Kiel University
Christian-Albrechts-Universität zu Kiel

Distributed Systems
Research Group

STARC

Low-power Decentralized Coordination Primitive for Vehicular Ad-hoc Networks

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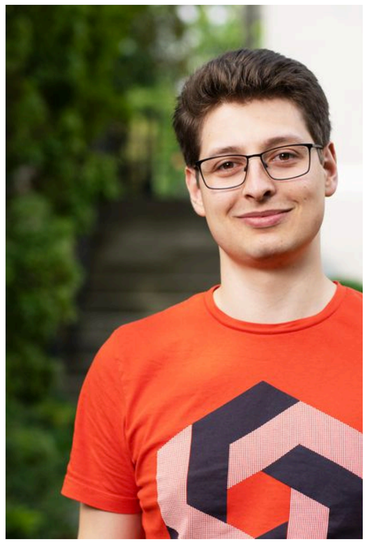
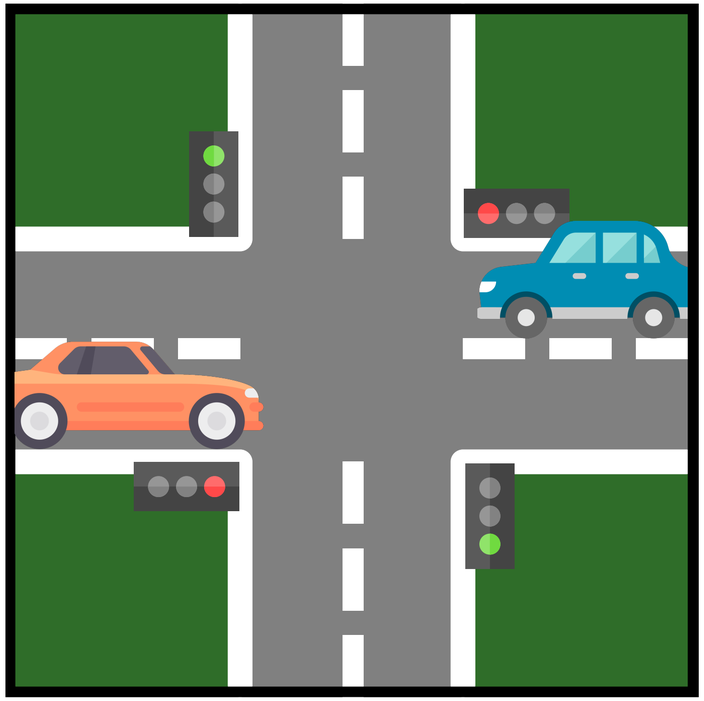


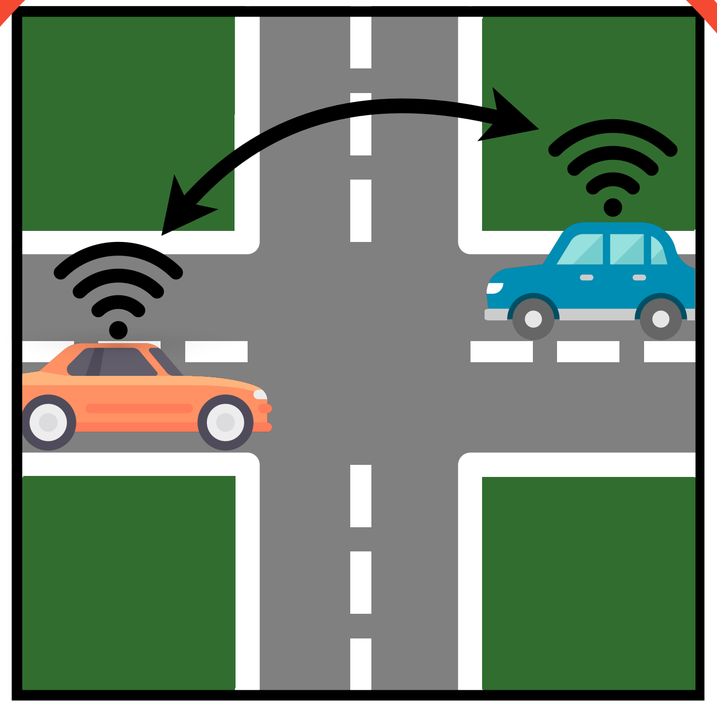
Intersection Management

Centralized



- Single authority responsible
- Infrastructure required

Decentralized



- Shared responsibility
- No infrastructure required

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Contributions

- Decentralized protocol for intersection management: *STARC*
  - Safe by design
  - Targets all traffic participants (such as cyclists)
- Open-source implementation for IEEE 802.15.4 radios
- Extensive evaluation using realistic wireless simulator

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Outline

1. Introduction
2. **Communication**
3. The STARC protocol
4. Evaluation
5. Conclusion

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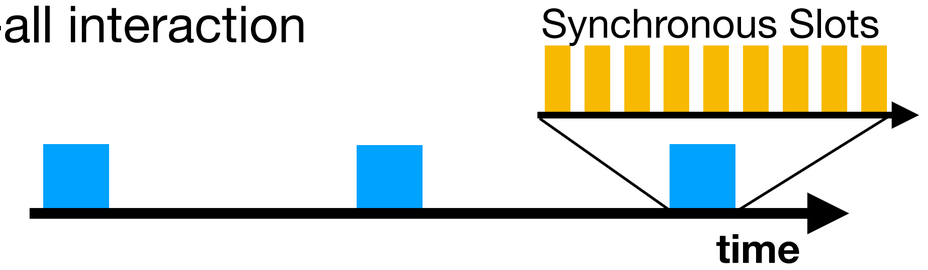
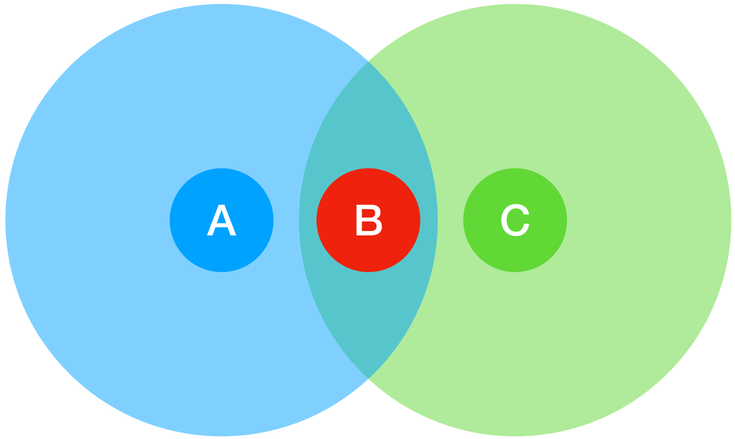
Communication with Synchrotron

- Highly reliable time-slotted MAC layer (A^2: Agreement in the Air, Sensys 2017)
- Designed for fast, energy efficient all-to-all interaction
- Members communicate periodically
  - Share information with neighbors
  - Merge and aggregate data until all share same information
  - Implicitly supporting multiple hops





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IEEE 802.15.4

- Outside coverage up to 100m
- 250kbps ~127 Bytes payload
- Transmitters small and cheap
  - 4 MHz CPU
  - Powered by two AA batteries
- 5G-D2D possible substitute

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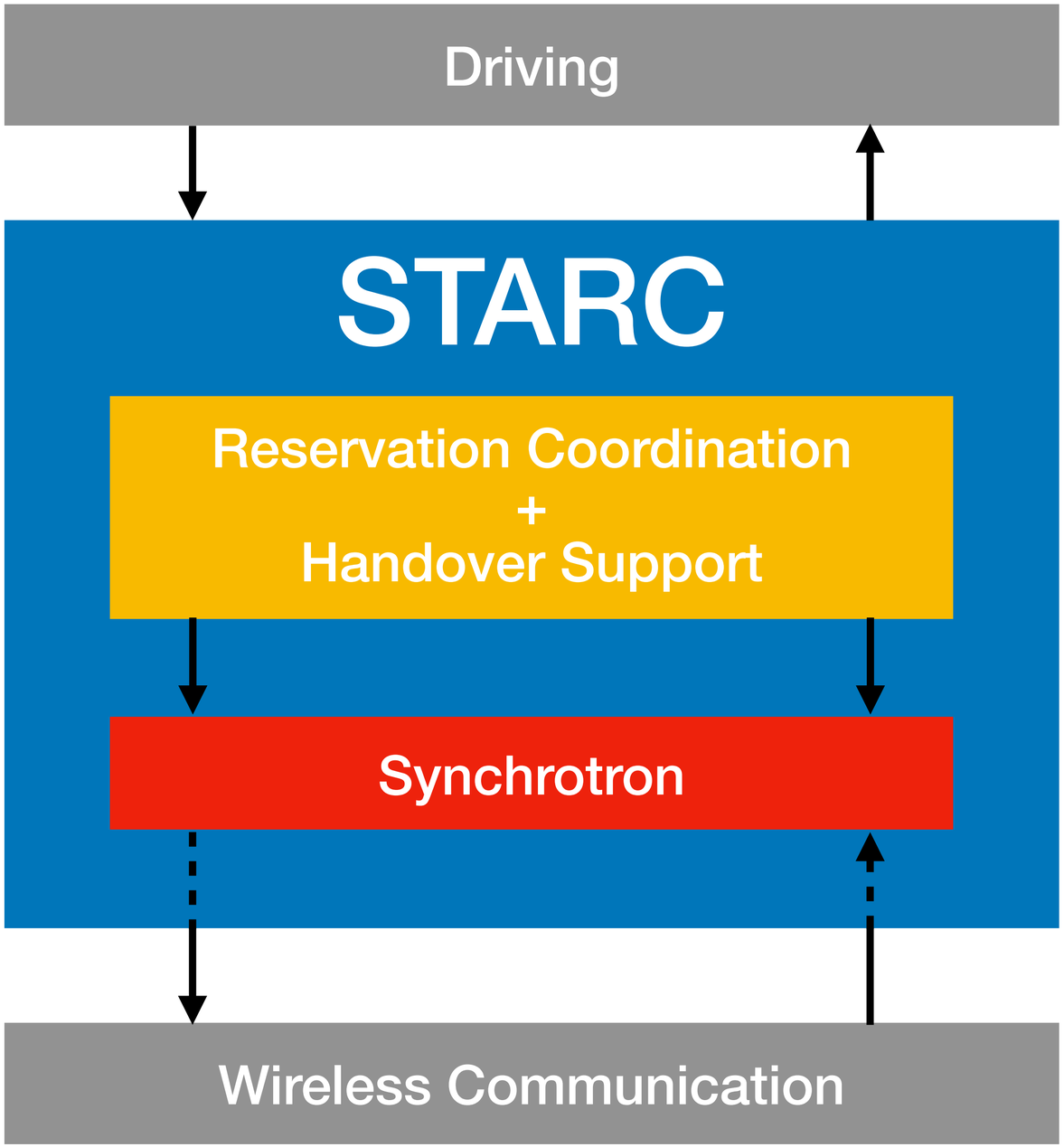

