Energy efficient MAC protocols for Wireless Sensor Networks

Andri Toggenburger
tandri@student.ethz.ch

14.12.2004

Overview

- Introduction to Sensor Networks
- „A Distributed TDMA Slot Assignment Algorithm for Wireless Sensor Networks“
  - Goals
  - Model
  - Algorithm
- Conclusion

Wireless Sensor Networks: The Beginnings

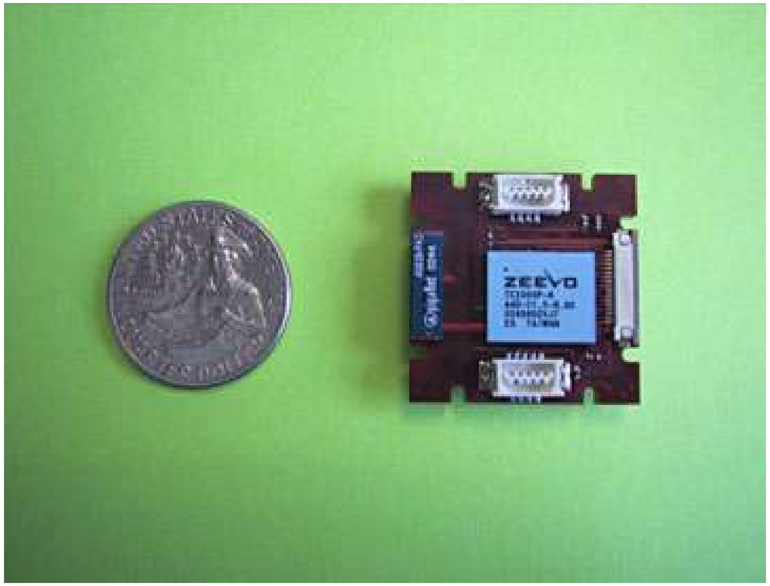
- DSN (Distributes Sensor Network) project of DARPA, 1985
- Acoustic sensors
- Includes quiet diesel generator (power for days)
- 4 computers to process data (256 KB RAM)
- No dynamic topology

Mobile Node

Equipment Rack

Wireless Sensor Networks: Today

- Intel Mote prototype
- Includes antenna for Bluetooth
- 12 Mhz processor
- Operation time: up to several months with AA Batteries (larger than sensor itself)
- Ad-hoc networking



Wireless Sensor Networks: Future?

- „Smart Dust“
- Size: like a grain of sand
- Solar powered
- Ad-hoc, P2P
- 1000's of nodes
- Price: below 1$

Wireless Sensor Networks: Technical Problems

- Limited hardware resources
  - Computing power
  - Memory
  - Communication power
  - Power supply
- Ad-hoc networking: node failure, dynamic topology, **M**edia **A**ccess **C**ontrol (MAC)

A Distributed TDMA Slot Assignment Algorithm for Wireless Sensor Networks

Ted Hermann and Sébastien Tixeuil

ALGOSENSORS 2004

Goal

MAC protocol which has the following properties:

- Distributed computation
- Self-stabilizing
- Expected local convergence in time O(1)
- Fairness among nodes
- Energy conservation

Why TDMA?

- Fairness
- No collisions
- Scheduled slots
  - Nodes can turn off their power

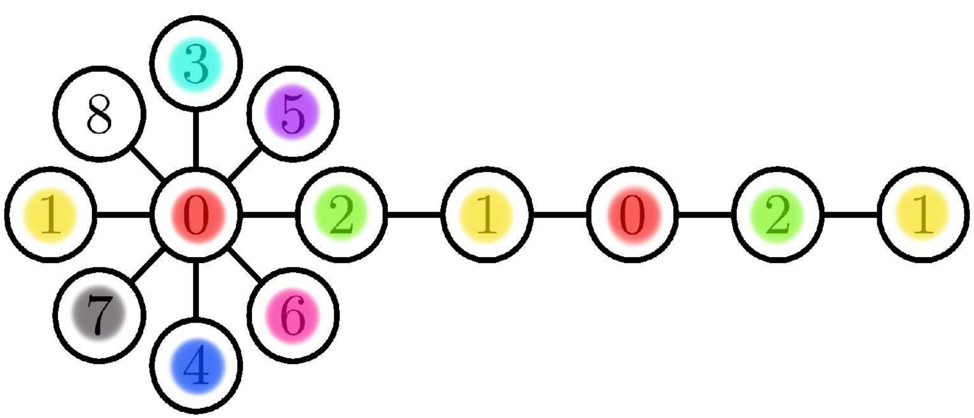
But recent work shows:

