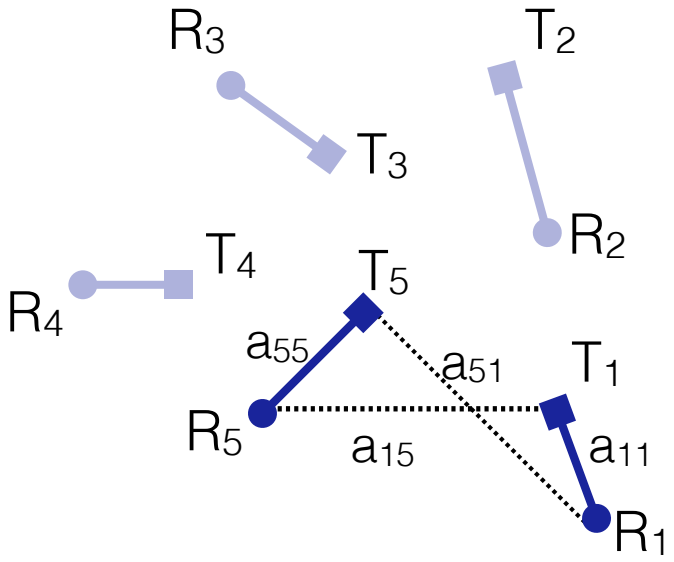

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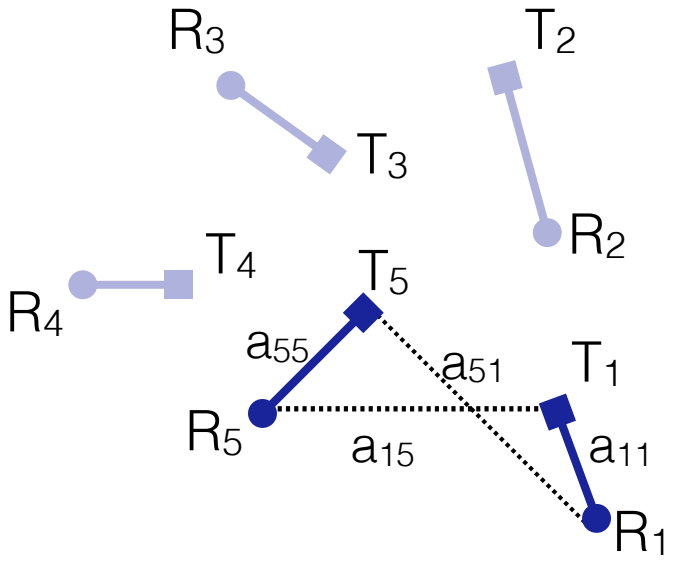

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- CSMA/CA will schedule at most one link.

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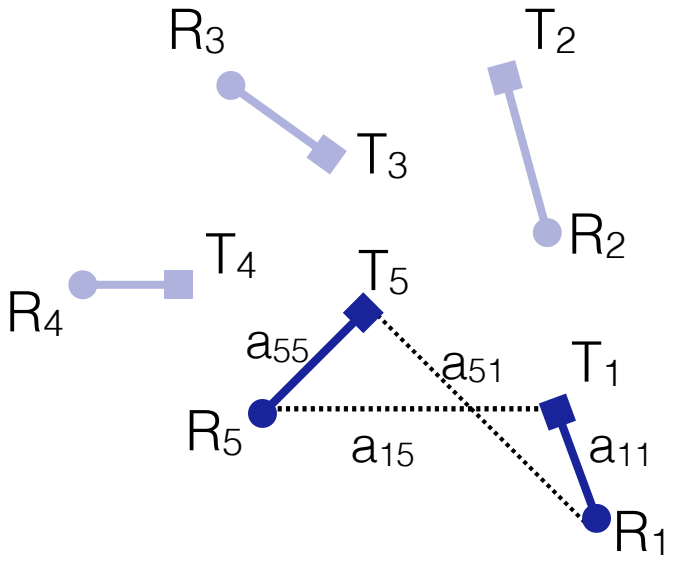

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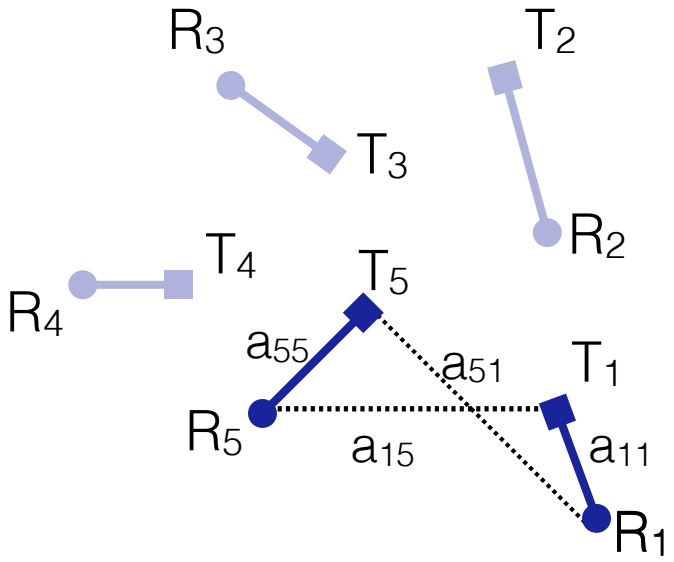

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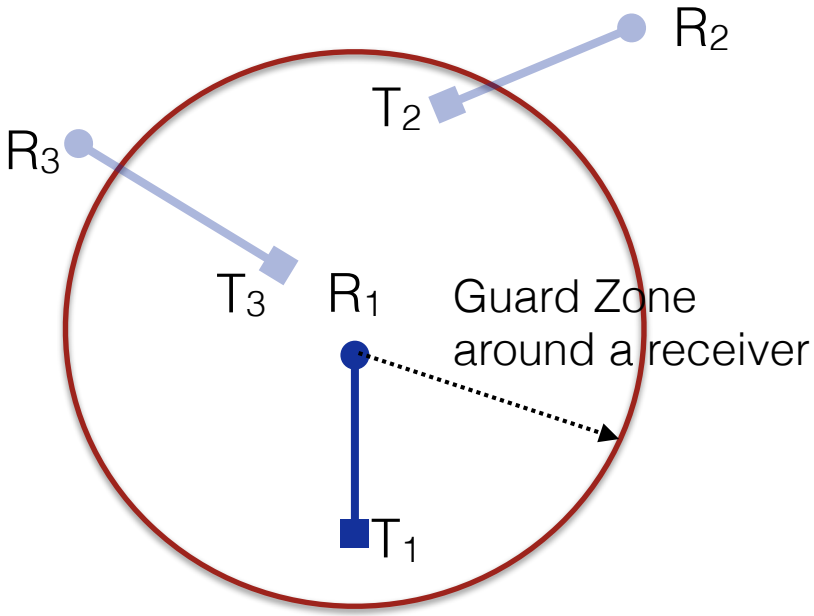
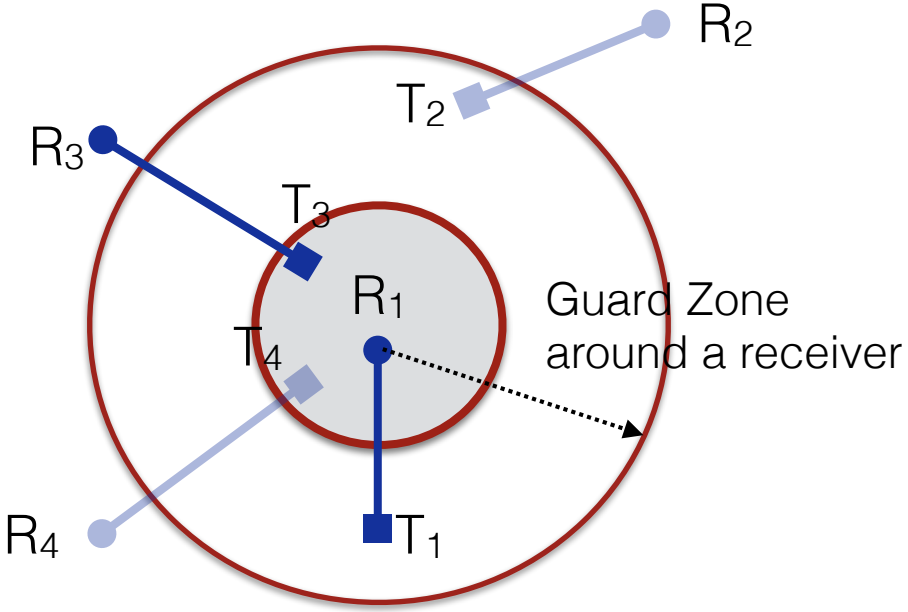
Need to define when a cross interference is ‘strong’.

CSMA 1-SIC Protocol

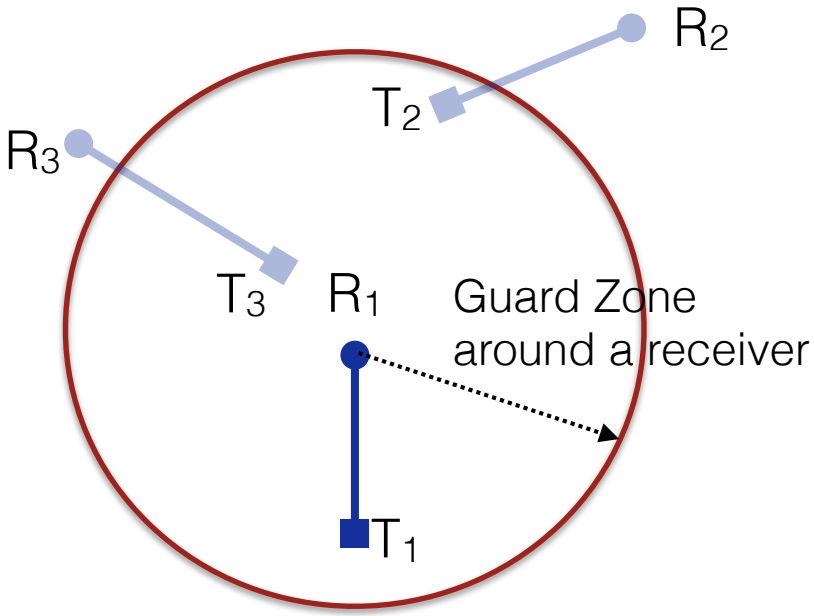


Schematic of CSMA/CA



Schematic of proposed CSMA 1-SIC protocol.