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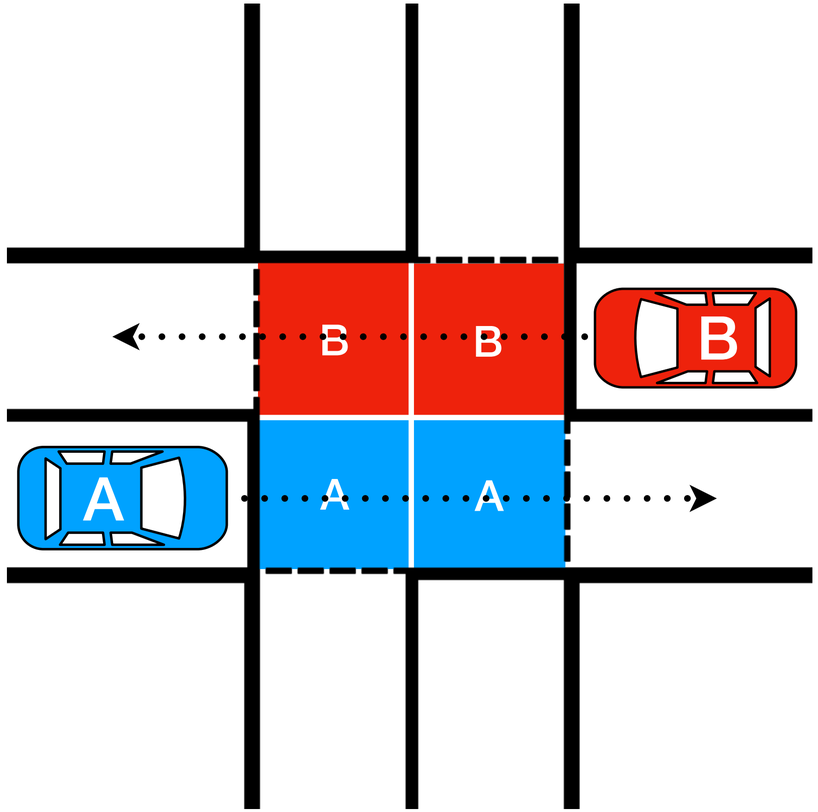
Reservation



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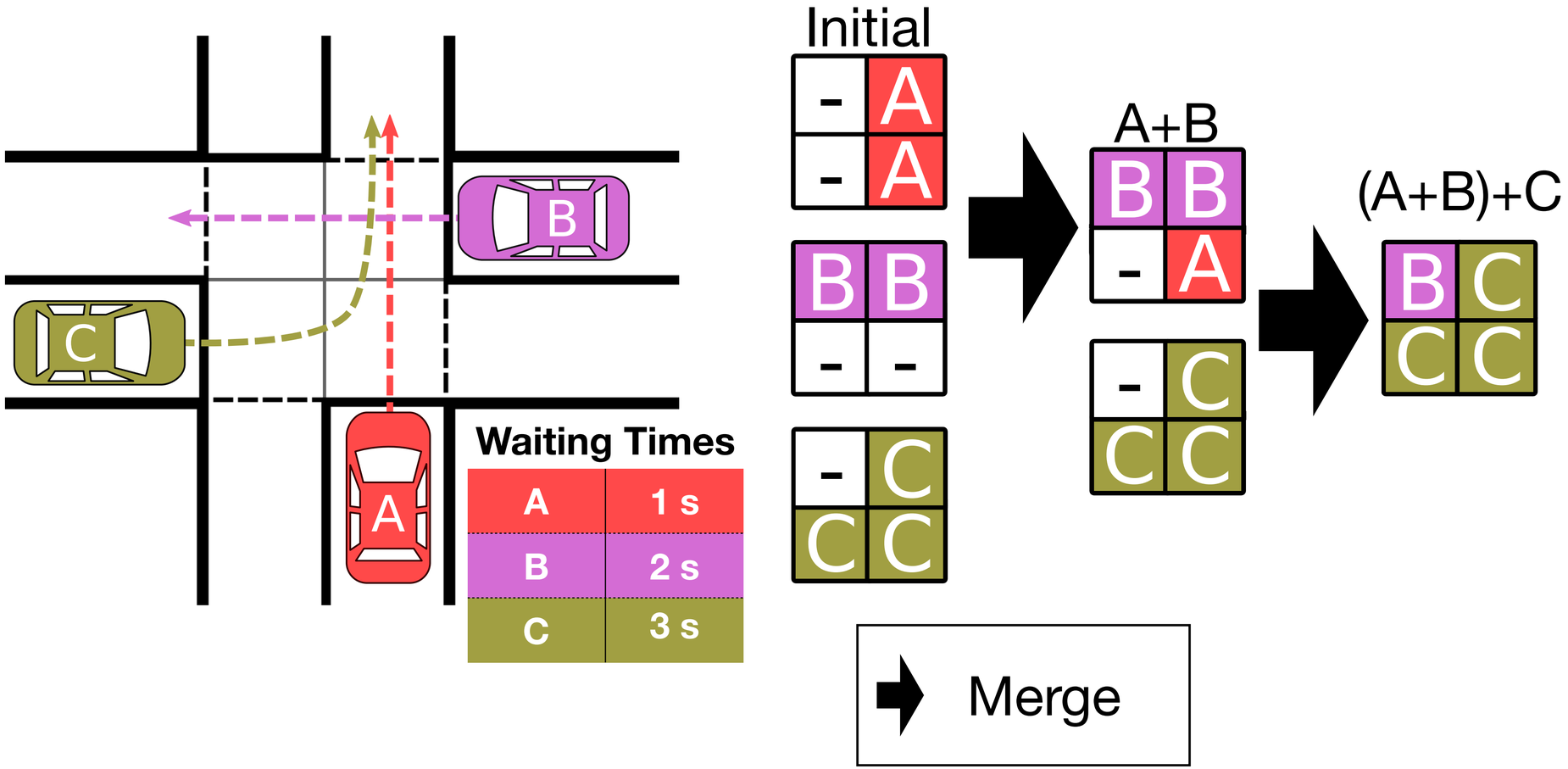
Reservation Coordination Example



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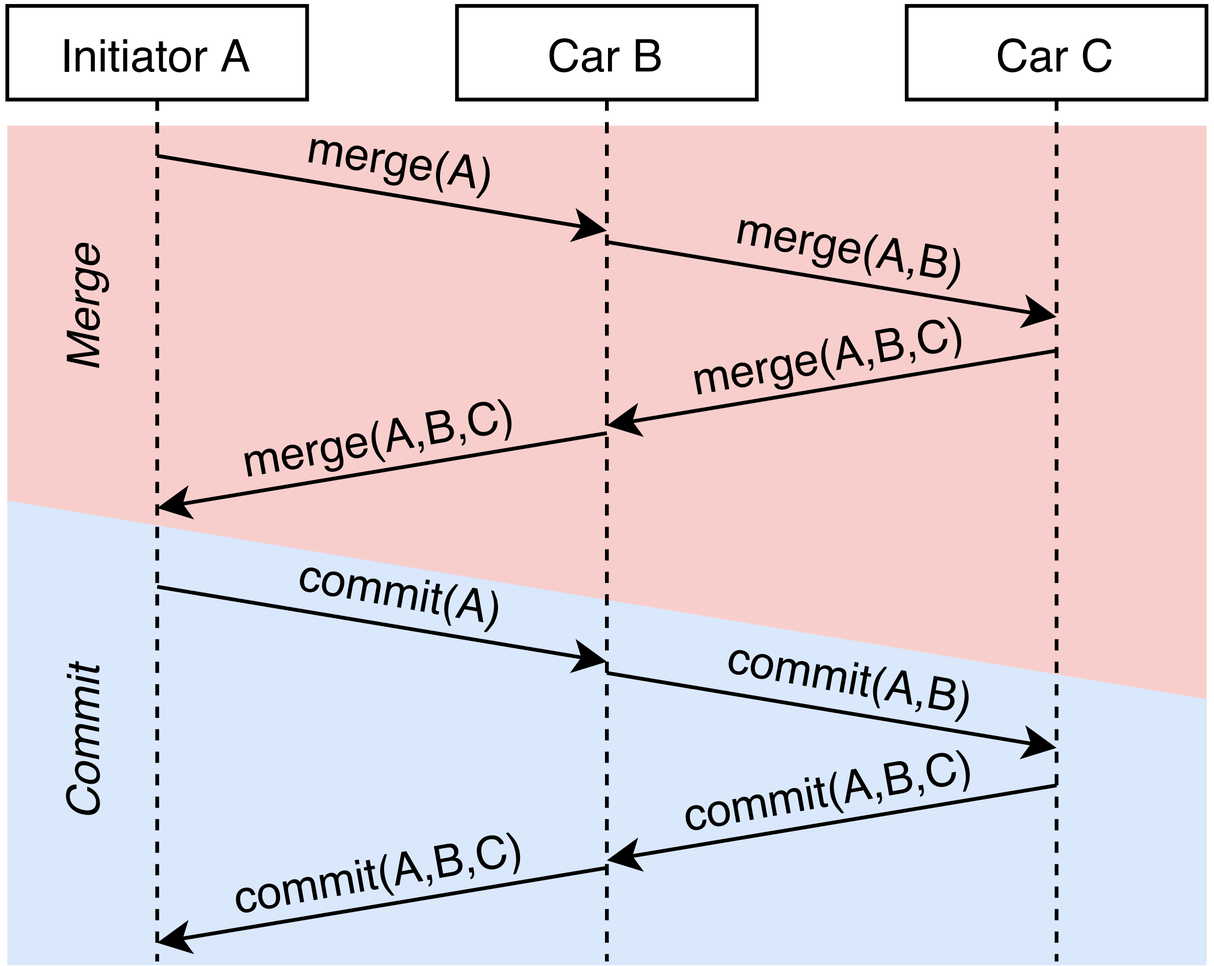
Two-Phase Commit Semantics



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Reservation Coordination Summary

- Aggregate reservations with neighbors
  - Conflicts resolved by priorities
- Intersection-wide coordination
  - Full-participation required
  - All conflicts resolved
  - Safe crossing over reserved tiles
- Repeated in rounds

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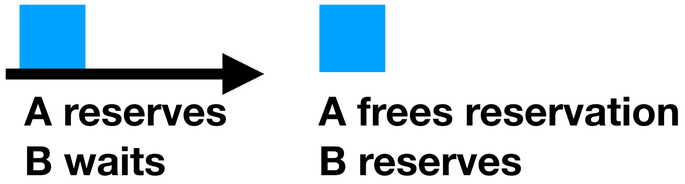

Handover Support

- Explicit join and leave
- Designated initiator node handles network membership
  - On top of coordination with commit semantics
  - Hands-over before leaving