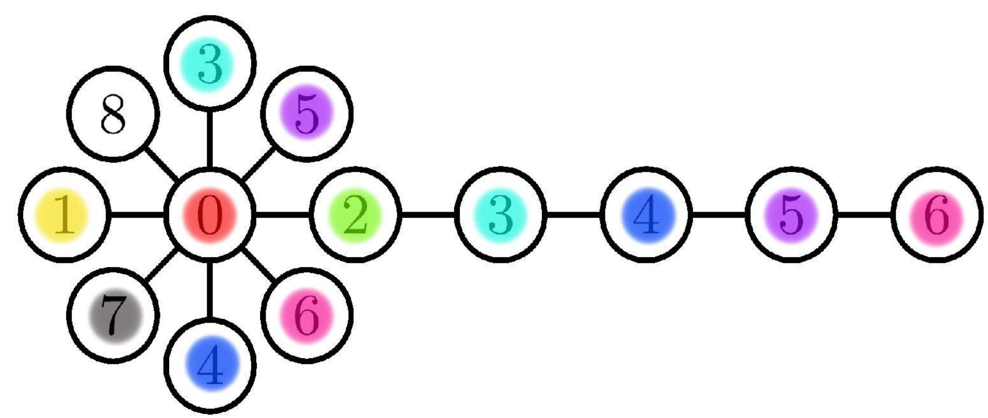
- TDMA may not improve bandwith compared to other MAC protocols.

Graph Coloring and TDMA slot assignment

Distance-two coloring:

- No nodes within distance two have same color
- Can be used to assign time slots
- Different solutions possible:

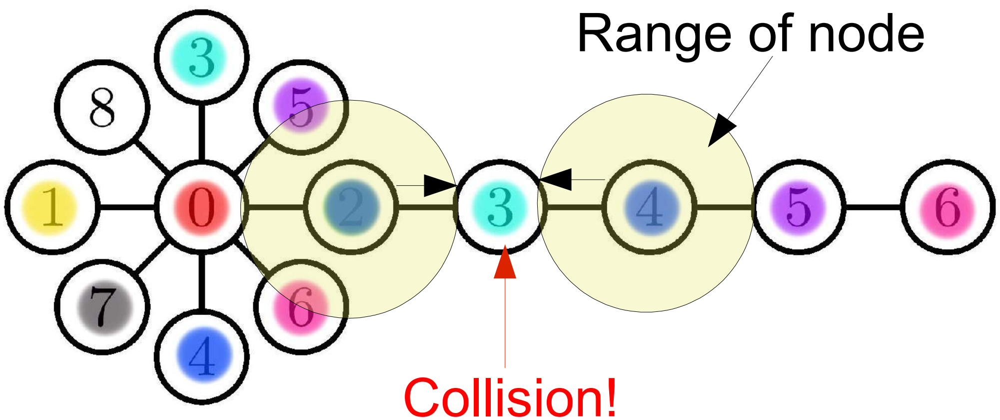




Graph Coloring and TDMA slot assignment

Distance-one coloring:

- does not work because of the „Hidden Terminal Problem“



Wireless Network Model

- Synchronized clocks
- All nodes use the same frequency
- Node density is upper-bounded

- Infinite repetition of the algorithm at each node
- Shared variables among nodes, updated by messages.
- CSMA / CA slot for reservation of TDMA slots

Wireless Network Model

- Neighborhood of a node p at distance i:

$$N_p^i \qquad |N_p| \leqslant \varrho$$

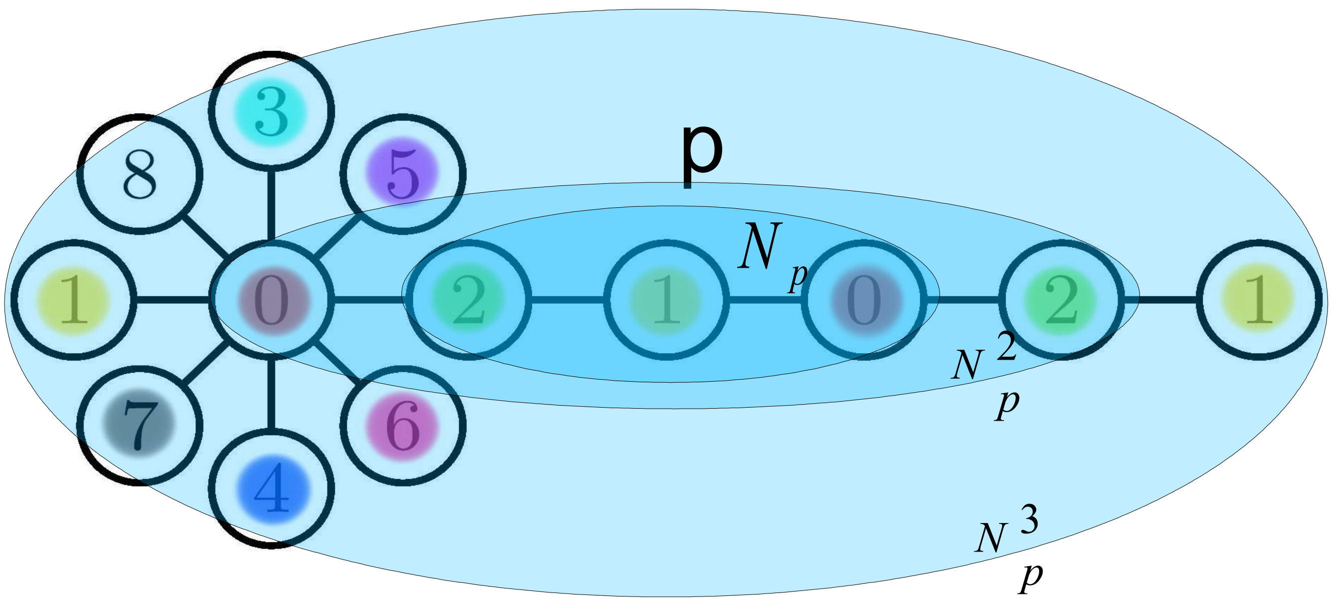
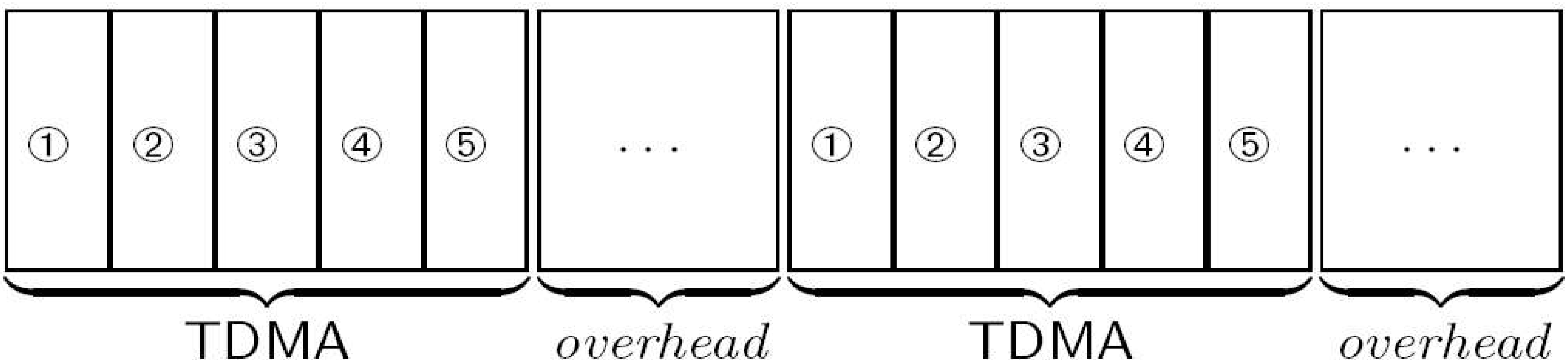


Illustration of a schedule

Final result schedule should look like this:



5 Algorithms to accomplish TDMA

1. Neighborhood identification
2. Neighborhood-unique naming
3. Leaders via maximal independent set
4. Leader assigned minimal coloring
5. Assignments of time slots from colors