CSMA 1-SIC Protocol



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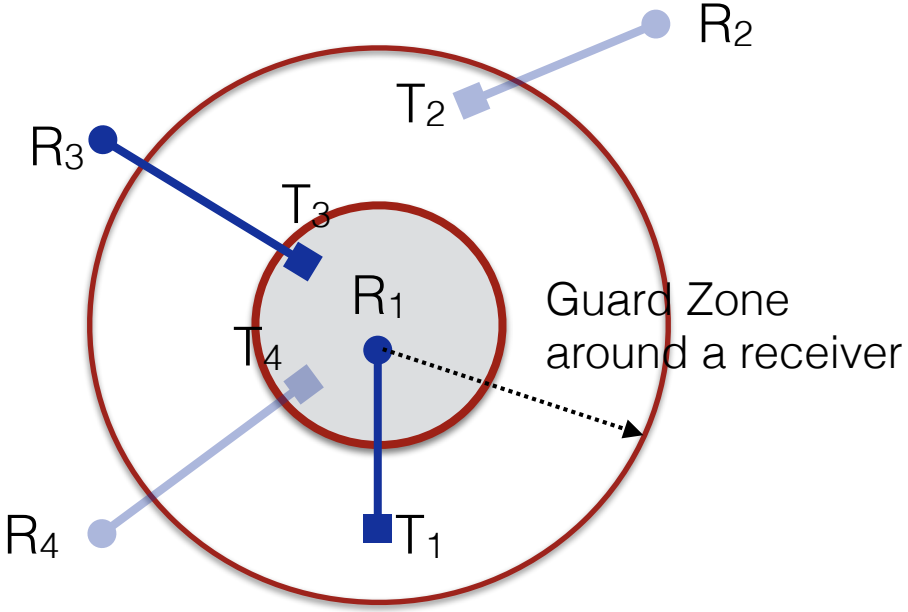
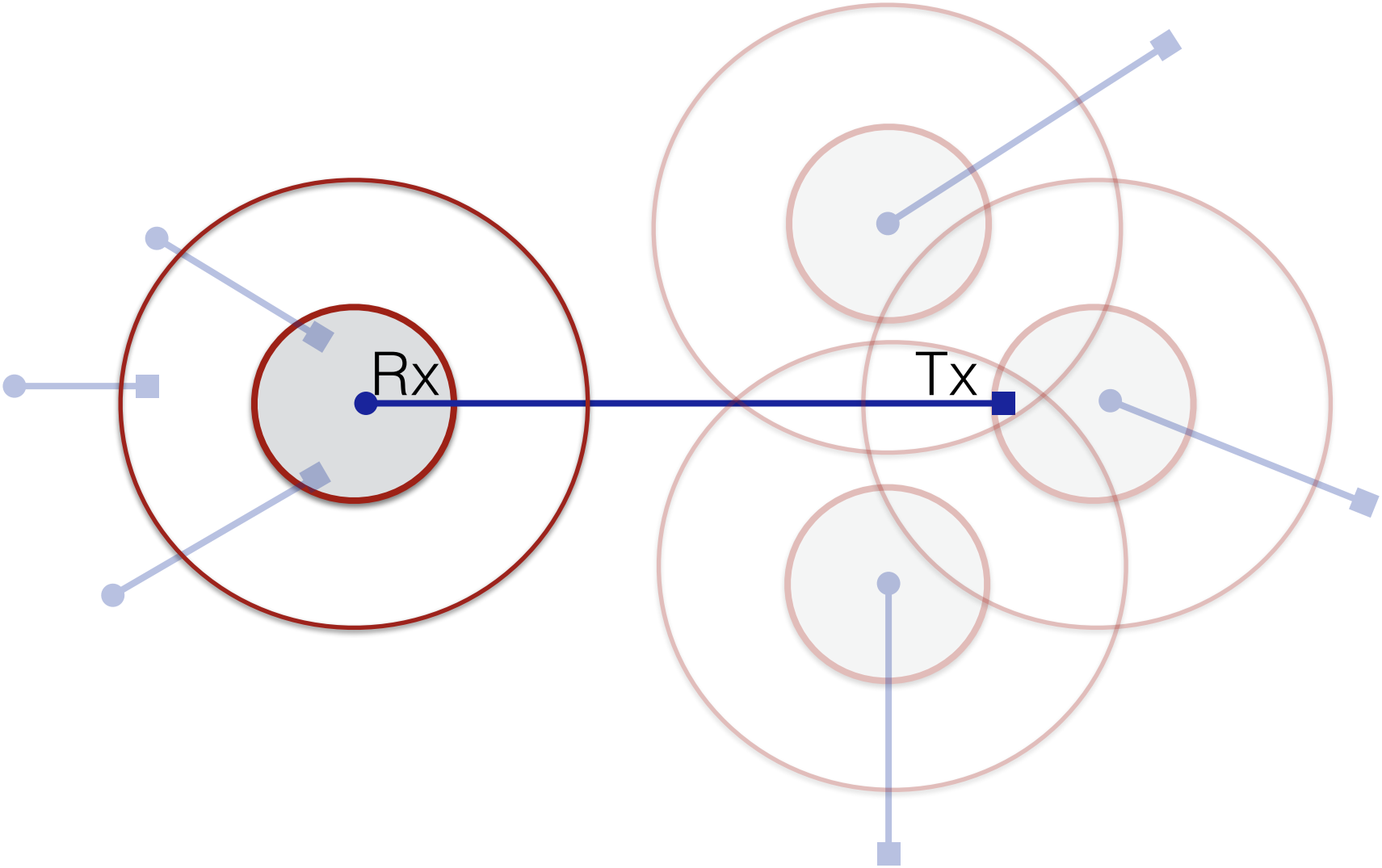


Schematic of proposed CSMA 1-SIC protocol.

Separation of Received Powers - Donut Shaped Guard Zone.

CSMA 1-SIC Signaling

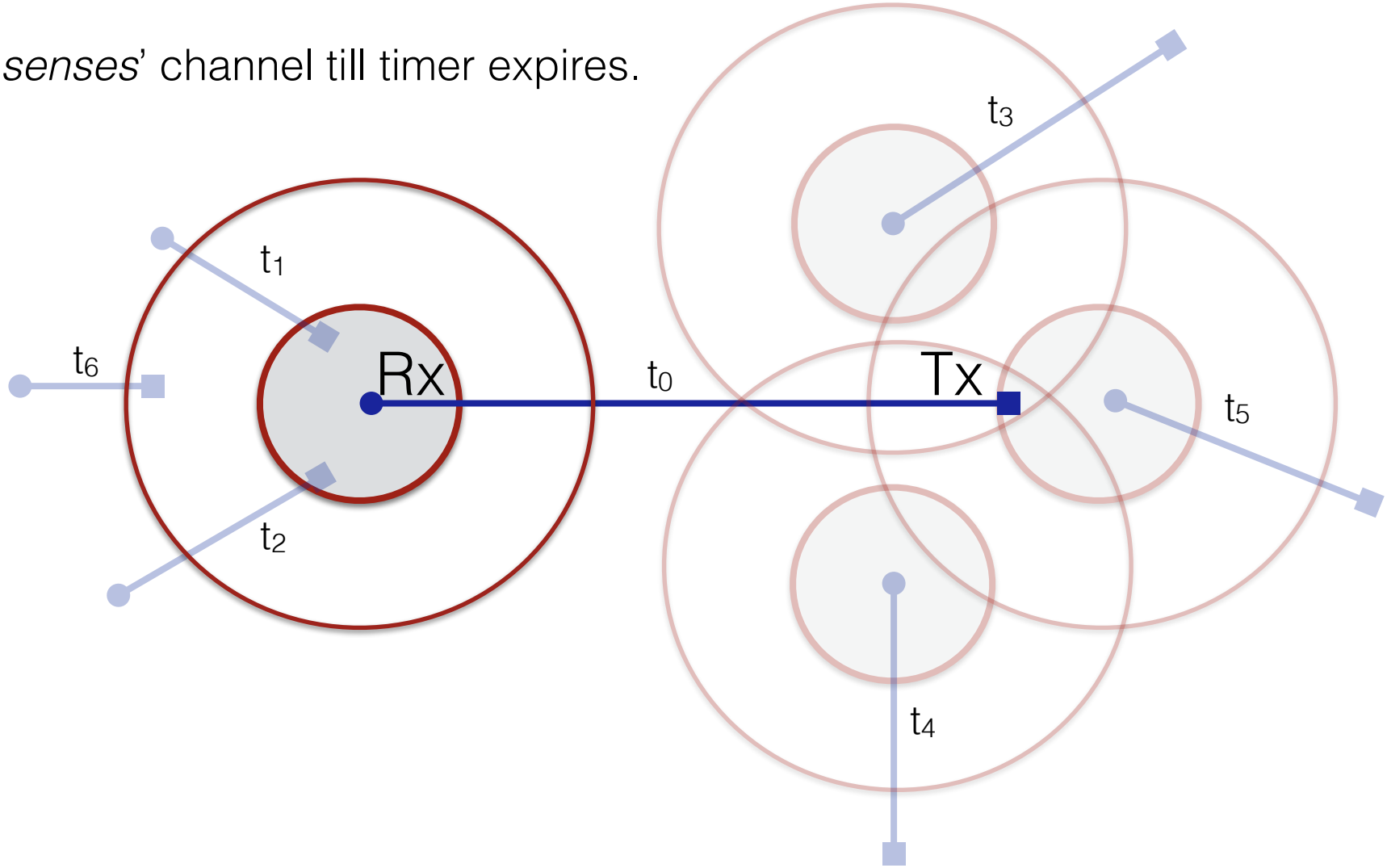
Assume time-slotted system.



CSMA 1-SIC Signaling

Each link (Tx) samples a Random Timer Value in say [0,1]

Tx '*senses*' channel till timer expires.