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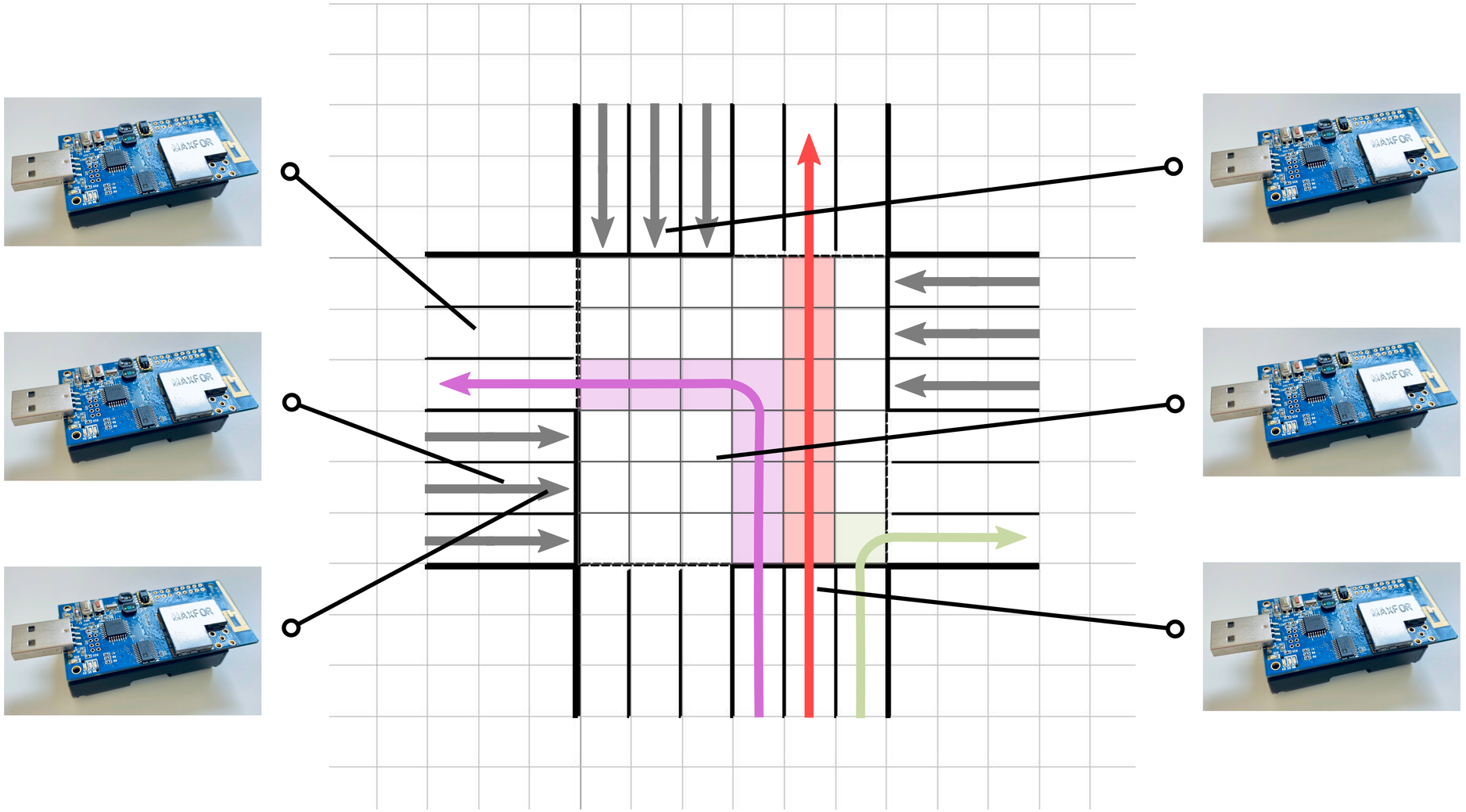
Evaluation



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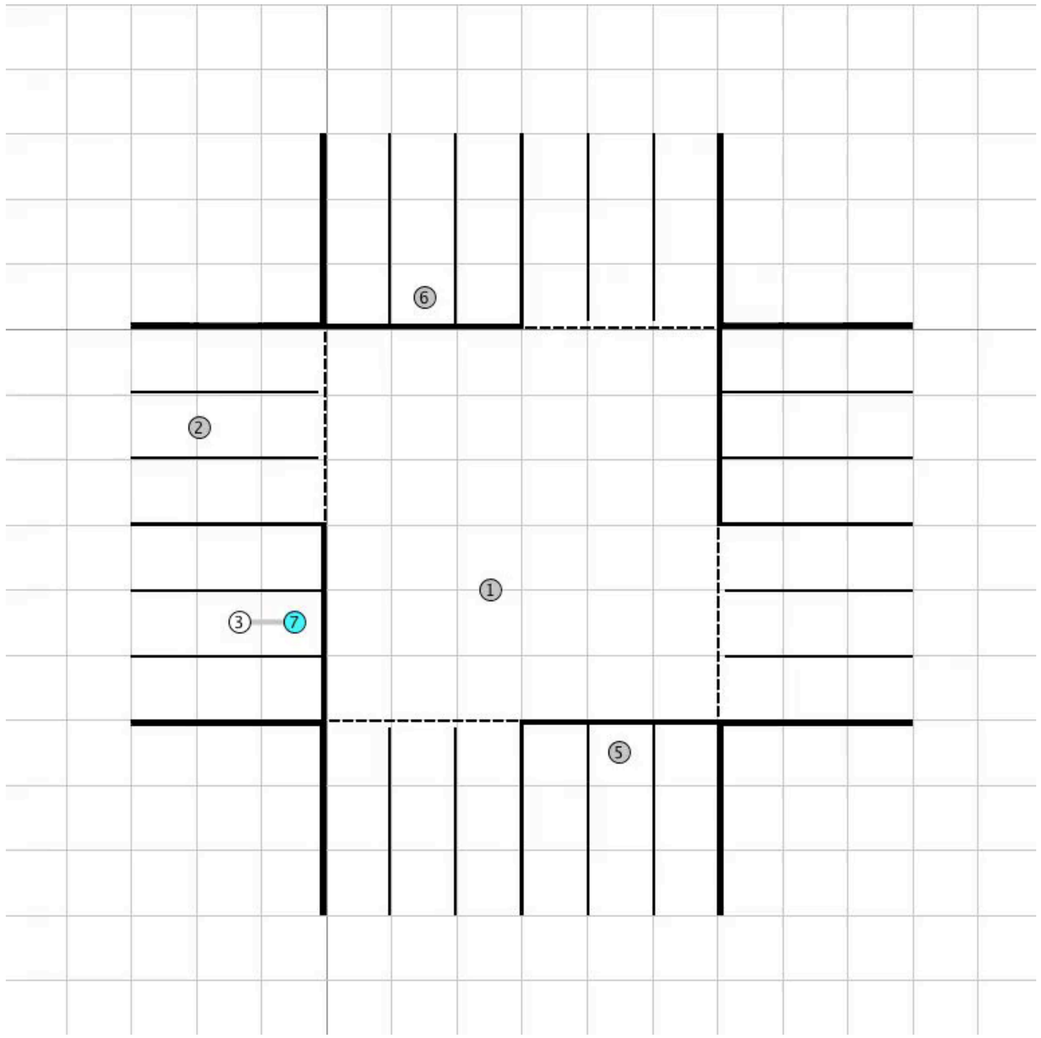
Simulation Demo



Without platoons

With platoons

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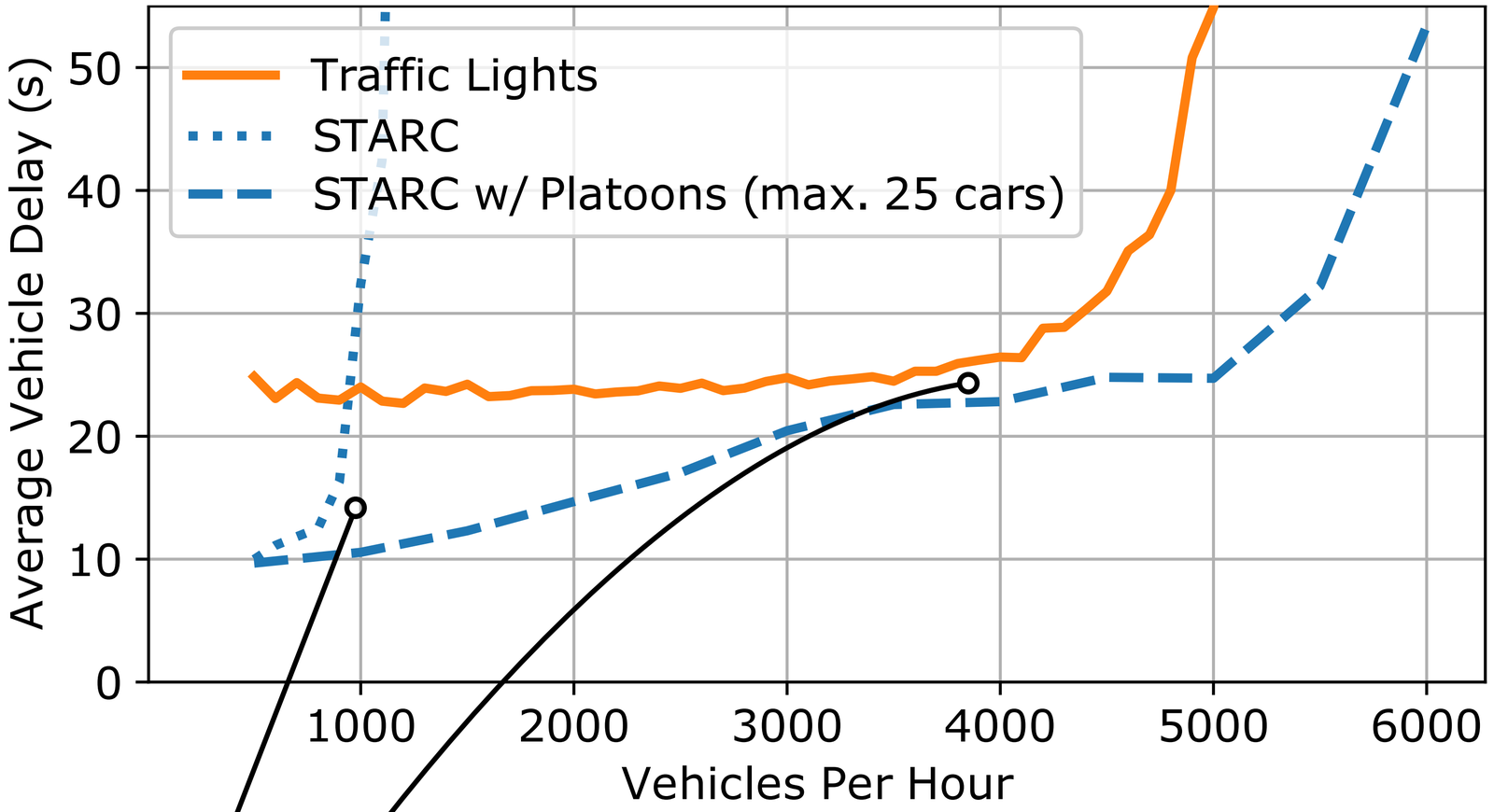
Efficiency Comparison



- 50% less delay than fixed traffic lights (less than 1000 vehicles per hour)
- Platoon extension lowers delay overall

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Conclusion

STARC

- Decentralized, extendable protocol for intersection management
- Safe by design
- Supporting cheap, low-power devices targeting all traffic participants
- Implementation for IEEE 802.15.4
  - Available at https://github.com/ds-kiel/starc

Results

- Average delay reduced by up to 50% compared to static traffic lights (< 1000 vehicles per hour)
- Platoon extension boosts overall efficiency (especially with more than 1000 vehicles per hour)