Neighborhood identification

Goal: Learning of N_p^2 and N_p^3

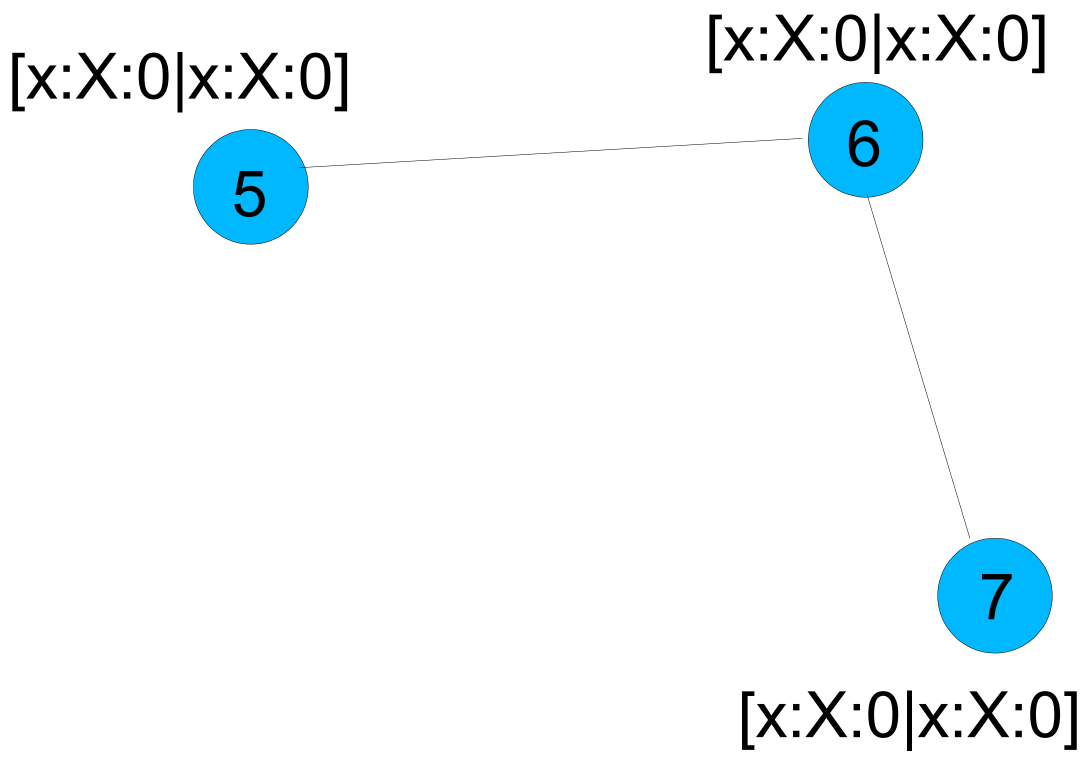
- Shared List *L* with pairs *(a:A)*, where *a* is an id and *A* is a list of id's.
  (*A* = list of nodes known by *a*)
- List L_p: *L* augmented by an age value for each element
- *MaxAge*: maximum age of a list entry

Neighborhood identification

- N0: receive mN(a,A) ⇨ update(L_p,a:A\{p})
- N1: drop old entries in L_p
- N2: send mN(p,neighbors(L_p))

