Self-stabilization and Sensor Networks

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Outline

Sensor Networks and Self-stabilization
- Model(s)
- Cached Sensornet
- Self-stabilizing Unison

TDMA
- Motivation
- Algorithm stack

Clustering
- Density
- Self-stabilizing Clustering
- Simulation Results

Conclusion

Sensor Networks

- processor + sensors + radio
- 2 AA batteries, on/off switch
- 3 LEDs for debugging

Sensor Networks

While (batteries supply power)

- Collect, aggregate and reduce data
- log into memory

In spite of numerous fault modes

- Permanent sensor failures, node failures
- restarts, radio failures
- transient faults, reconfigurations

Distributed Systems

Definition (Classical System, *a.k.a.* Non stabilizing)

Starting from a particular initial configuration, the system immediately exhibits correct behavior.

Definition (Self-stabilizing System)

Starting from any initial configuration, the system eventually reaches a configuration from with its behavior is correct.

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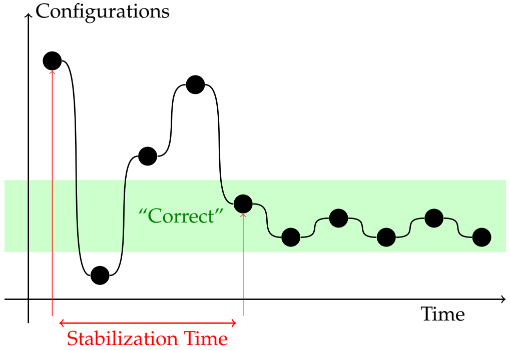
- Self-stabilization permits to recover from transient failures

Self-stabilization



Complexity Criteria

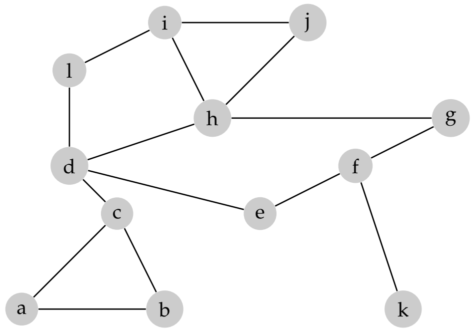
Maximize useful lifetime of system

- "maximise useful": correct quickly from illegitimate state
  - Self-stabilization, scalability
- "maximise lifetime": use minimal energy to preserve batteries
  - local vs. global preserving

System Specifics

- only one radio frequency
- no collision detect
- access technique: CSMA/CA
- use CRC to detect collision
- no directional send/receive
- msg. are small (30 bytes)
- radio range about 1 meter
- number of neighbors < 10
- could be large number of nodes (perhaps > 100000)
- unique node IDs (probably)
- cost a few ¥(someday)
- slow processor (4 MHz)
- limited memory (4 KB RAM)
- item nodes have real-time clocks ≡ drift between 1 msec and 100 msec per second
- several power modes available

The Model(s)



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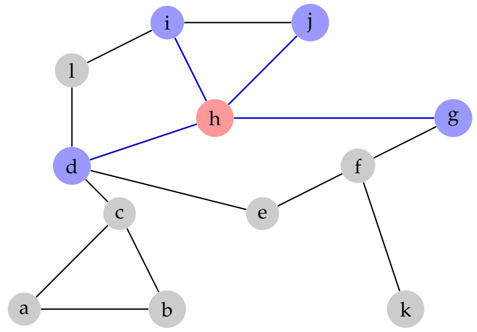

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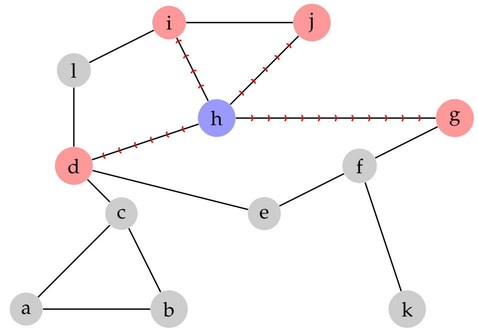