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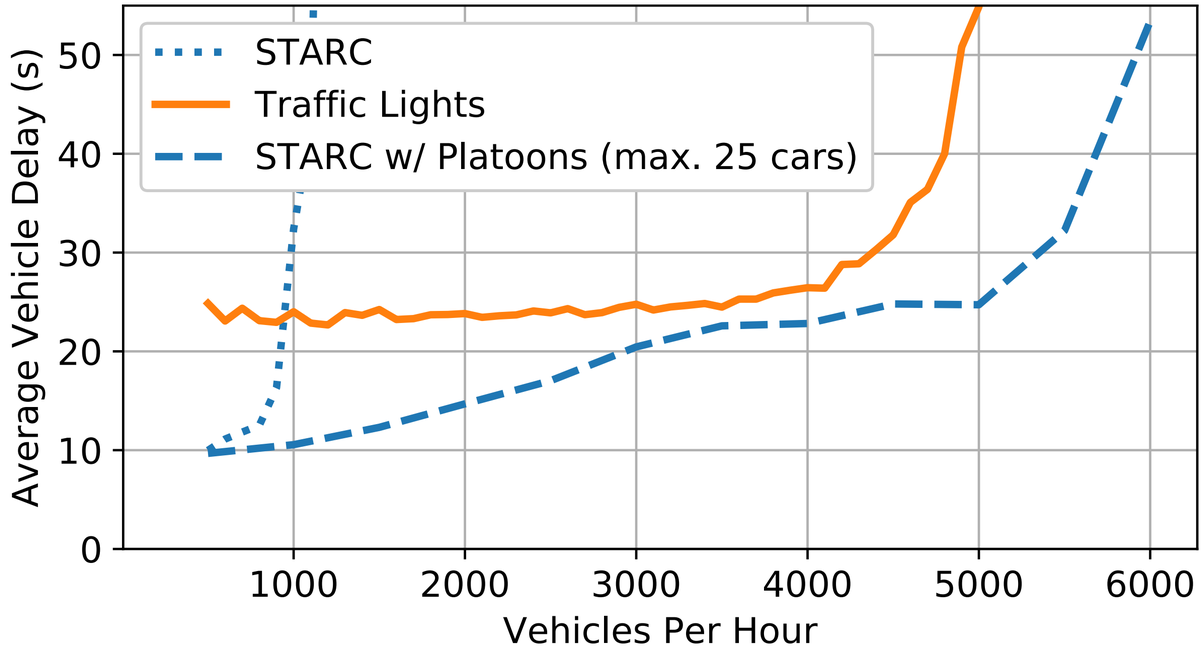
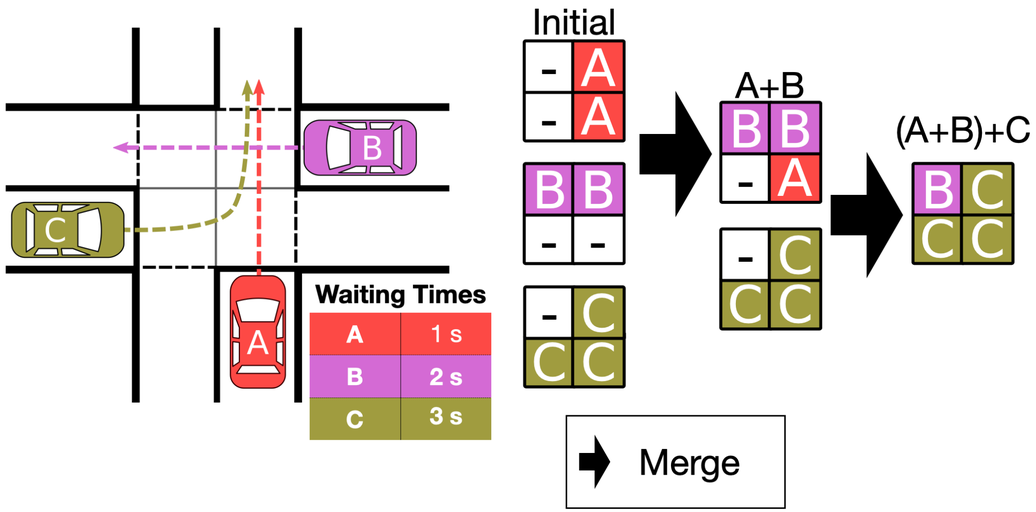
Questions?





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Implementation:
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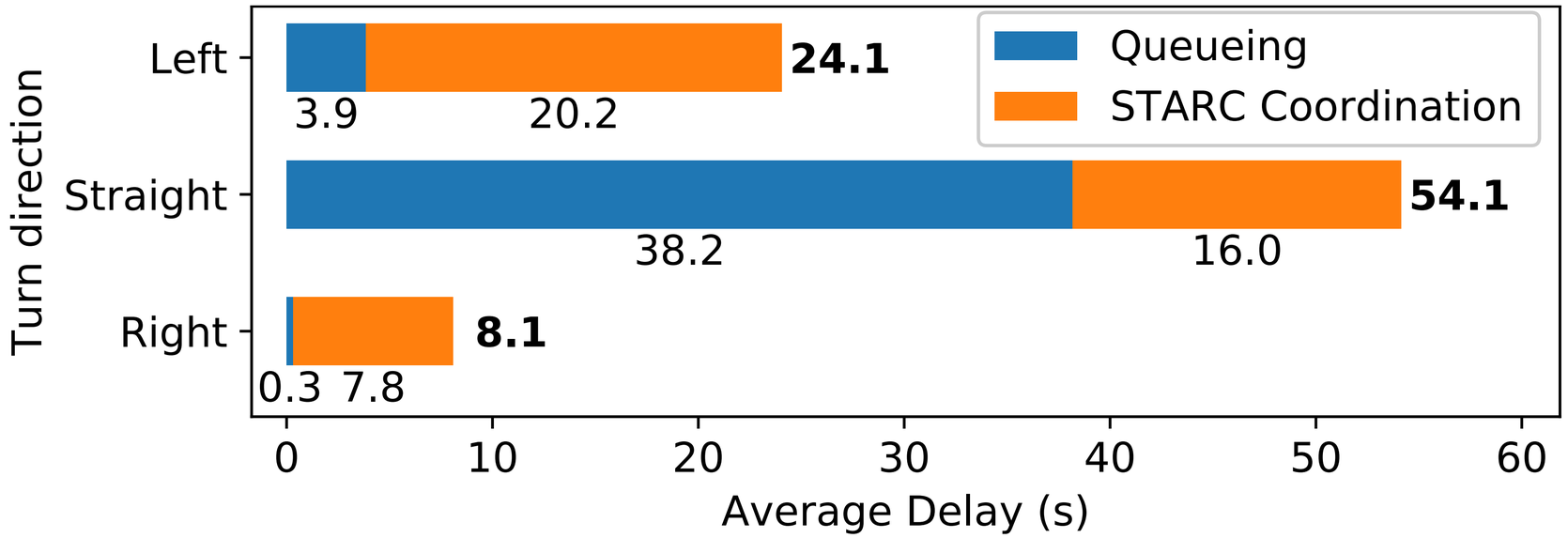
Appendix

STARC: Low-power Decentralized Coordination Primitive for Vehicular Ad-hoc Networks

Delay By Turn Direction



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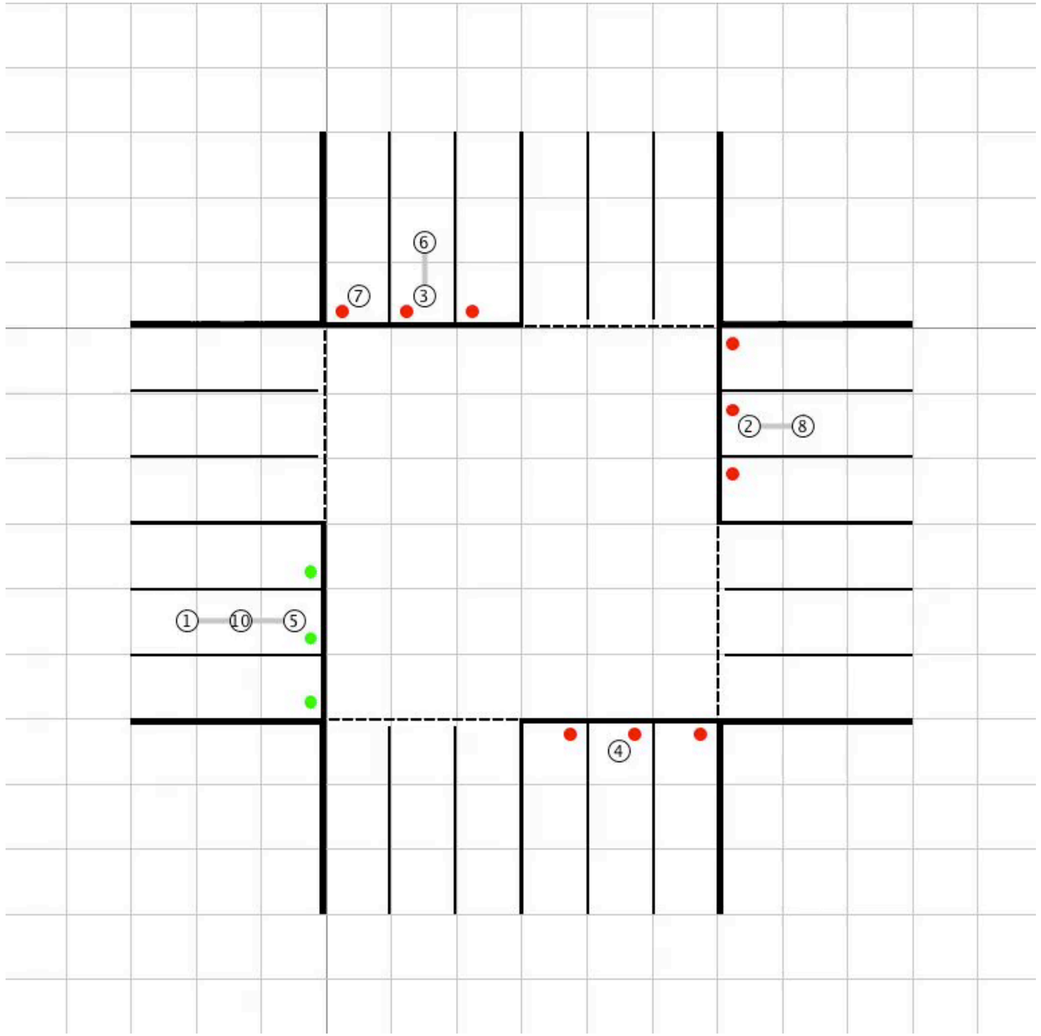
Traffic Lights

- All lanes of one direction get green light
- 15 s per direction → overall 60 s
  - Green phase for 9 s