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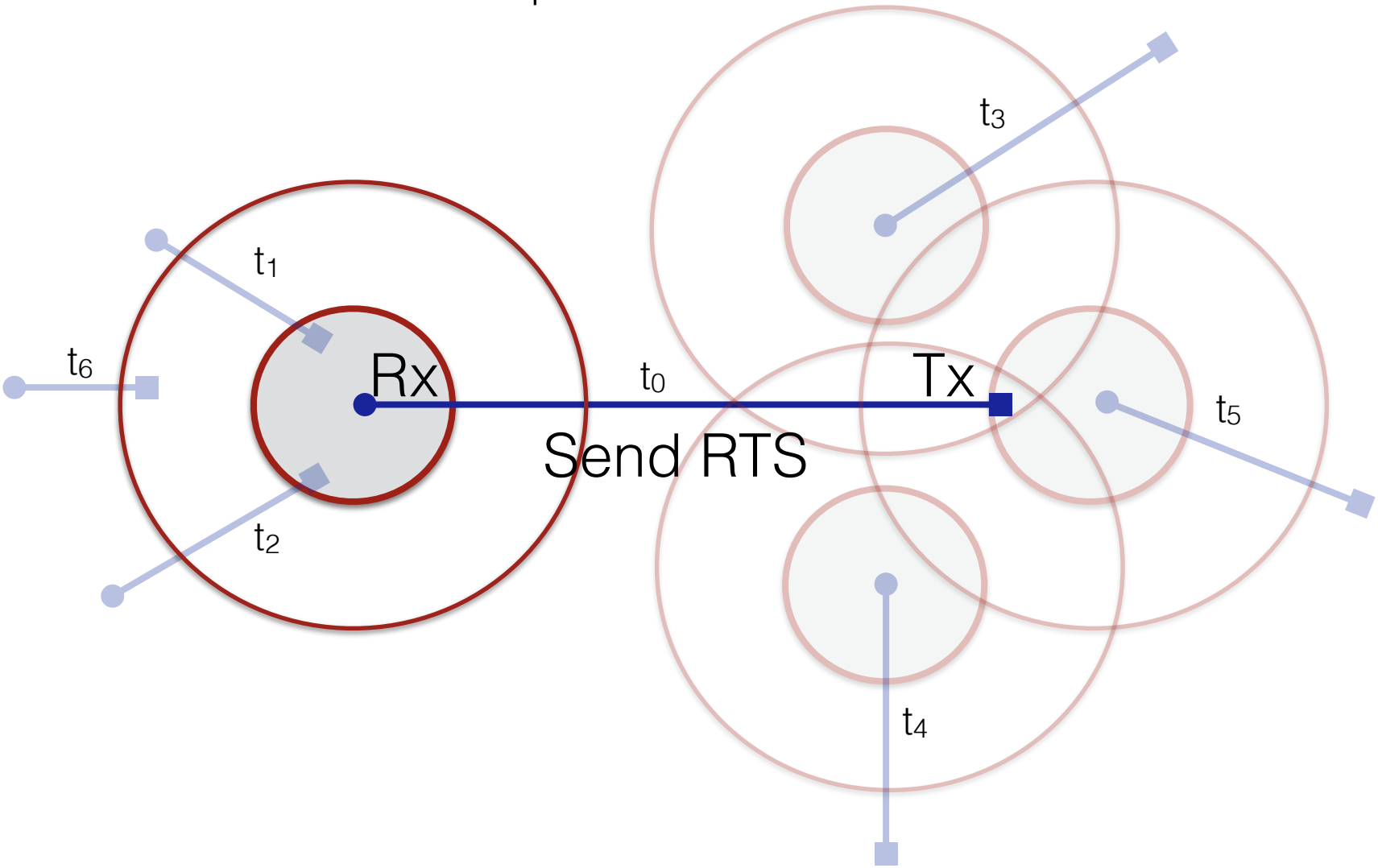
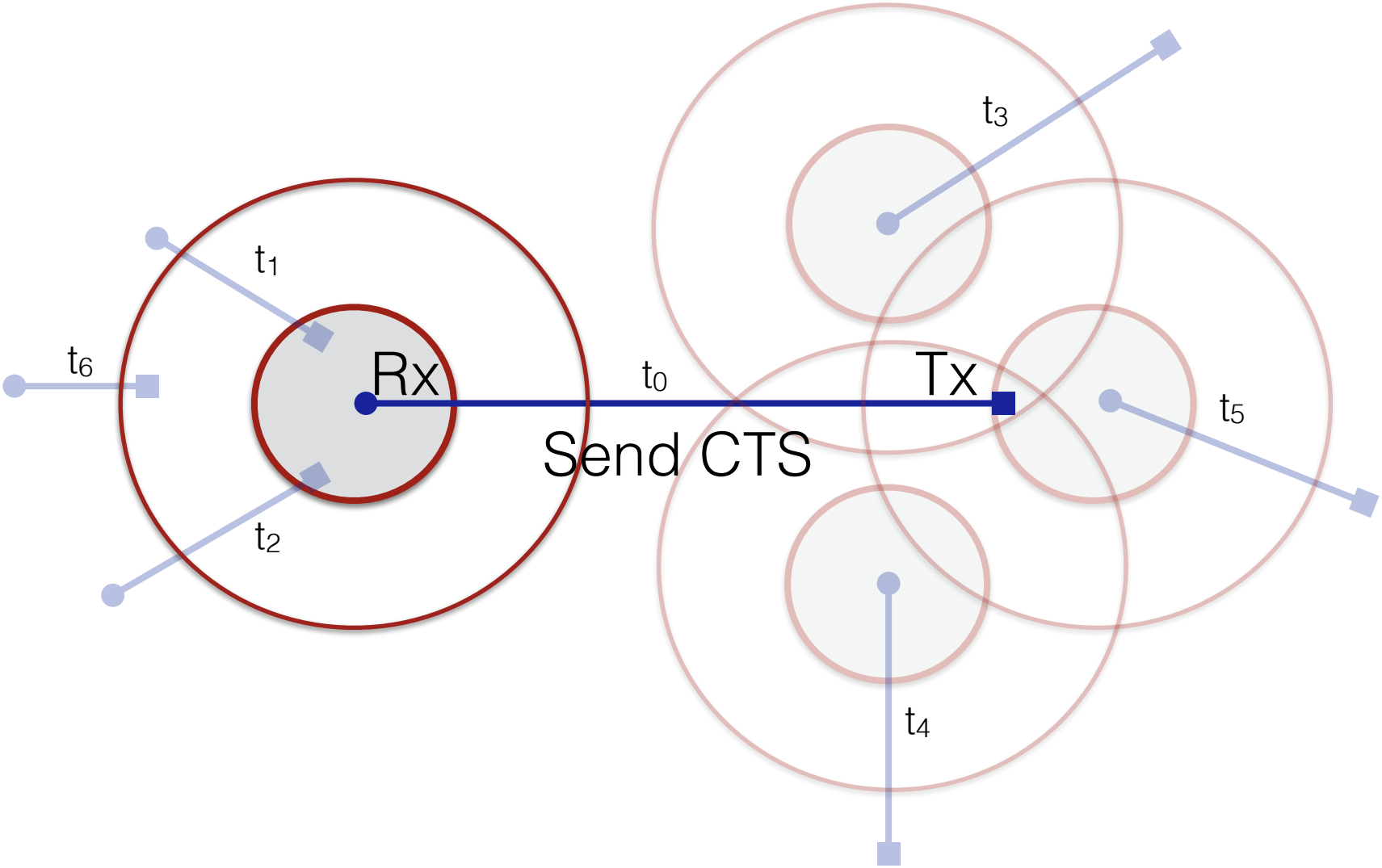


CSMA 1-SIC Signaling

Rx '*senses*' to hear a RTS.



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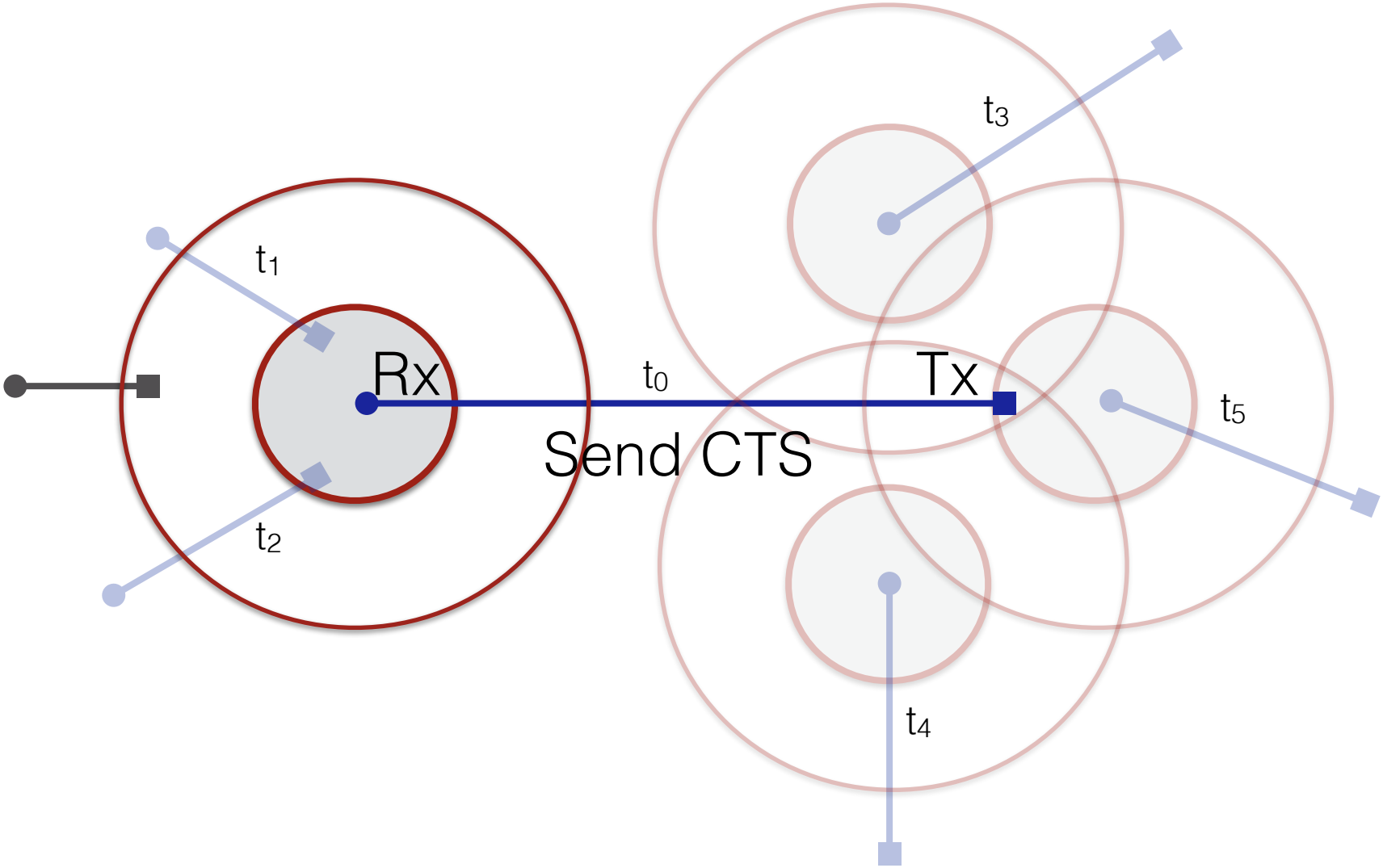
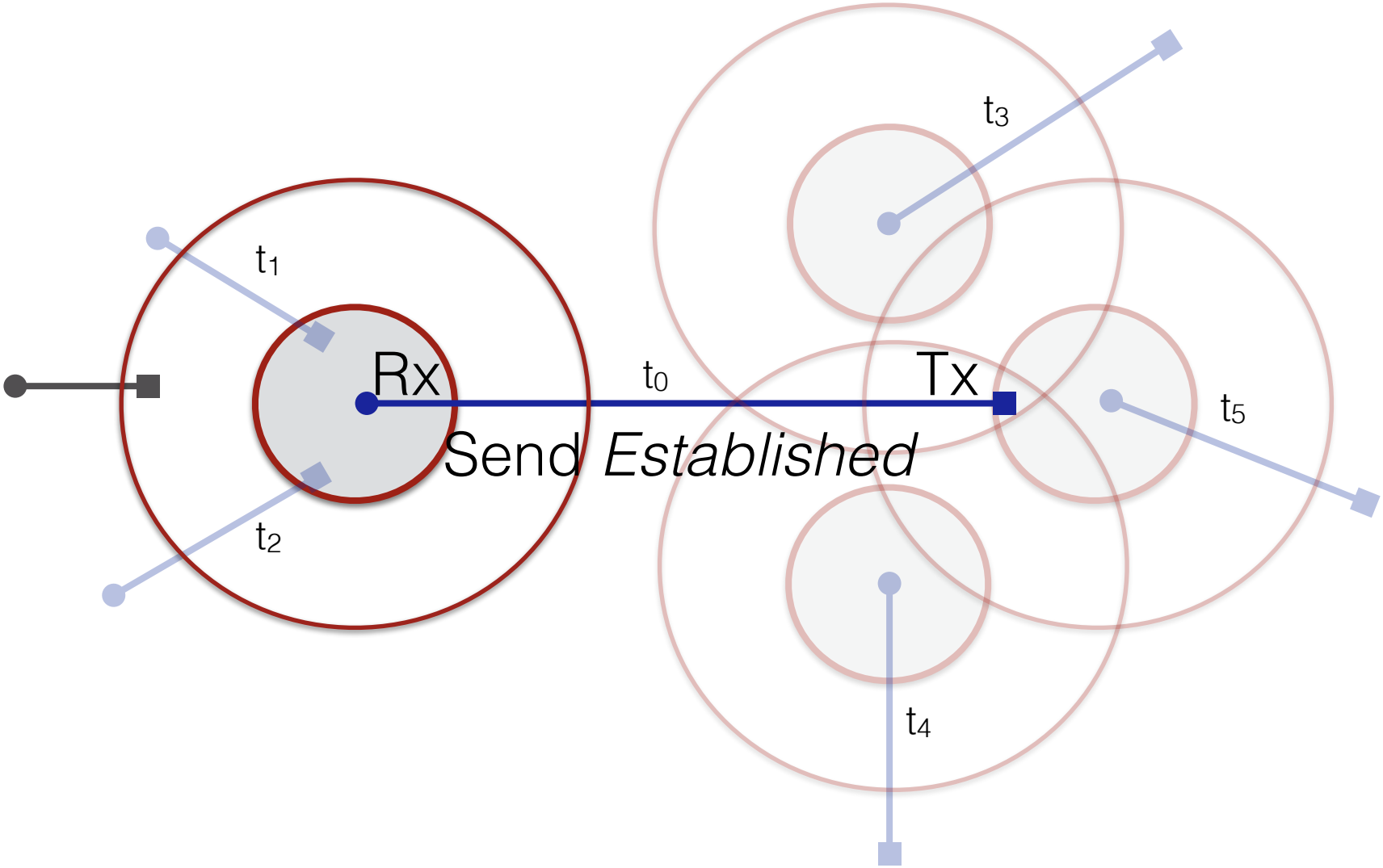