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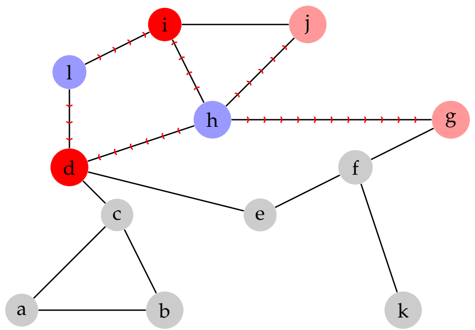

The Model(s)

Self-stabilizing model

- Read neighborhood state,
- compute and update local state

Sensor Network model

- Read local state,
- compute and broadcast to neighborhood
- Collisions may appear

Self-stabilization in Sensor Networks

Transform (i.e. Simulate) the self-stabilizing model into the sensor networks model

- Pros: reuse existing SS algorithms
- Cons: potentially inefficient, overhead

Design self-stabilizing algorithms for the sensor networks model

- Pros: potentially efficient
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Design self-stabilizing algorithms for the sensor networks model

- Pros: potentially efficient
- Cons: ignore previous SS work
- [Herman 03] Unison with collisions

Cached Sensornet Transform

Basic Algorithm

- Each node p has a variable v_p
- Each neighbor q of p has a variable $c_q v_p$
  - $c_q v_p$ is the cached value of v_p at q
- Whenever p assigns v_p, p also broadcasts the new value to the neighborhood
- Whenever a neighbor q of p receives v_p, q updates $c_q v_p$ accordingly

Cached Sensornet Transform

Definition (Cache coherence)

For all neighbors p and q, $c_q v_p = v_p$

Lemma (Closure)

If started from a cache coherent state, and without collisions, the self-stabilizing model is simulated by replacing all occurrences of $c_q v_p$ by v_p

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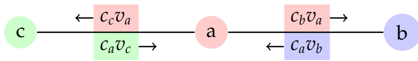

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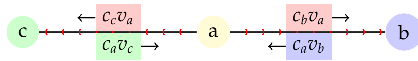

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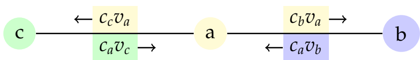

Cached Sensornet Transform

Periodic retransmit

- Each node p periodically broadcasts v_p to its neighborhood

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If started from an arbitrary state, and without collisions, a cache coherent state is eventually reached

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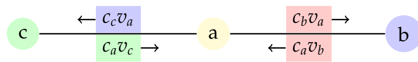

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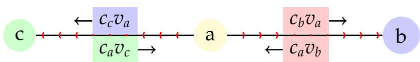

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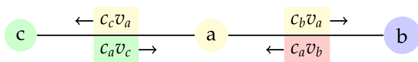

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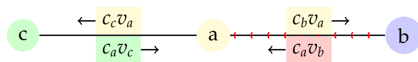

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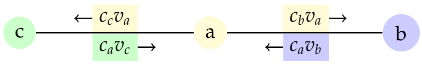

Cached Sensornet Transform

Message Corruption

- Each neighbor q of p has a Boolean variable $b_q v_p$
- If q receives v_p correctly, $b_q v_p$ becomes true
- $G \to A$ becomes
  for all neighbors q of p, $b_p v_q$ and $G \to A$; for all neighbors q of p, $b_p v_q$ becomes false

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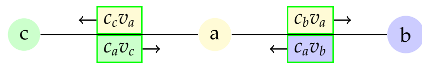

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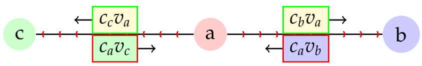

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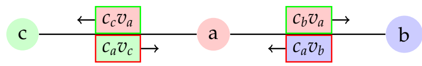

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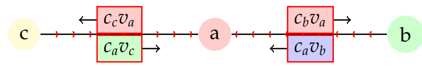

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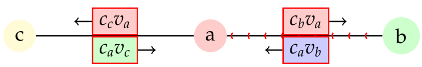