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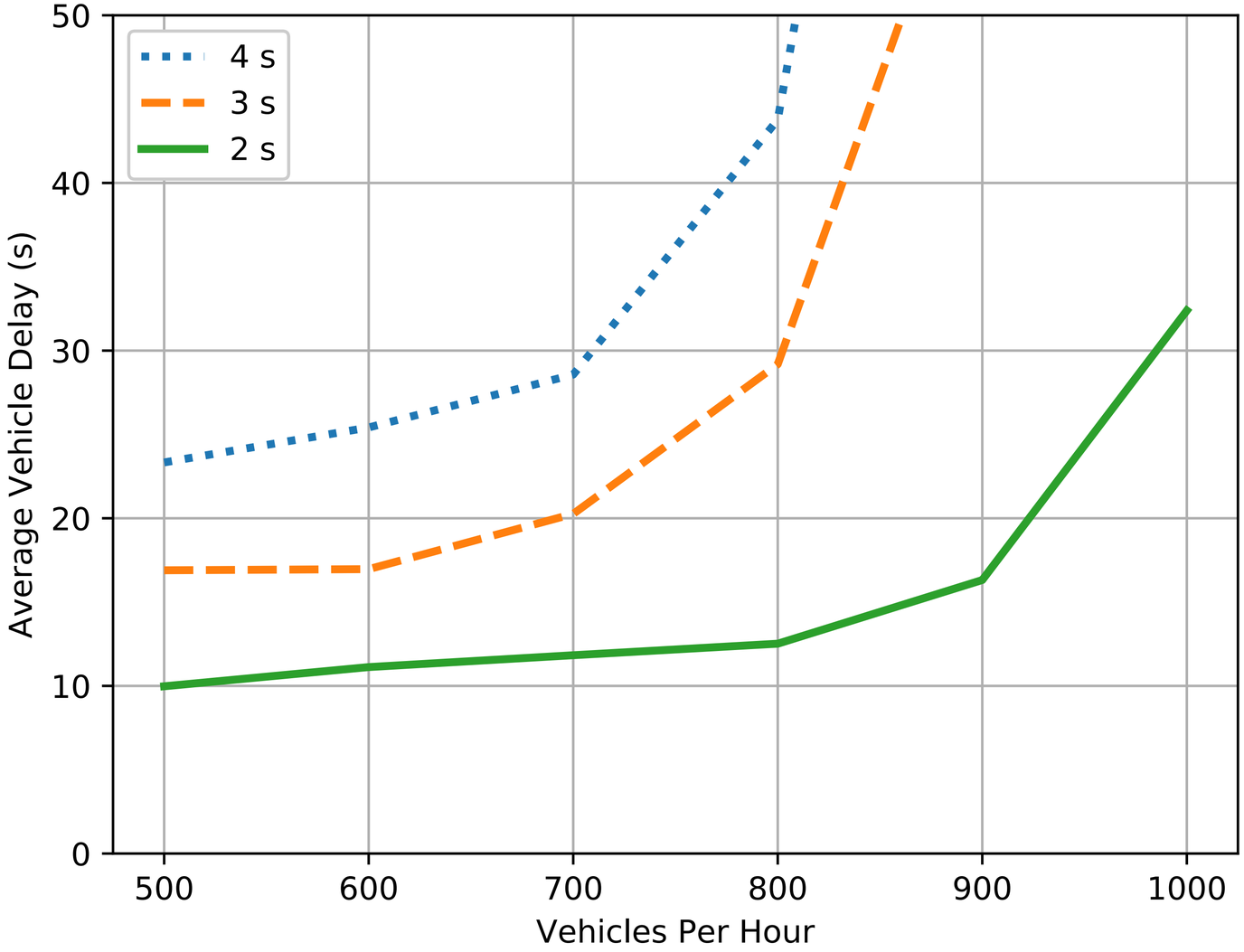
Interval Comparison



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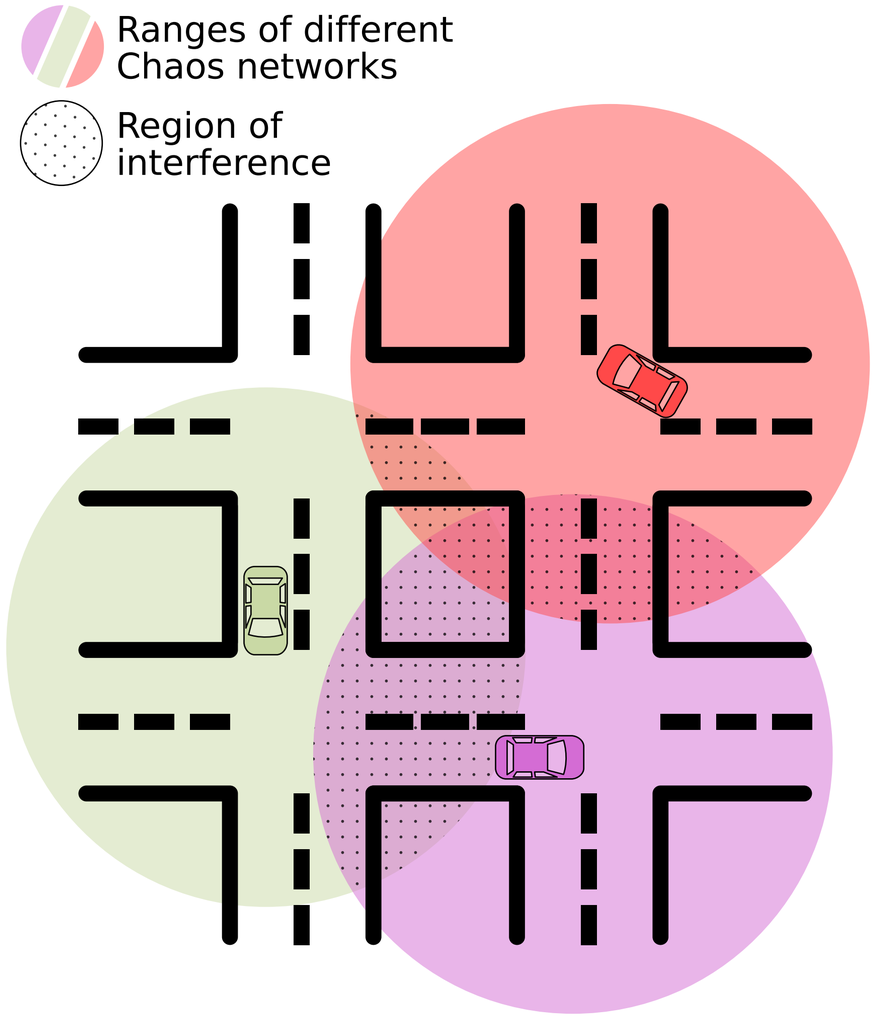
Multiple Intersections



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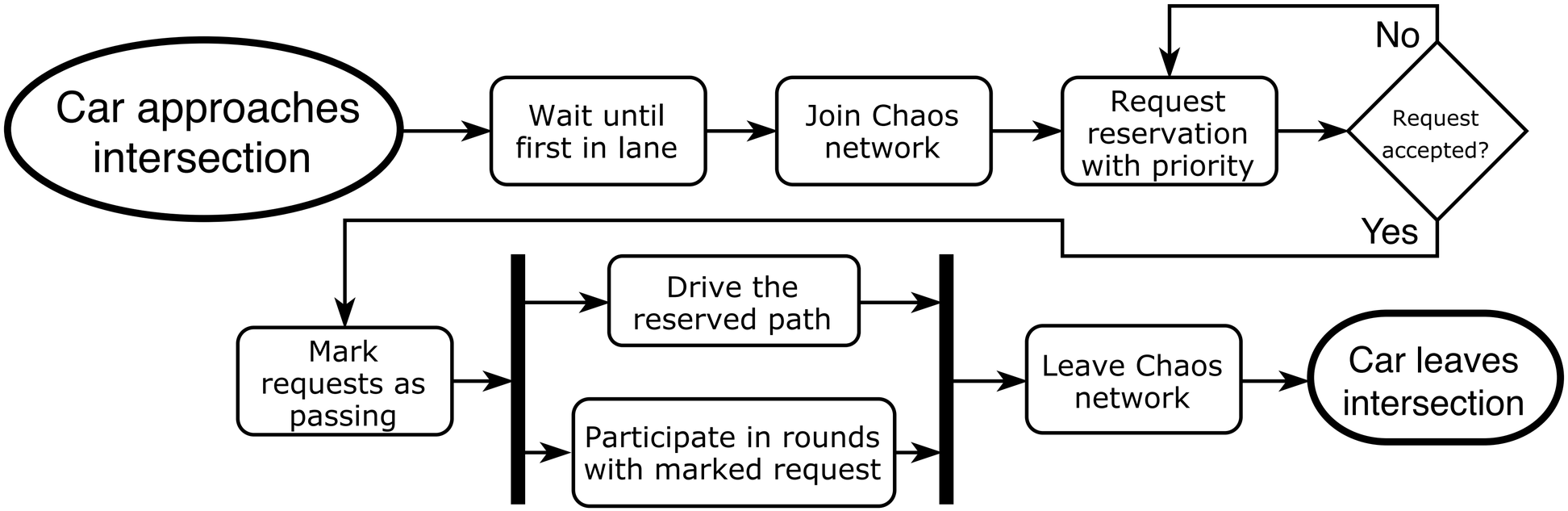
Protocol Flow



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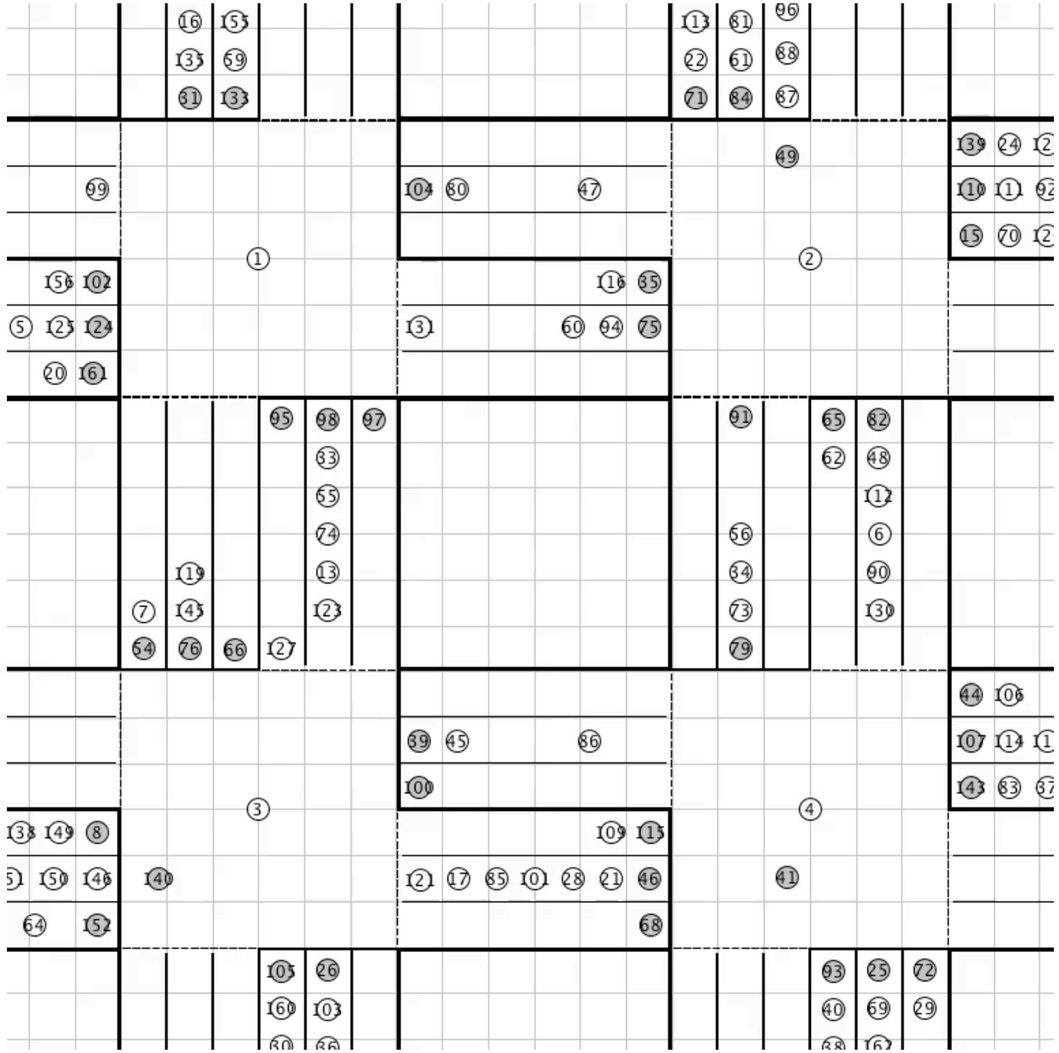
Multiple Intersections Demo