CSMA 1-SIC Signaling

Tx broadcasts '*Established*' to silence nearby receivers



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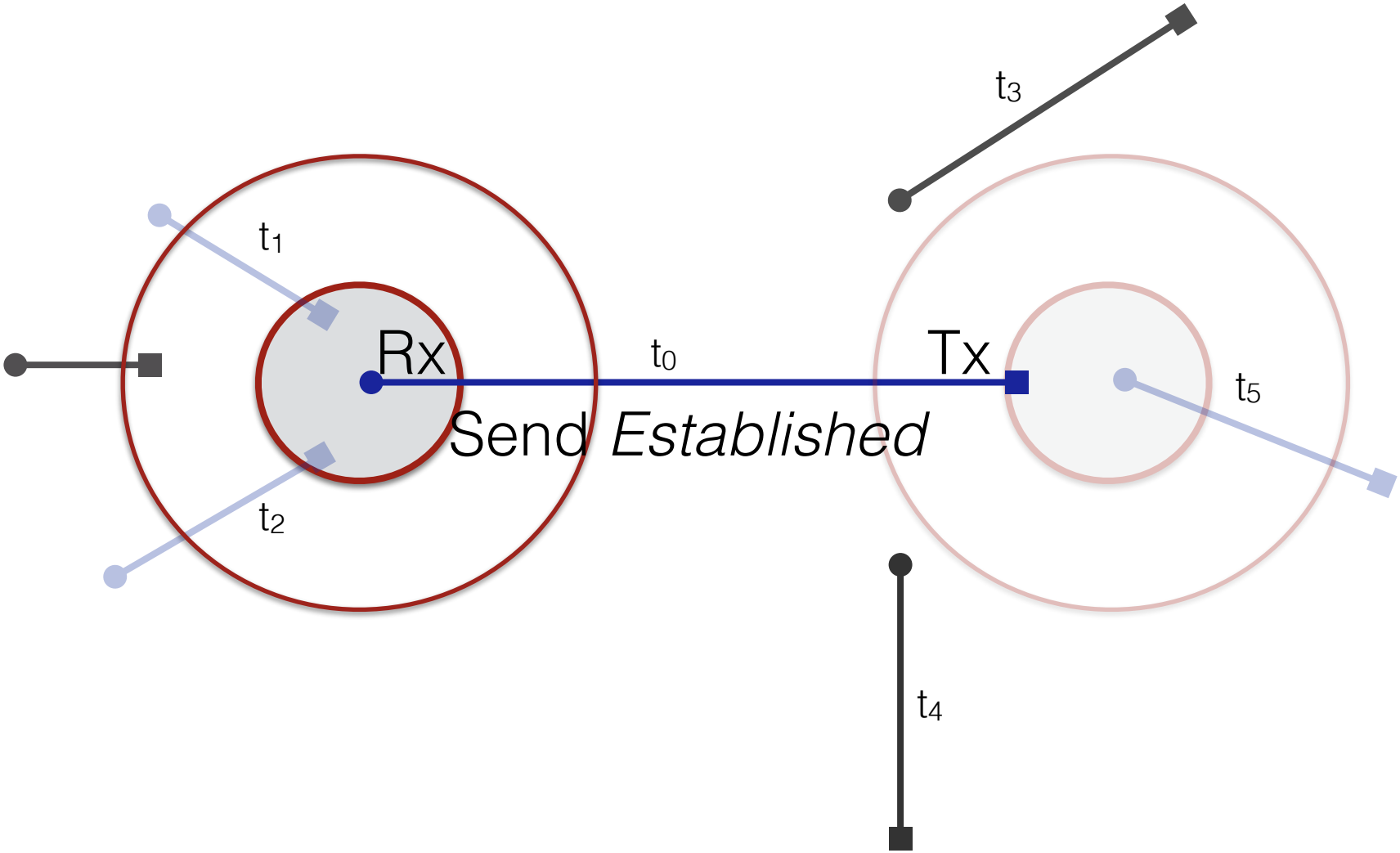
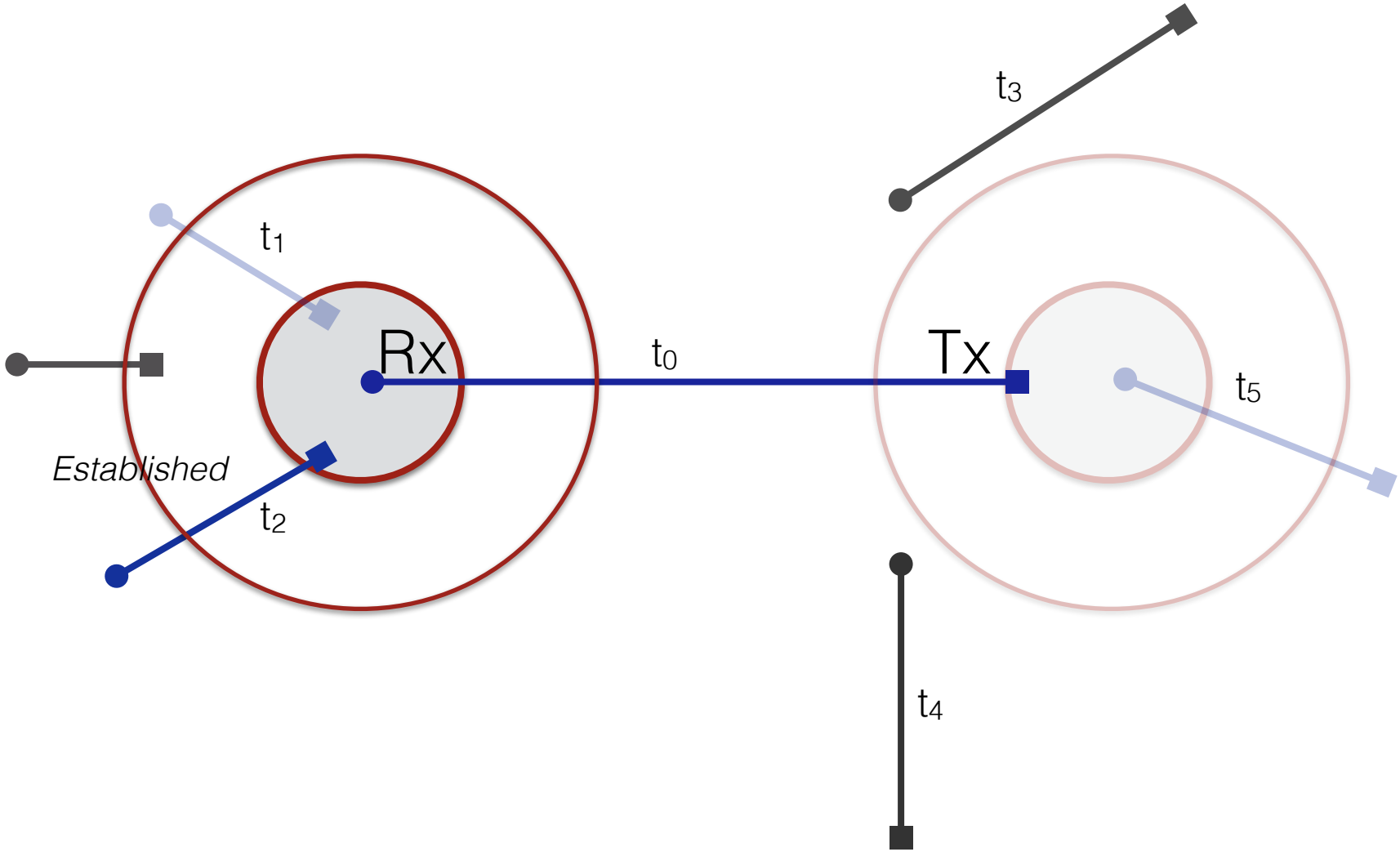