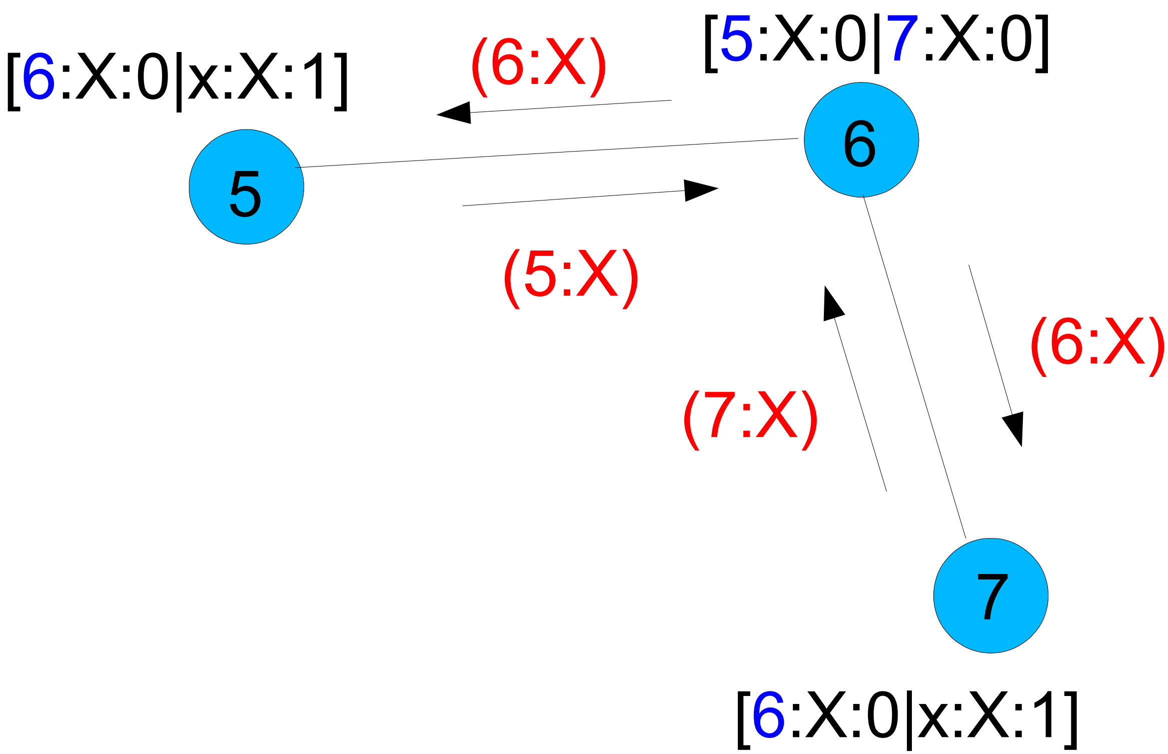
Neighborhood identification

- A simple example:



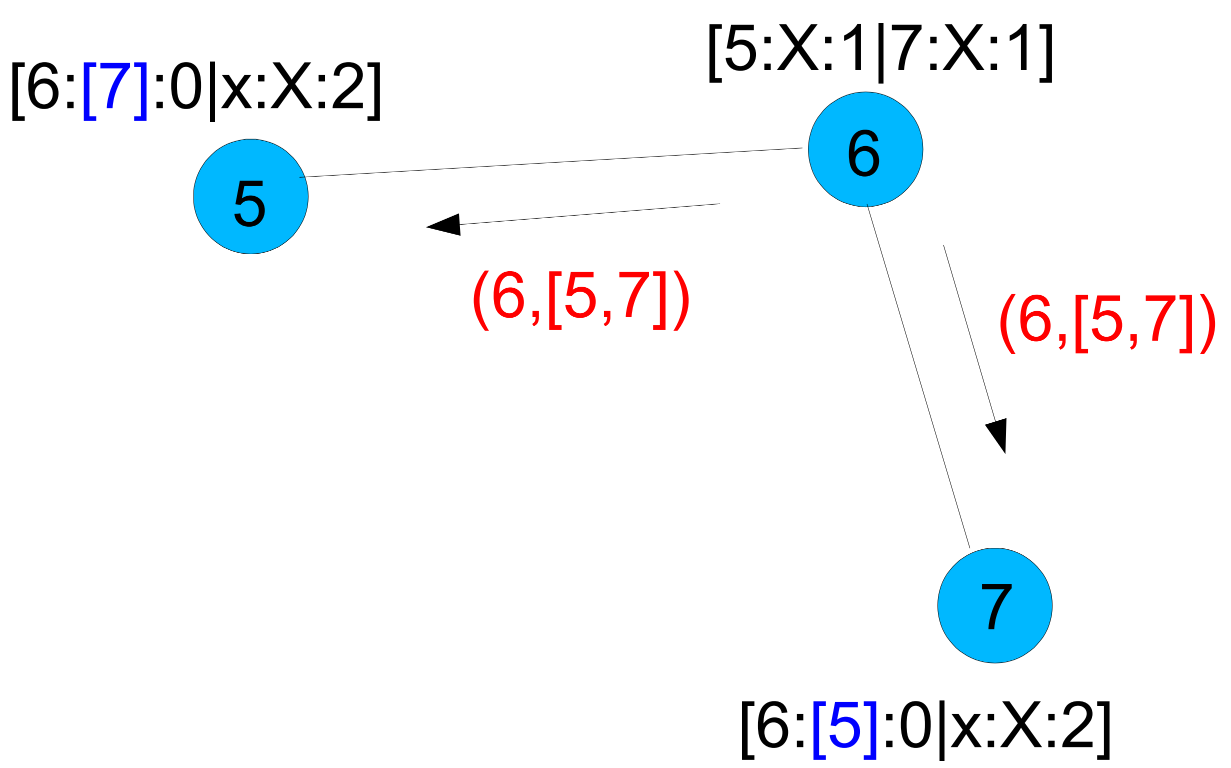
Neighborhood identification

- After round 1:



Neighborhood identification

- After round 2:



Neighborhood-unique naming

Goal: Each node in N_p^3 has unique id

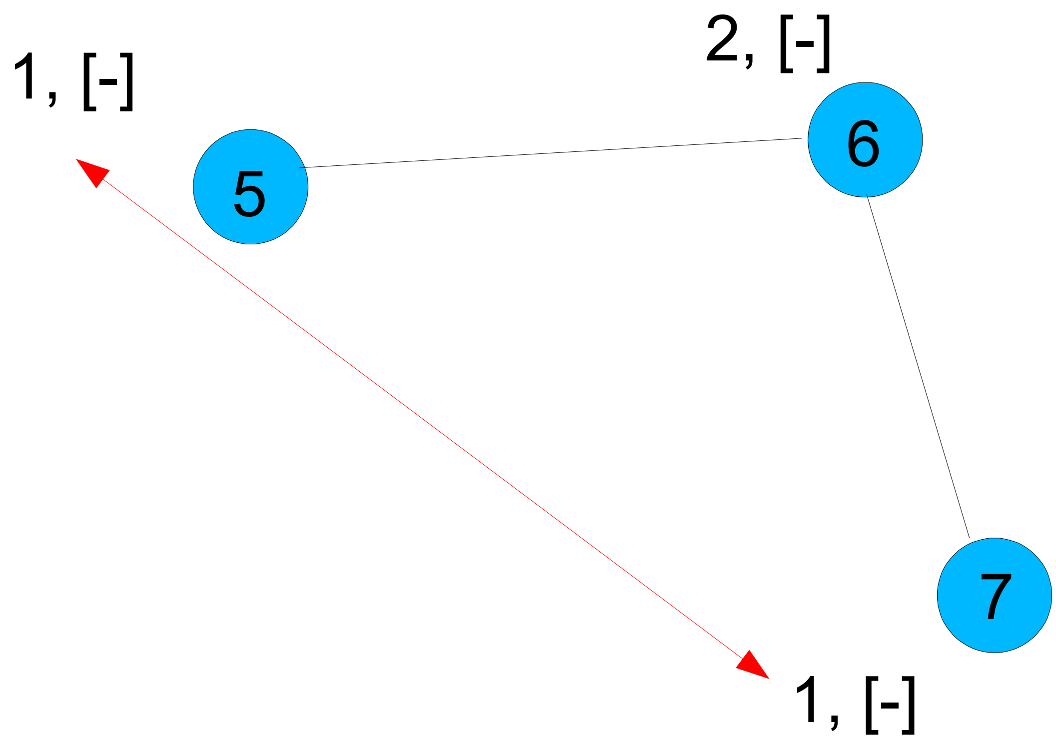
- Smaller and constant name space (as compared to physical addresses)
- Provides (no good) solution for graph coloring

Neighborhood-unique naming

- Namespace: $\Delta = \varrho^{t}, t > 3$
- Every node stores set of latest known ids of all neighbors (ϱ^{3} entries)
- Node keeps id if no other node has the same id
- Node changes id to random id if other node has same id