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Real Life Comparison: Westring

www.bing.com/maps

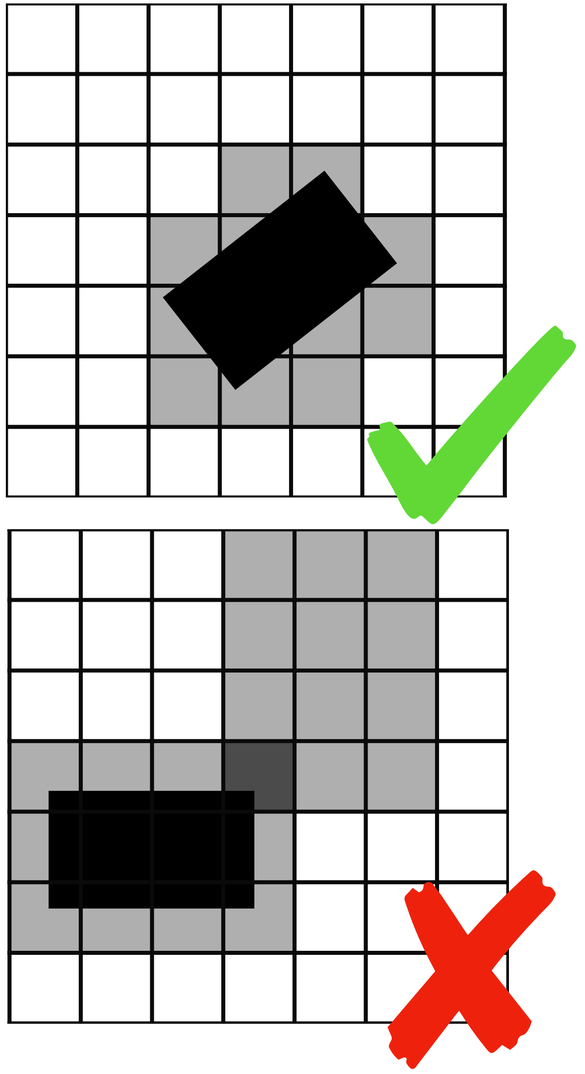
23.08.2012 (rounded)

Daytime	05:00-06:00	06:00-07:00	16:00-17:00
VPH	1100	3600	8000

www.kiel.de/de/kiel_zukunft/kiel_plant_baut/_dokumente_moebel_kraft/gutachten_verkehr_und_erschliessung.pdf

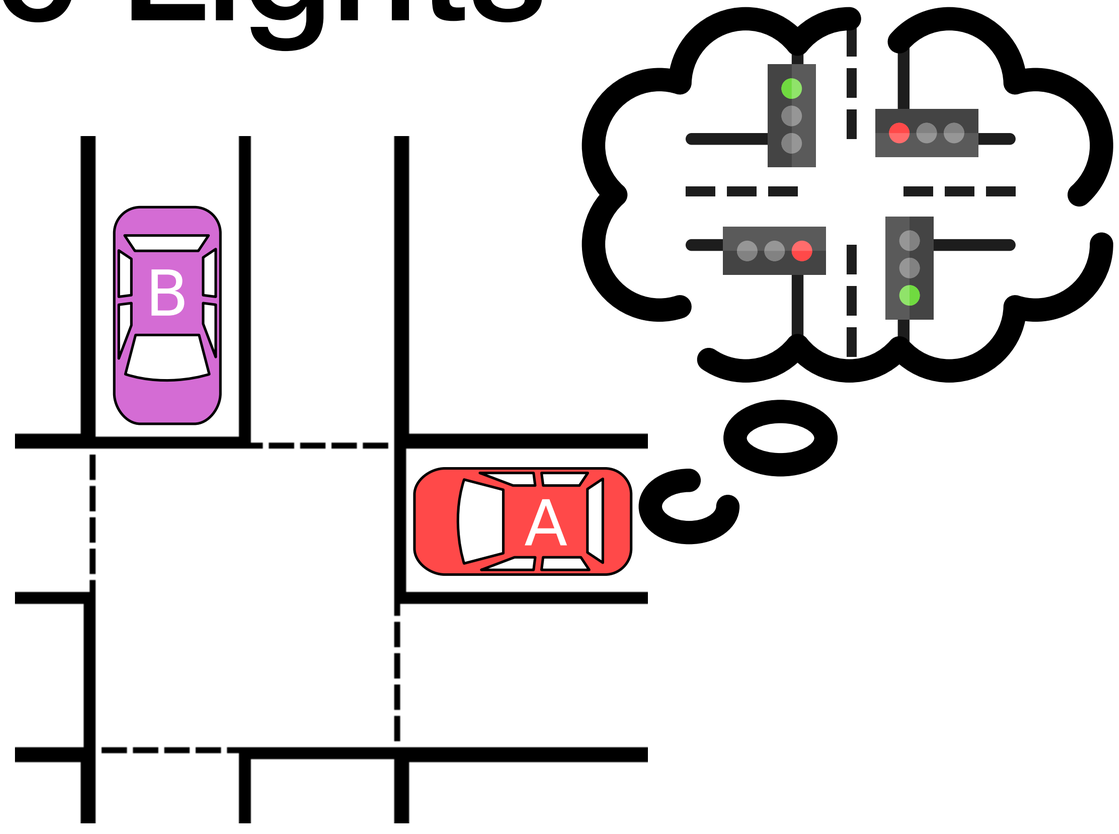
Autonomous Intersection Management (AIM)

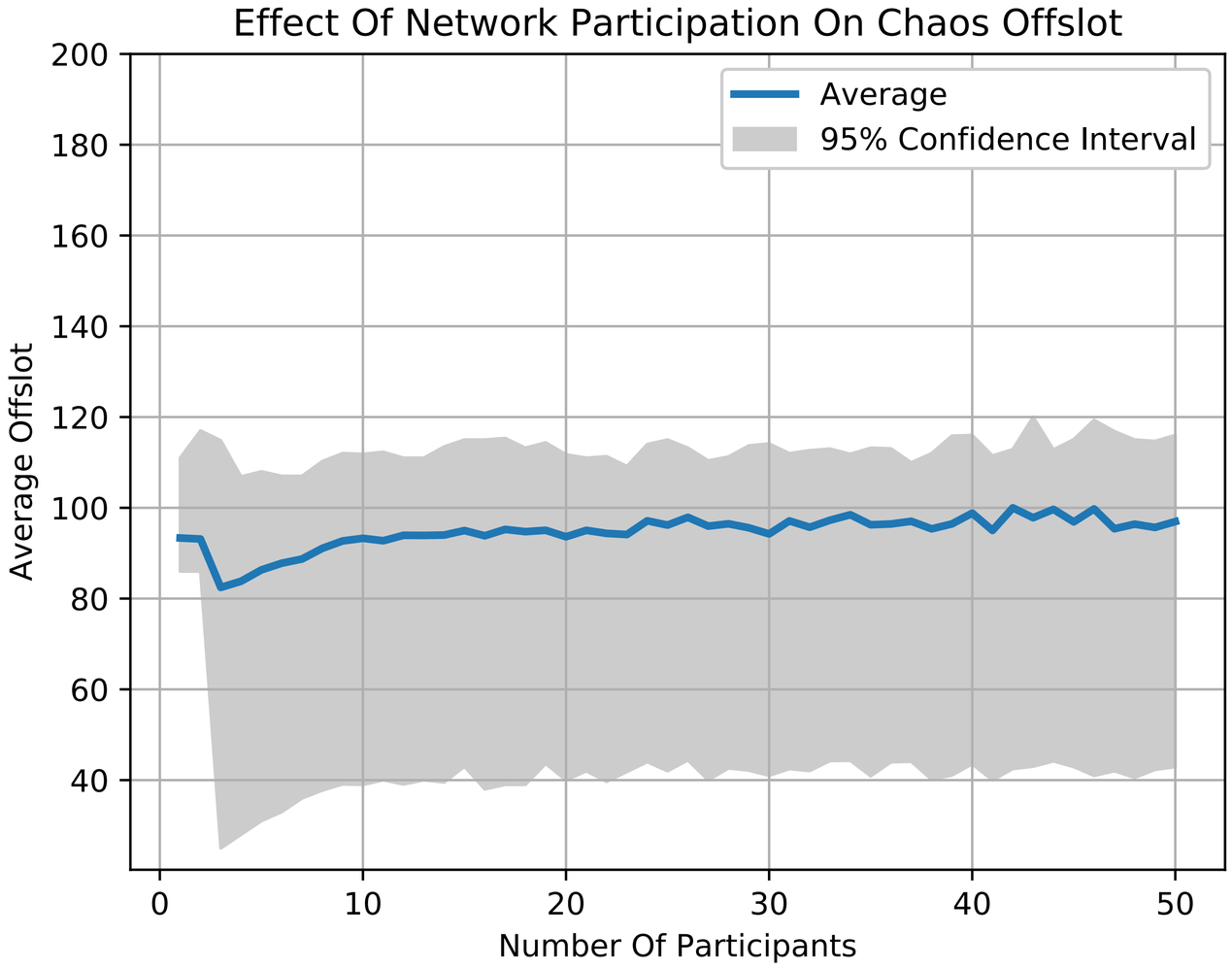
- By Dresner and Stone (2008)
- Utilize precision of autonomous cars
- Central Intersection Manager coordinates movement