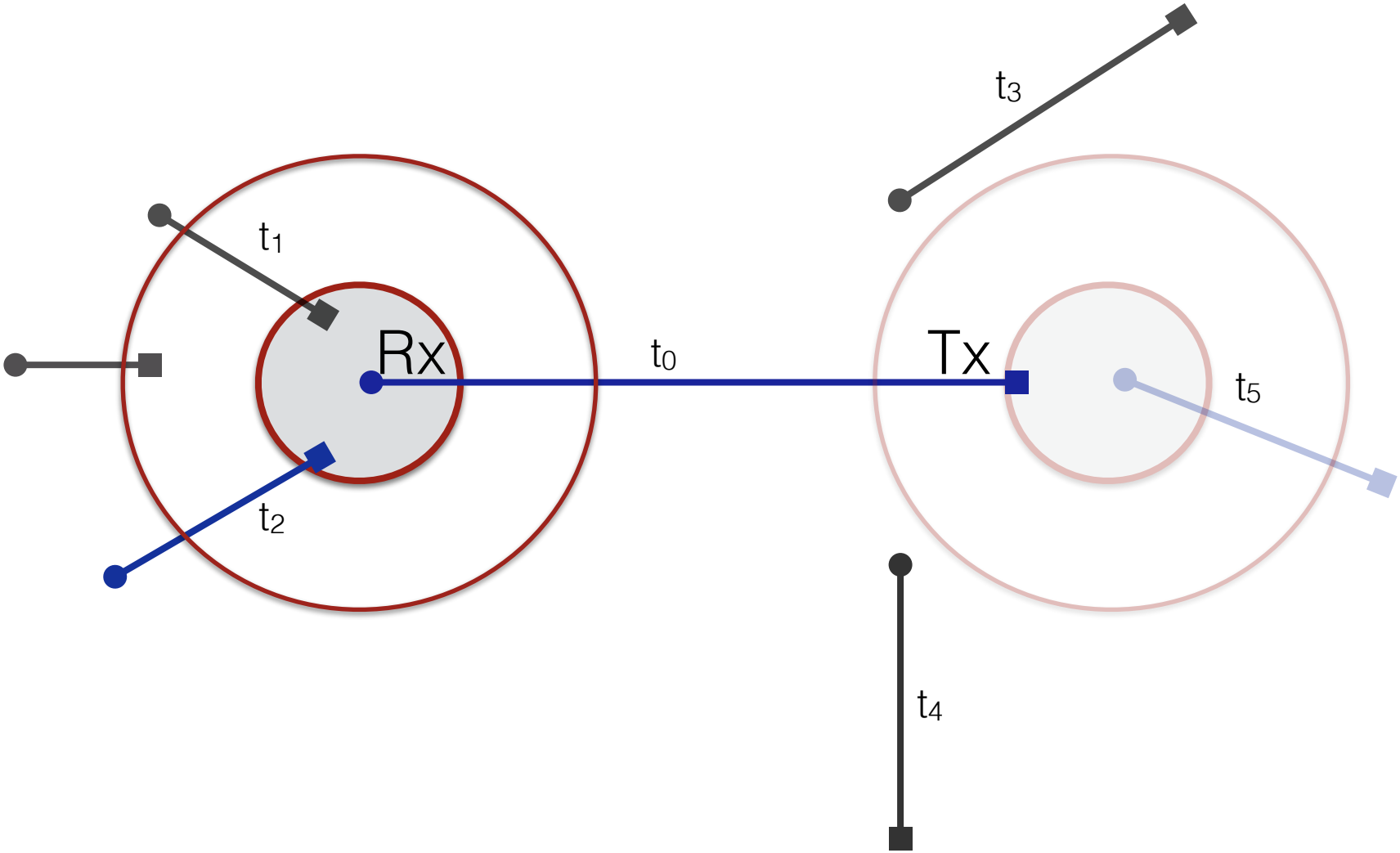
CSMA 1-SIC Signaling

Tx transmits '*Established*' signal



CSMA 1-SIC Signaling

Rx transmits '*Blocked*' signal to silence all other strong interferers



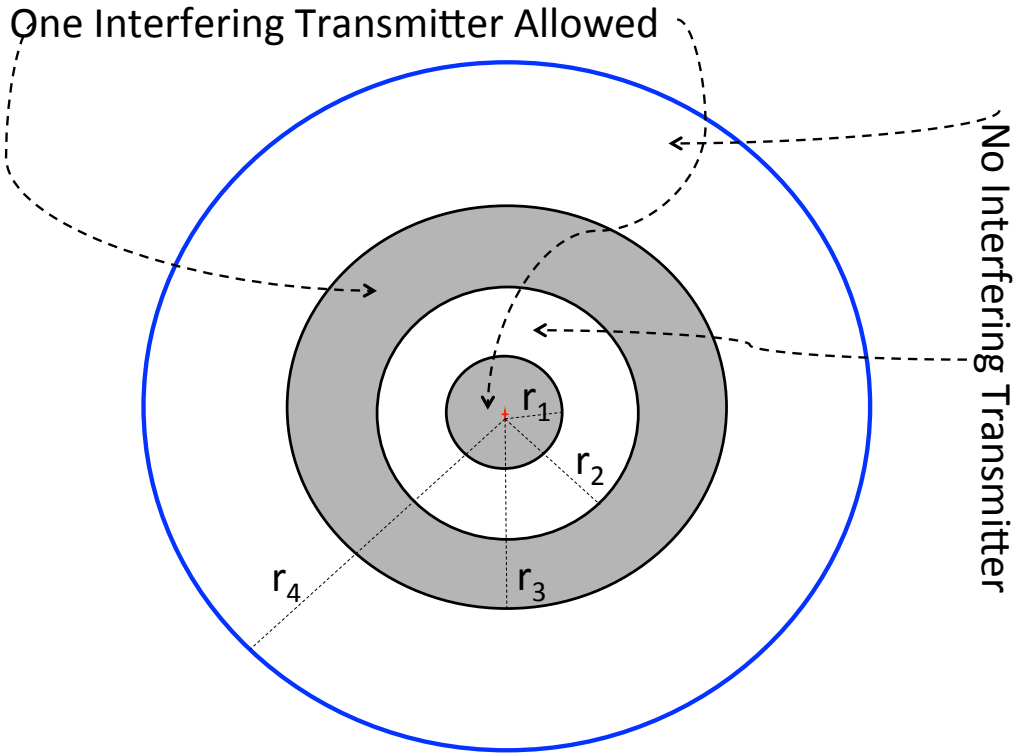
CSMA 1-SIC Signaling

Summary

- Randomized Protocol (Timers Chosen randomly).
- 2 parameters to tune.

- Guarantees to any scheduled receiver that there will be at-most one '*strong*' interfering transmitter.

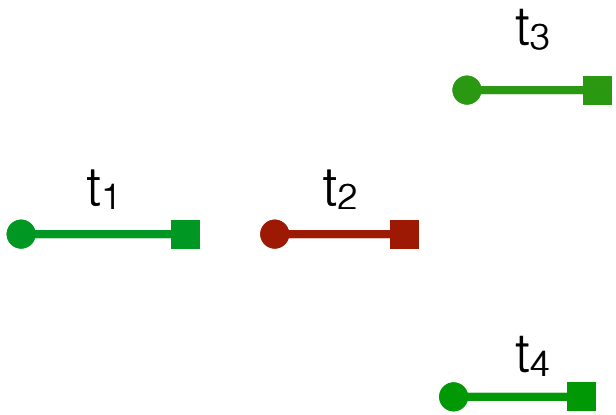
CSMA k-SIC Protocol



- The separation of powers leads to 2k parameter protocol.
- One can then develop a similar signaling algorithm.

CSMA /CA Versus CSMA 1-SIC

Non-Monotonicity



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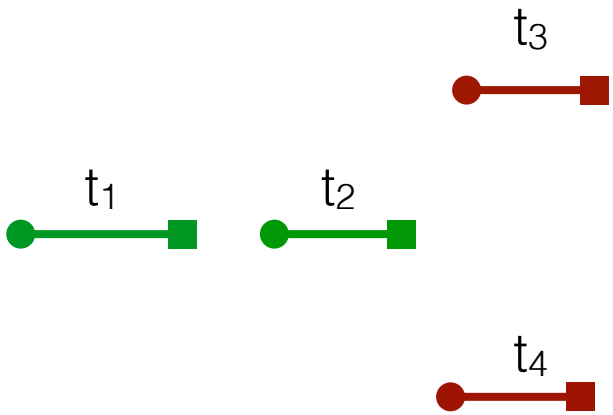

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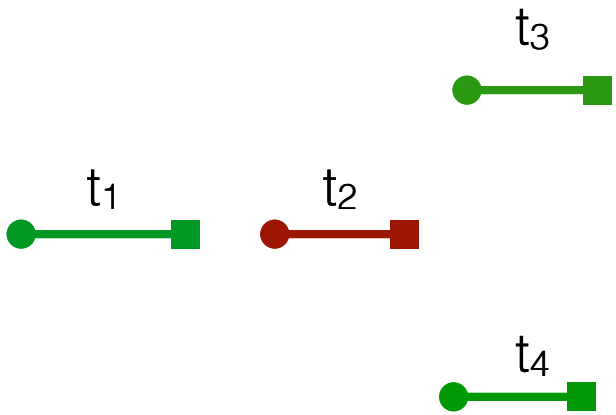

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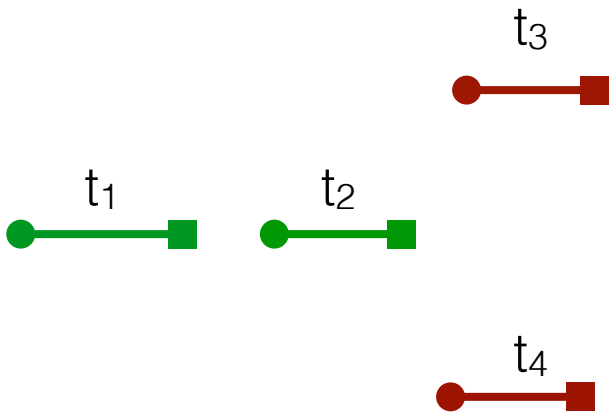

CSMA 1-SIC

- *Averaged* over timer values however, CSMA 1-SIC schedules more links.

CSMA /CA Versus CSMA 1-SIC

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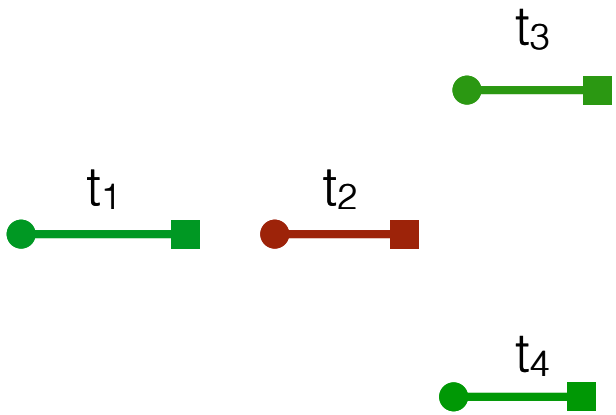

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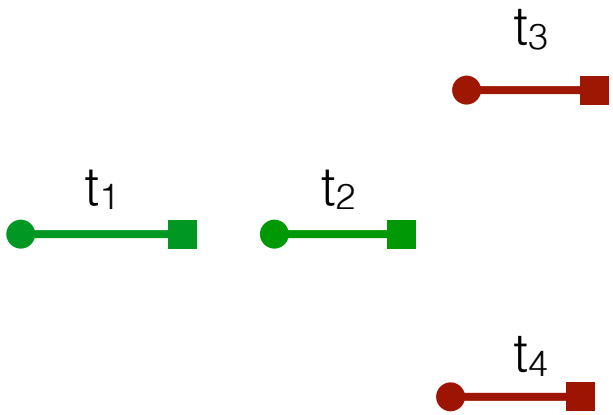


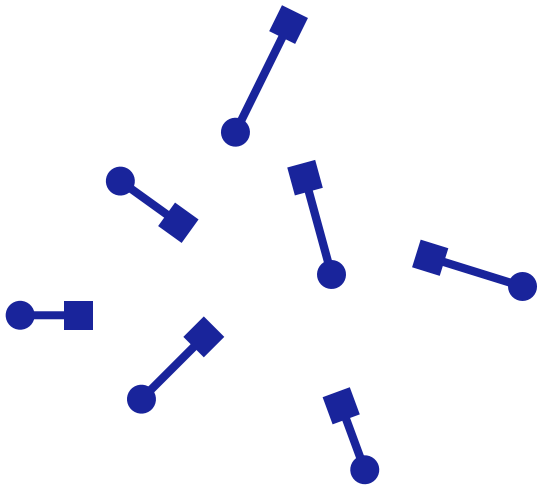
CSMA 1-SIC

- *Averaged* over timer values, CSMA 1-SIC schedules more links.
- This also means, that the interference levels are higher.