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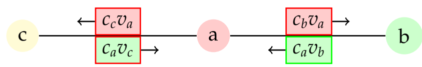

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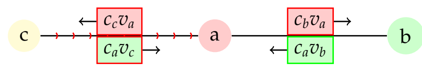

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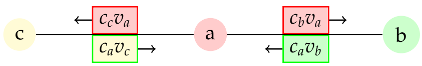

Cached Sensornet Transform

Periodic Retransmit

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If started from an arbitrary state, the self-stabilizing model is eventually simulated

Self-stabilizing Unison

Specification

- Each node p has a clock variable v_p
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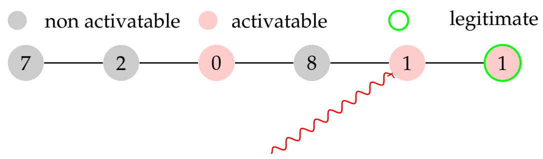

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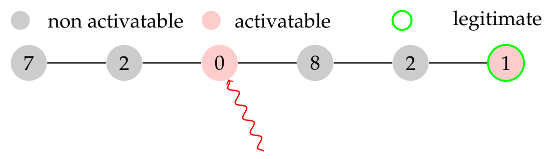

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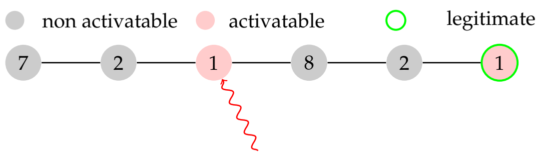

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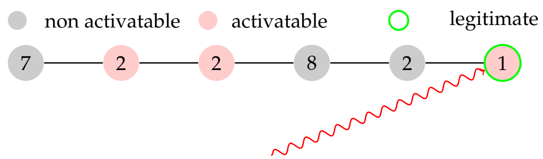

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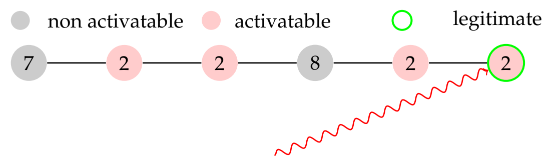

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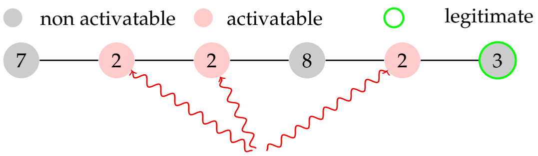

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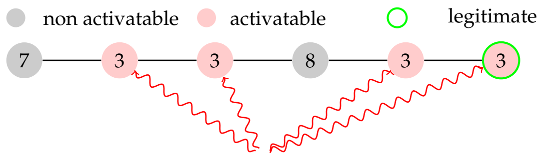

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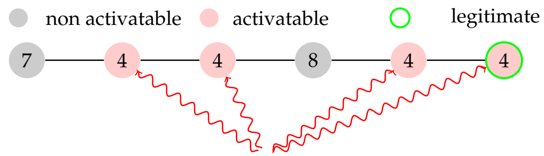

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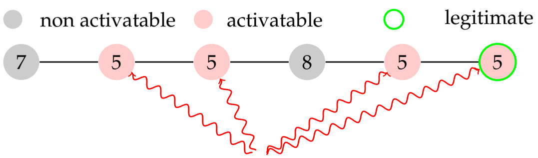

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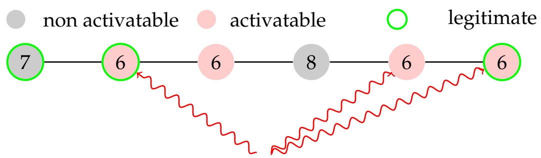

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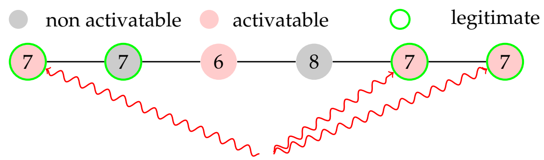