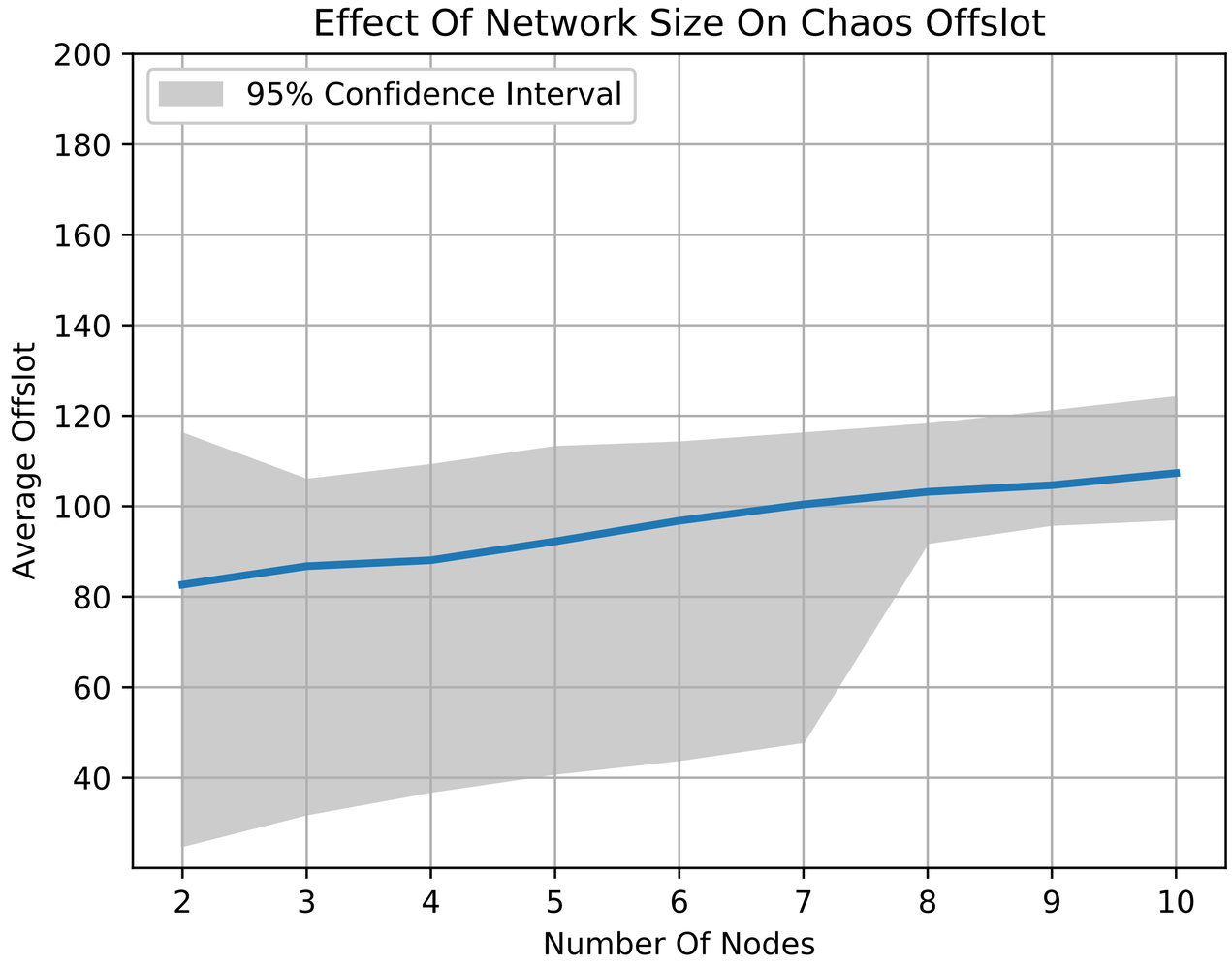


Virtual Traffic Lights

- Traffic lights replaced by messages
- Coordinator manages schedule
- Schedule is transmitted to vehicles
- Coordinator hands over role when passing

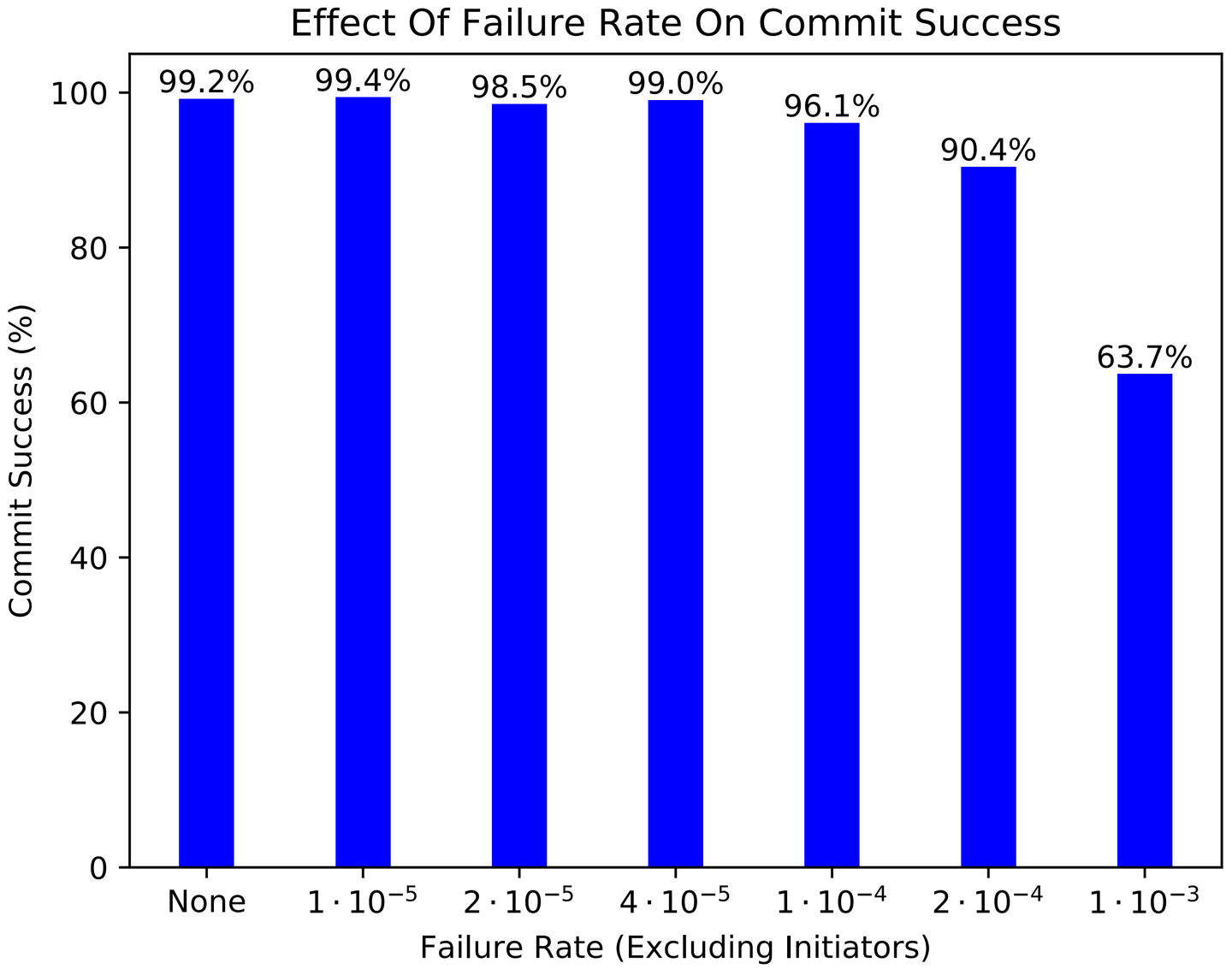



Effect Of Network Participation On Chaos Offslot
Average
95% Confidence Interval
Average Offslot
Number Of Participants
200
180
160
140
120
100
80
60
40
0
10
20
30
40
50


Effect Of Network Size On Chaos Offslot
95% Confidence Interval
Average Offslot
Number Of Nodes
200
180
160
140
120
100
80
60
40
2
3
4
5
6
7
8
9
10

Radio Failures

- Radio failures injected
- Probability to fail at each slot
- For rest of round
- Recovery for next round
- No collisions occurred



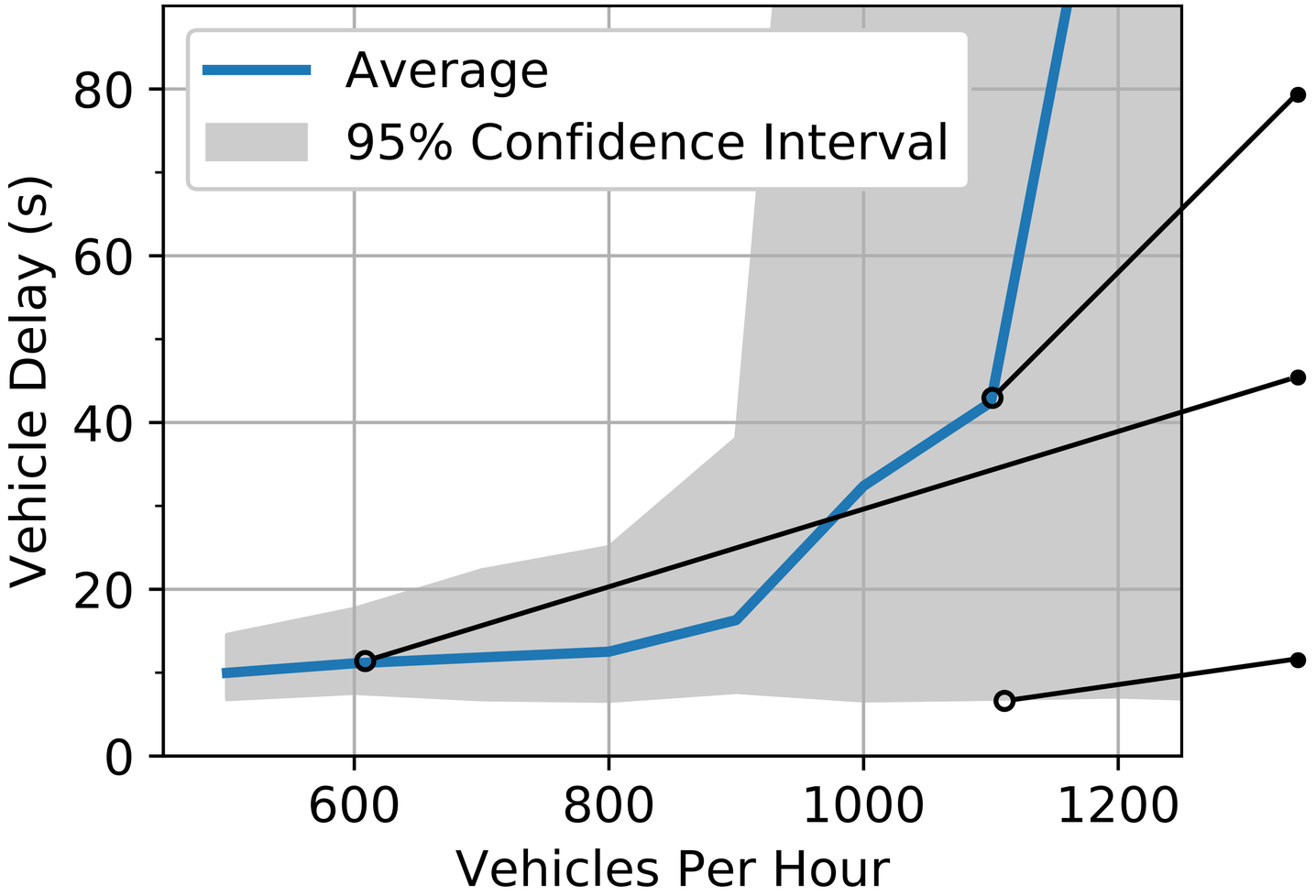
Implementation Details

- Implemented in ContikiOS
- Based on A²-Synchroton implementation
- Scenario simulated by Cooja
- Plugin for physics and vehicle control