Performance Evaluation - Setup

- A Stochastic Network Model to compare the gains in adopting the protocol.
  - Dipole Network Model -

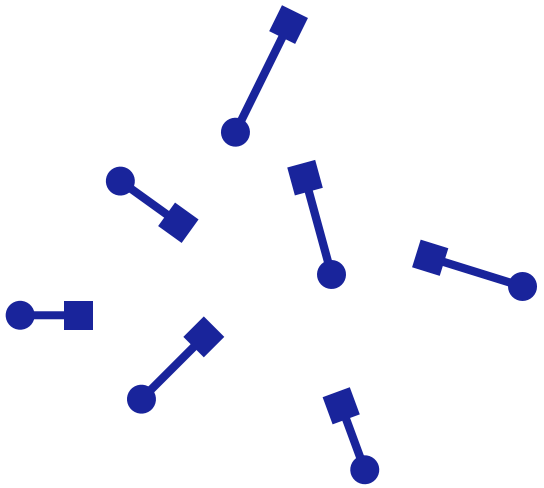
    Each Tx has an unique Rx. Tx form a PPP and the corresponding Rx is located at an uniform and independent angle away.



Performance Evaluation - Setup

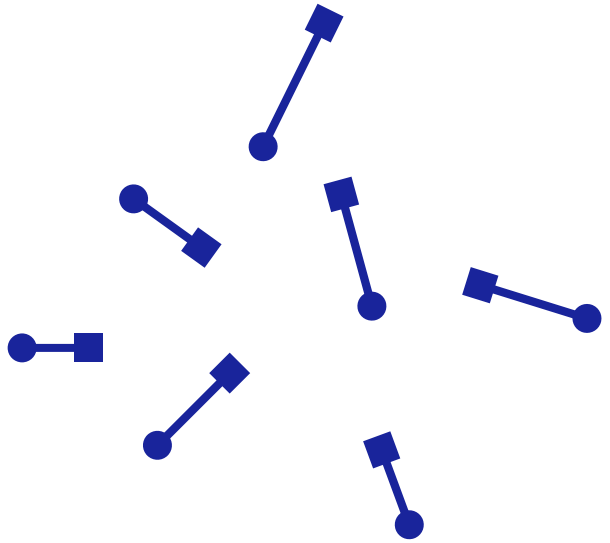
- A Stochastic Network Model to compare the gains in adopting the protocol.
  - Dipole Network Model -
    Each Tx has an unique Rx. Tx form a PPP and the corresponding Rx is located at an uniform and independent angle away.
  - No Power Control.
    All scheduled Tx transmit at unit power.
  - Fading -
    Channel between any pair of devices is random and symmetric
  - Path loss - $l(r) = r^{-4}$

$$F_{xy} l(||x - y||)$$



Performance Evaluation - Metrics

- The metrics
  - MAP - (Medium Access Probability (p_a))



Performance Evaluation - Metrics

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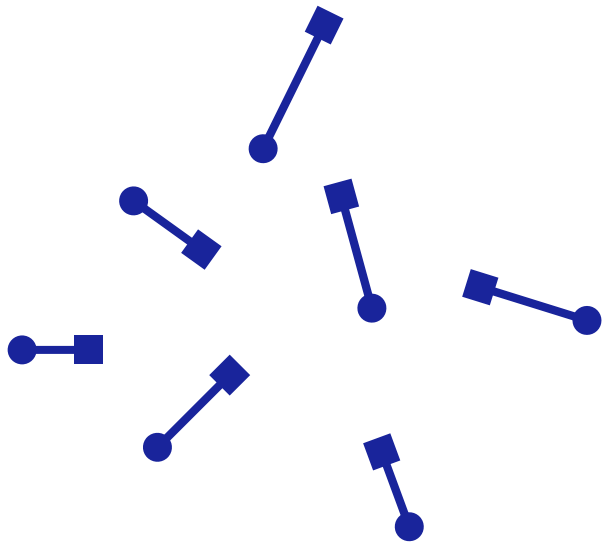
  - Success Density - (Fraction of scheduled links *successful (p_s)*)



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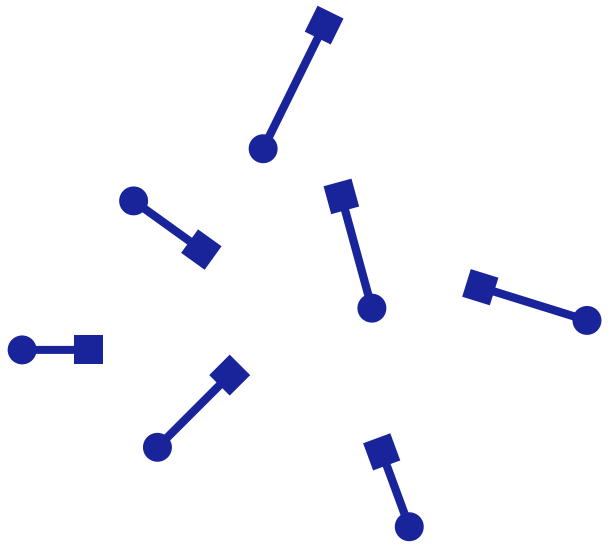

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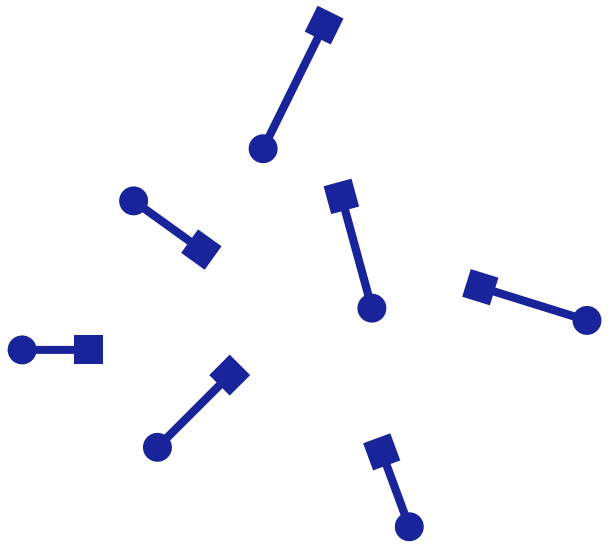
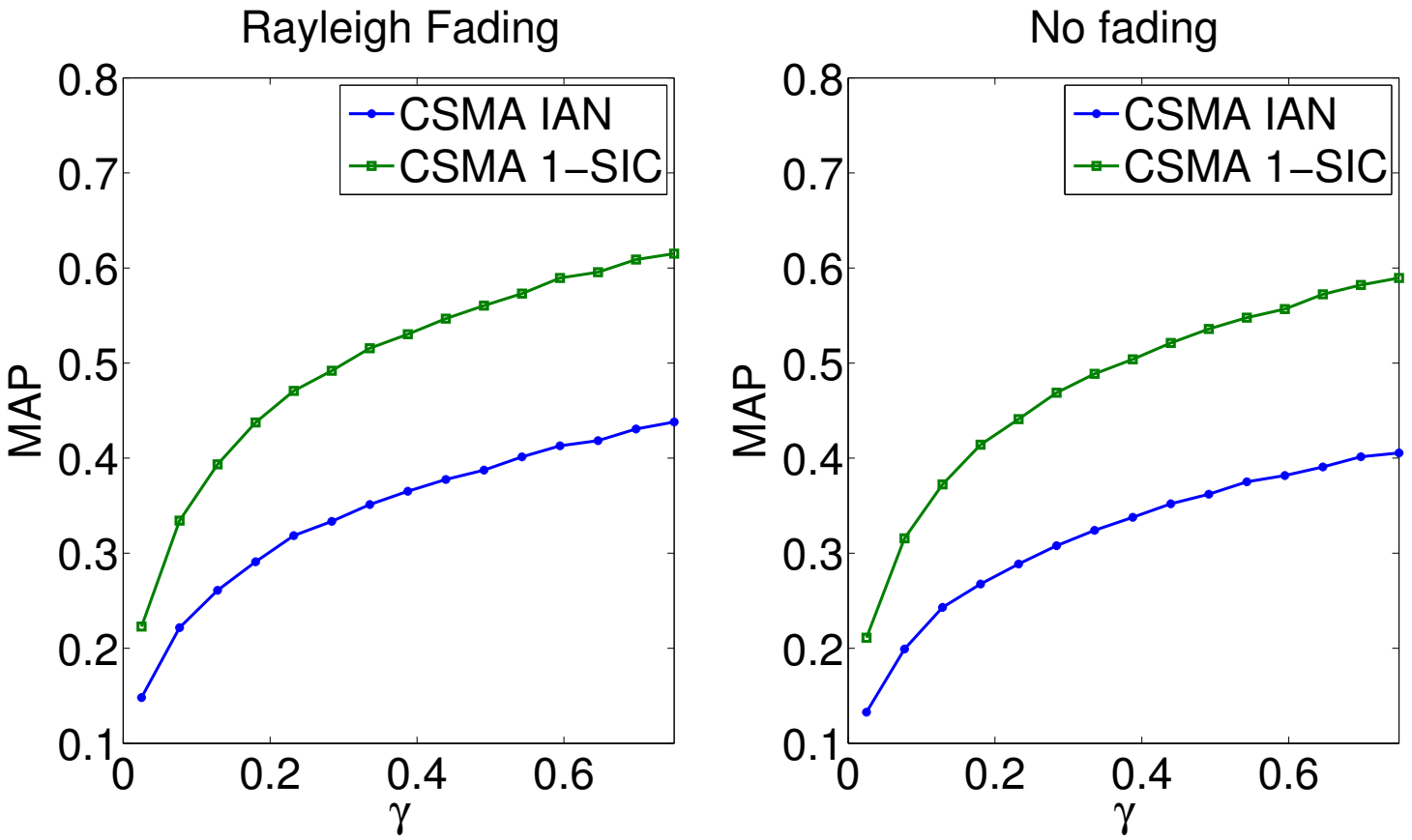
Throughput = $\lambda p_s p_a$