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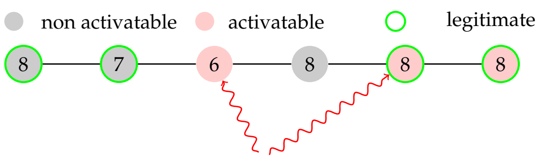

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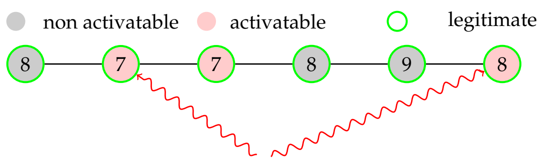

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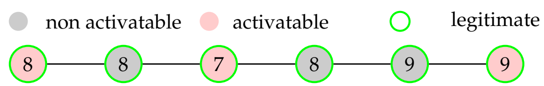

Unison with Collisions

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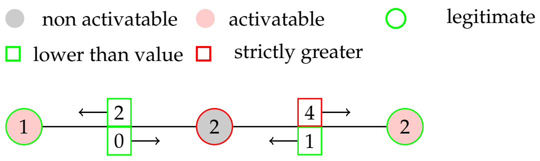
Self-stabilizing Unison with Collisions

- for every neighbor q, $c_p v_q \geqslant v_p \to v_p := v_p + 1$
- Only correctly received messages update cached variables

Example



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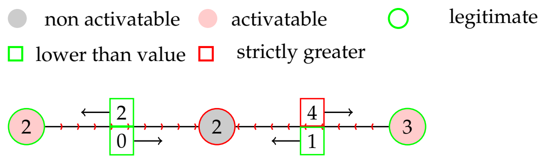

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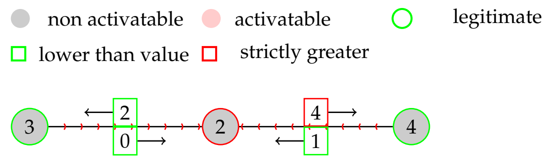

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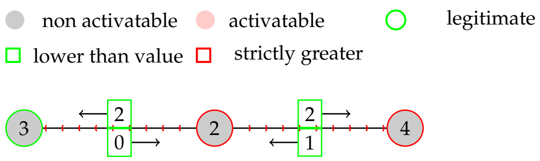

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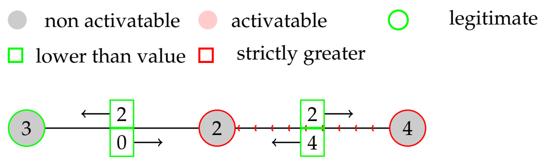

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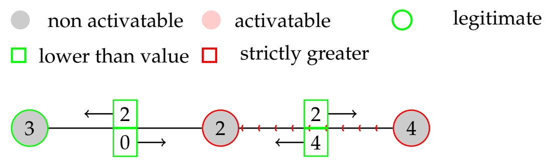
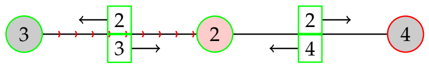


Example

non activatable   activatable   legitimate

lower than value   strictly greater



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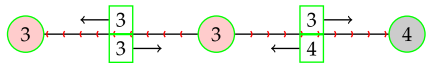

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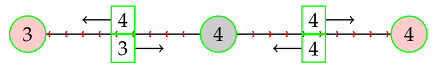

Unison with Collisions

Cache coherence weakening

- For every neighbors p and q, $c_p v_q \leqslant v_q$

Self-stabilizing Unison with collisions

- Unison and Weak cache coherence are preserved by program executions
- Unison and Weak cache coherence eventually hold
- Some extra work is expected to get bounded clock values

Self-stabilization in Sensor Networks

Transform (i.e. Simulate) the self-stabilizing model into the sensor networks model

- [Herman 03] Cached Sensornet Transform
- Overhead is not upper bounded

Design self-stabilizing algorithms for the sensor networks model

- [Herman 03] Unison with collisions
- Proof in the model is specific to the problem