Simulation parameters

Acceleration	2 m/s²
Deceleration	4 m/s²
Probability: Left / Straight / Right	15% / 70% / 15%
Chaos interval	2 seconds
Chaos slots per round	200
Maximum network size	16

Efficiency



Increasing with 1000 vph and more

10-20 seconds delay up to 900 vph

Lower confidence bound still low

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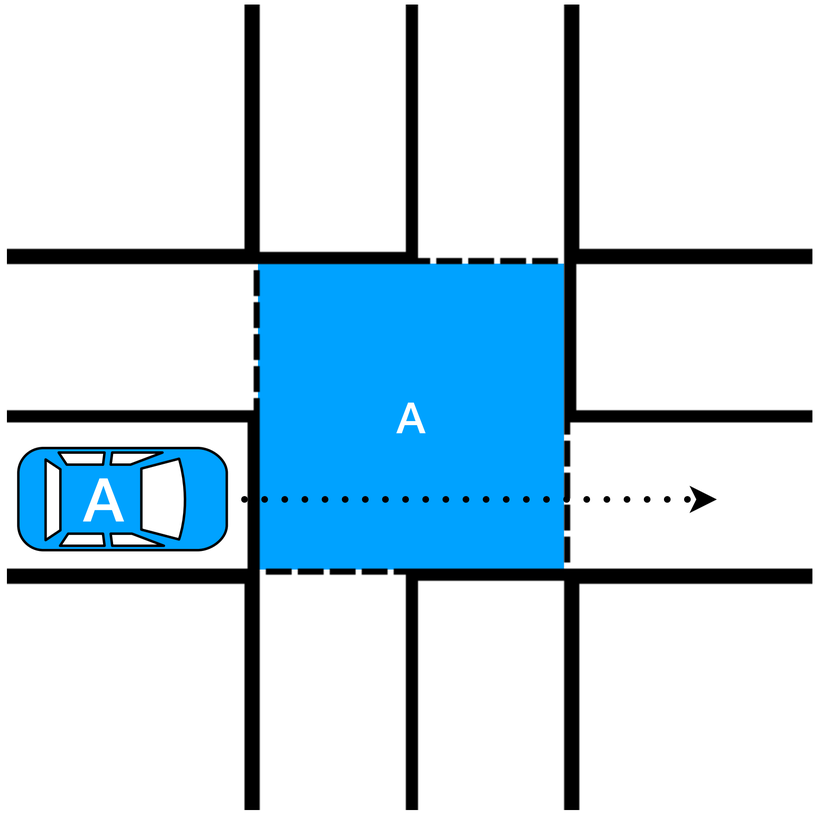
Parameters

Number of lanes	12
Tile-grid	6x6
Max speed	50 km/h
Probability: Left / Straight / Right	15% / 70% / 15%
Chaos interval	2 seconds
Chaos slots per round	200
Maximum network size	16

Reservations



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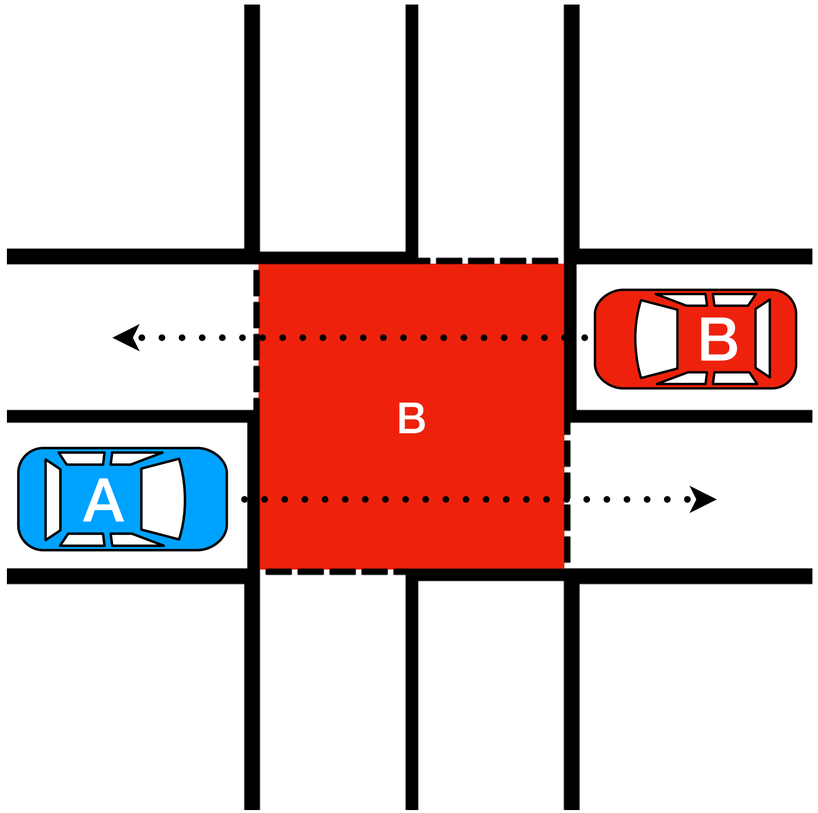
Coordination



Waiting Times

A	1 s
B	2 s

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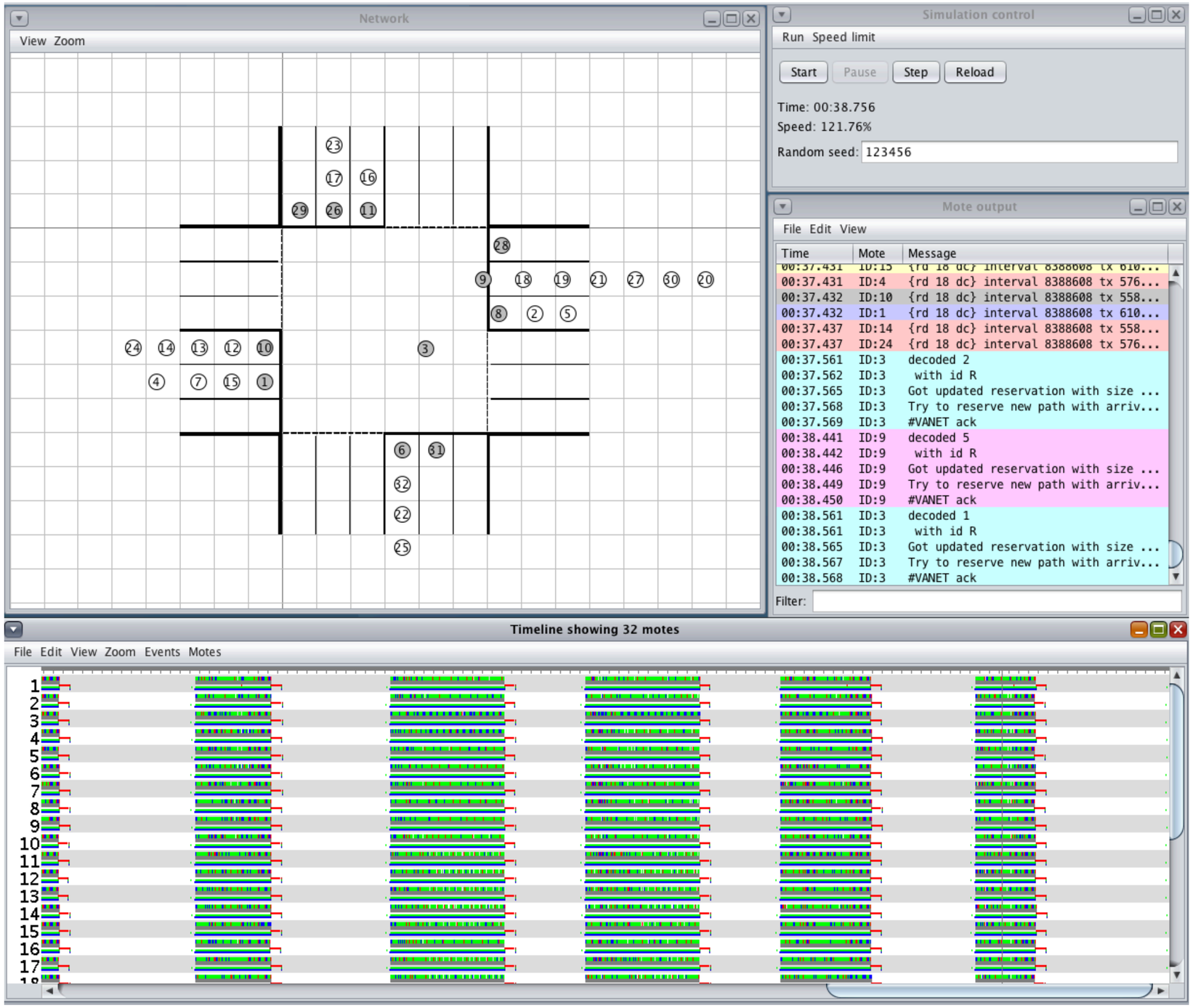

Cooja Simulation Run

IEEE 802.15.4

- Wireless protocol for low-power devices
- Up to 250kbps
- 127 Bytes payload
- Outside coverage up to 100m
- Allows small and cheap transmitters

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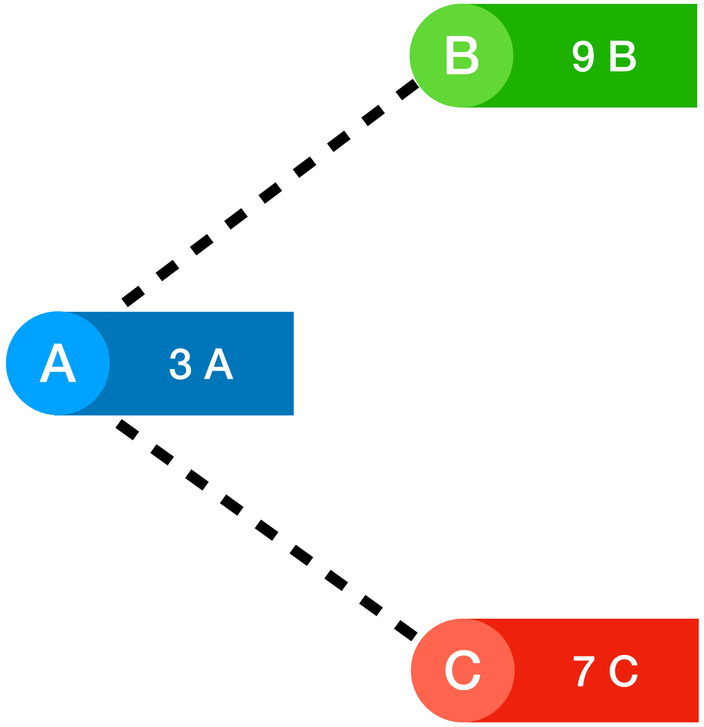
Chaos example: Maximum consensus

- Network and assigned Chaos indices known (A, B, C)
- Node A acts as the initiator
- Each node locally stores its value and participation flags
- **Goal:** Consensus about the maximum value in the network



Chaos example: Maximum consensus

1. Each starts with own flag and value
2. Initiator starts Chaos round
3. Operator application, flag merging
4. Further merging
5. Maximum value determined
6. Maximum is propagated
7. Consensus reached