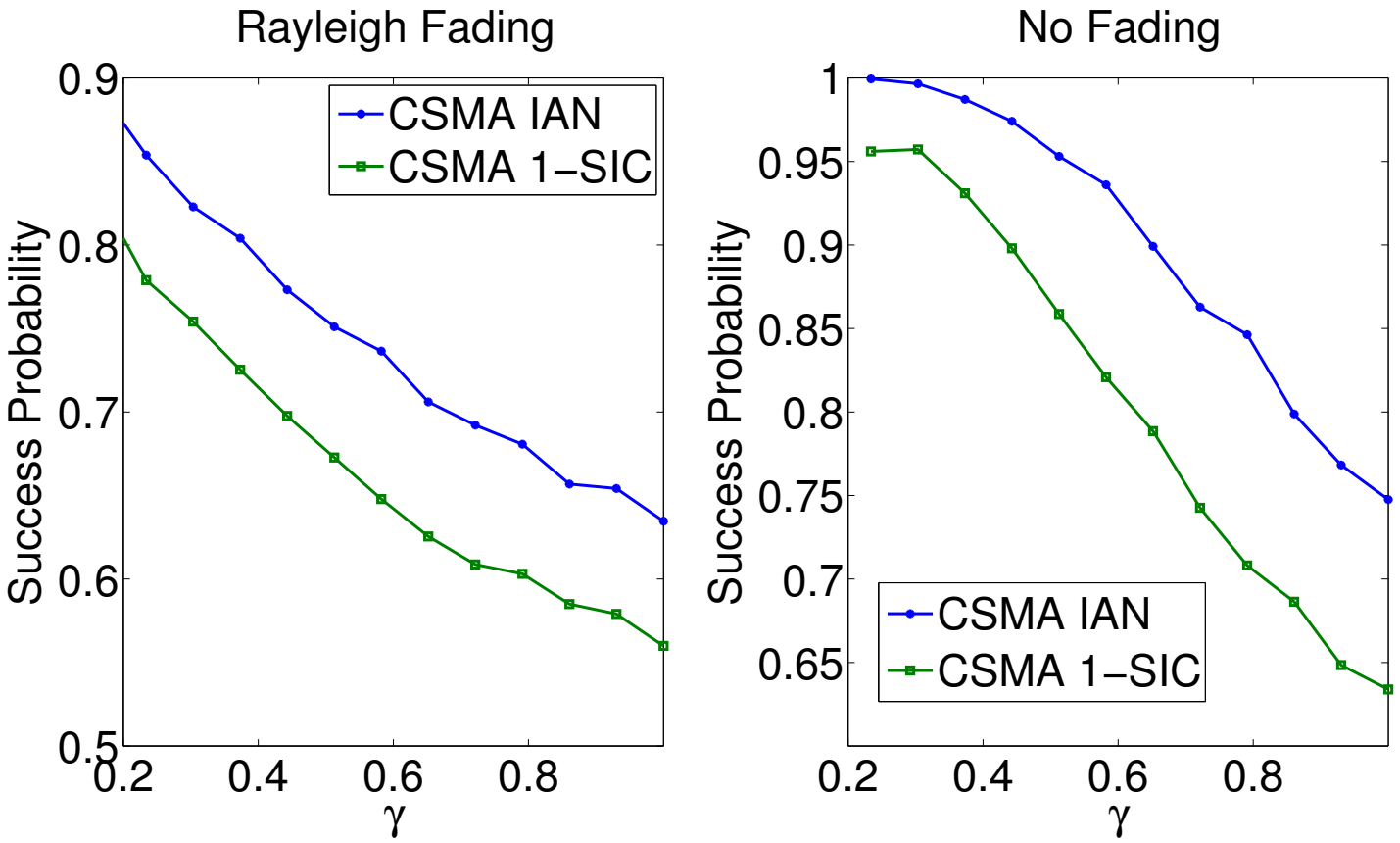


Performance Evaluation - MAP



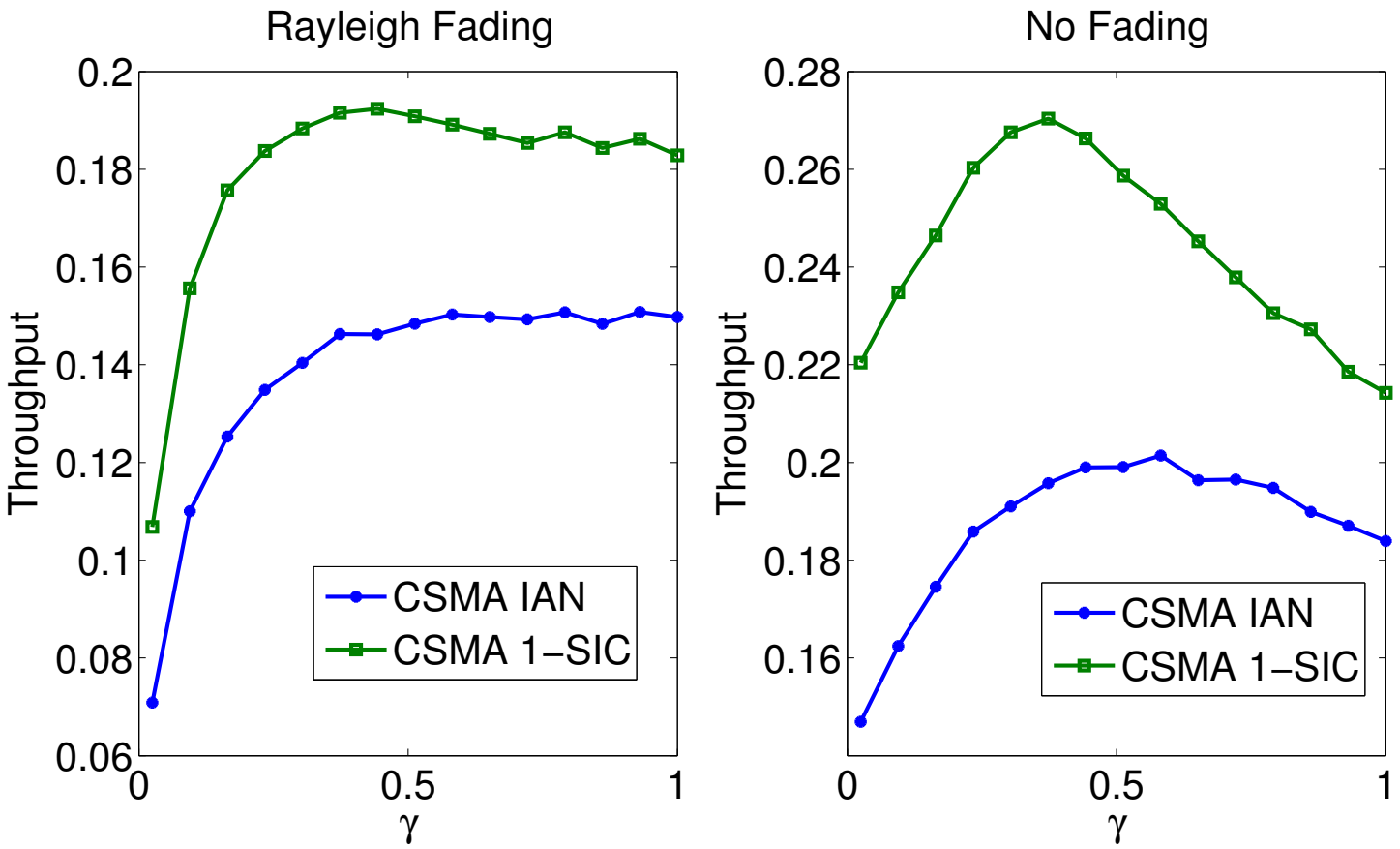
In large random networks, more links get scheduled on *average*.

Performance Evaluation - Success Probability



CSMA 1-SIC has higher interference since it schedules aggressively !

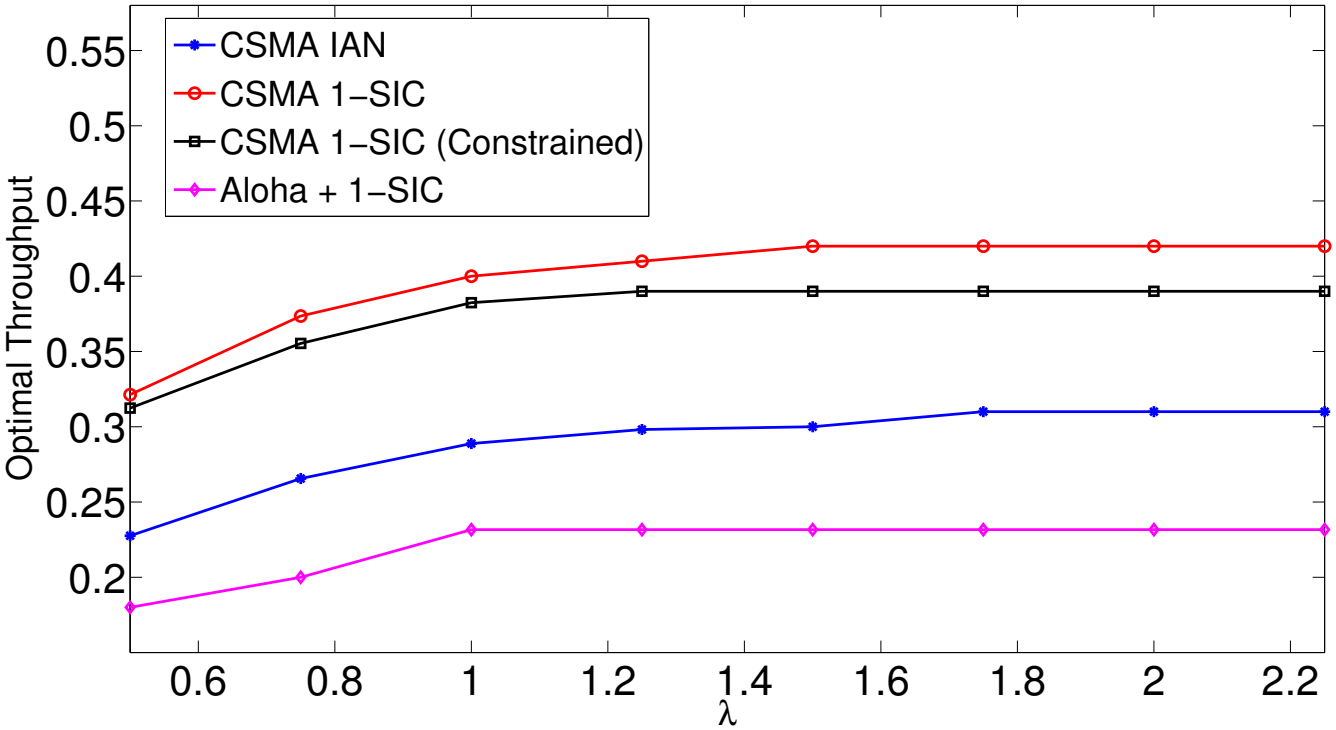
Performance Evaluation - Throughput



Nonetheless, CSMA 1-SIC has higher throughput !

Throughput Optimization

Throughput = $\lambda p_s p_a$



Donut shaped Guard zone is indeed required

Performing SIC improves throughput.

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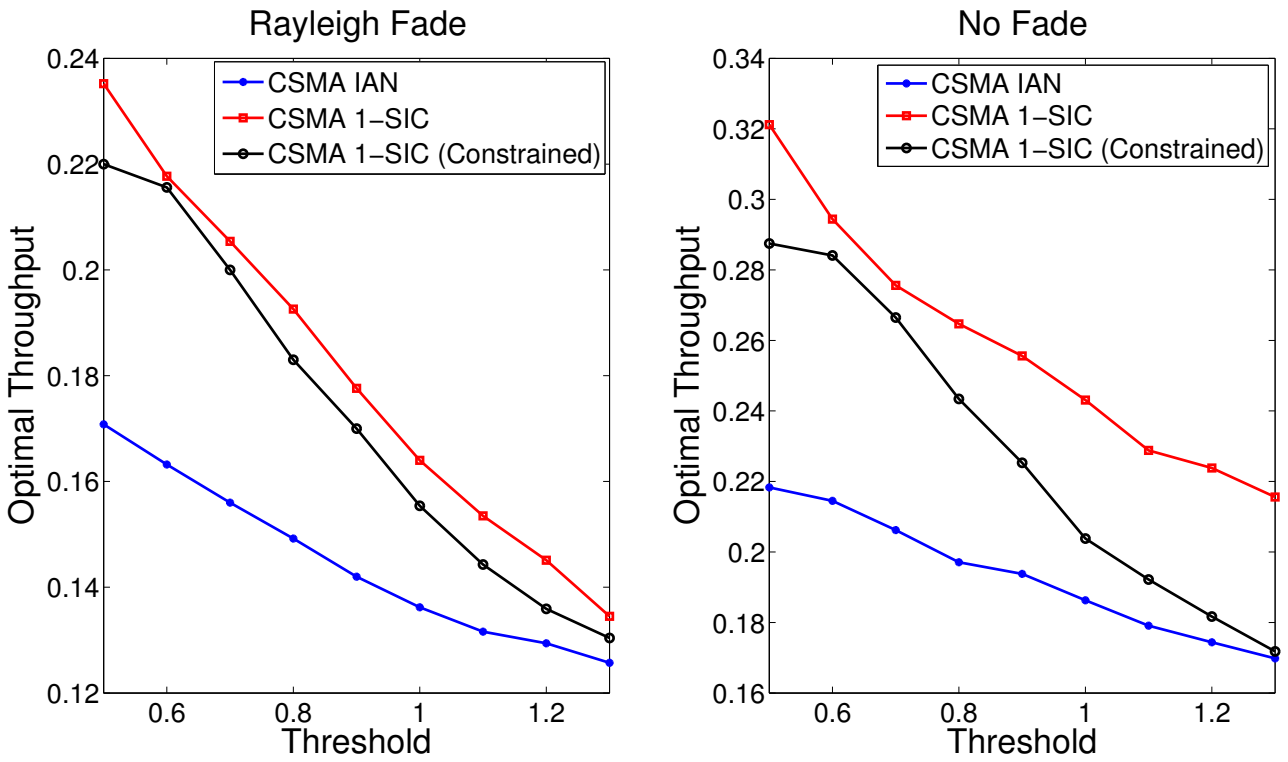
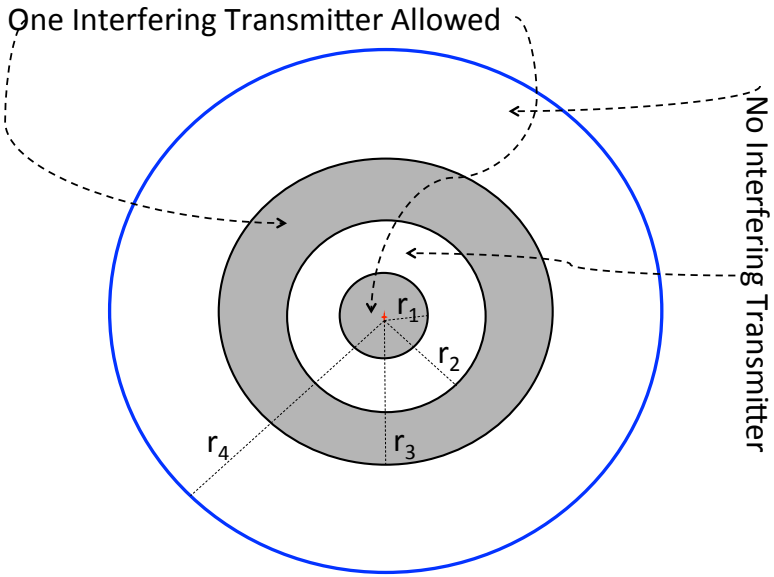


Donut shaped Guard zone is indeed required

Performing SIC improves throughput.

Higher order SIC

- 2k parameters to choose and optimize over.
- Expect some form of '*diminishing returns*' by increasing k.
- No clean performance comparisons with CSMA IAN yet.



Open Problems - Computational

Computation of densities (MAP)

- Exact computation is hard for even regular CSMA/CA.
- Matérn like approximation
  - An incoming link must compete with all other links having a smaller timer value regardless of whether they were scheduled.

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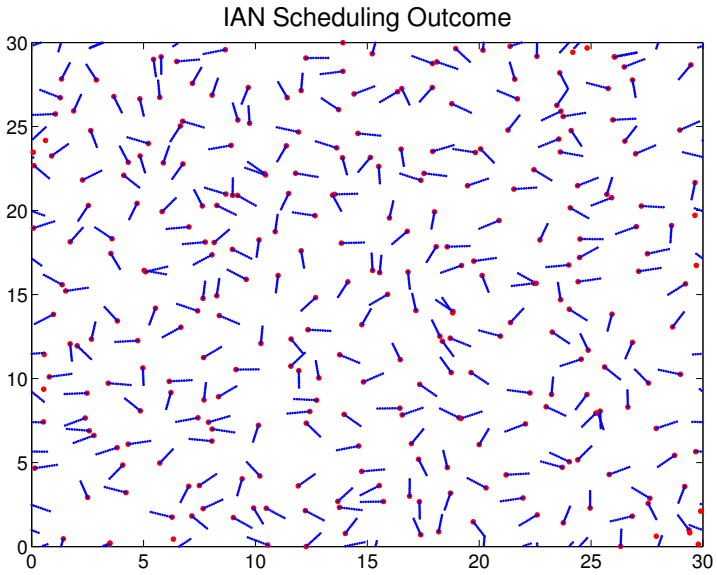
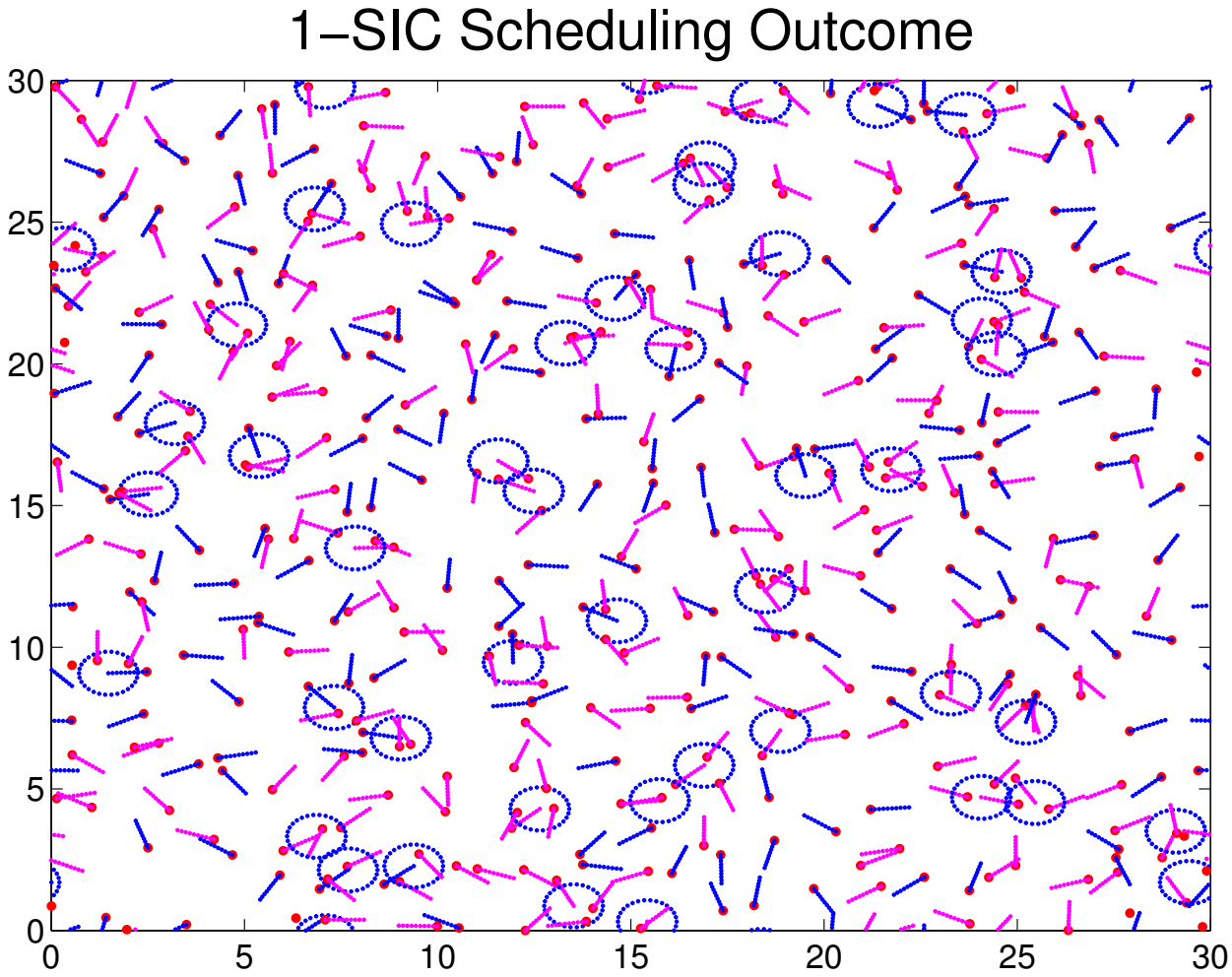
- Hard to compute even under this approximation !
  - A link is scheduled only if a transmitter does not *'kill'* a receiver with smaller timer value.
  - Extremal shot noise of the point process formed from all possible k+1 tuples of the points of a PPP is needed.

Open Problems - Physical



‘Jamming Regime’



Summary and Conclusions

- Looked at an improved paradigm for designing protocols.
  - Implementable distributed protocols from simple observations.

- A more fundamental question - ‘What is a *good* protocol’ ?
  ‘Fairness Efficiency’ tradeoff for spatial wireless resource.