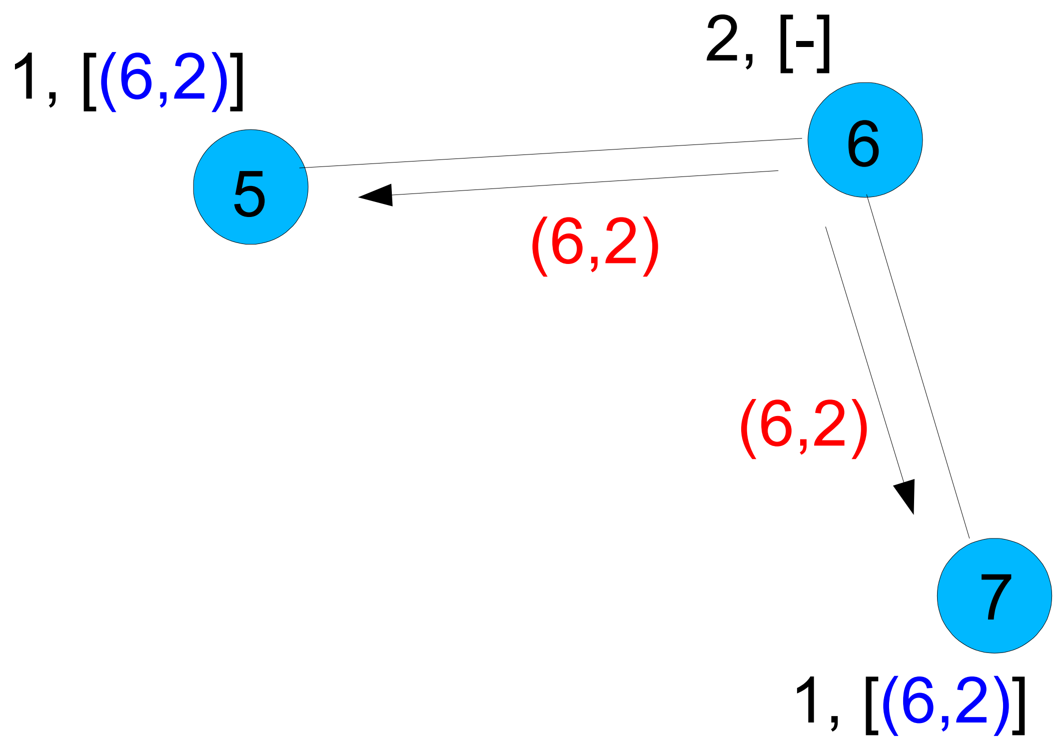
Neighborhood-unique naming

- A simple example, $\Delta=16, \varrho=2, t=4$



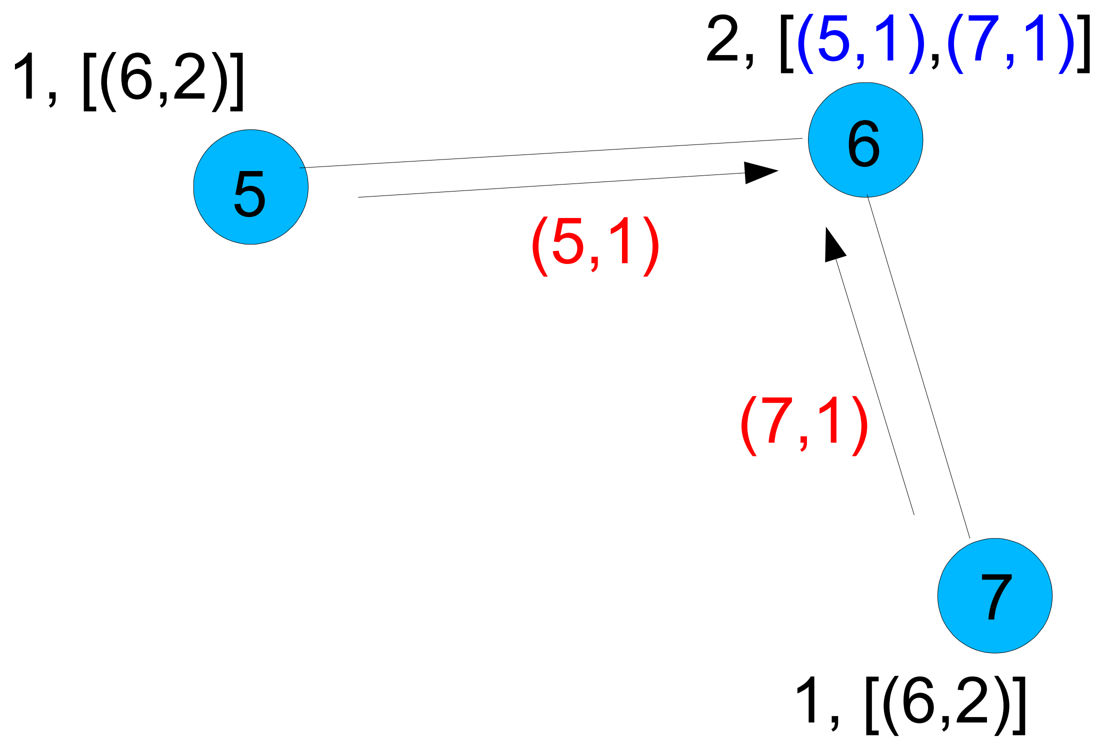
Neighborhood-unique naming

- After round 1:



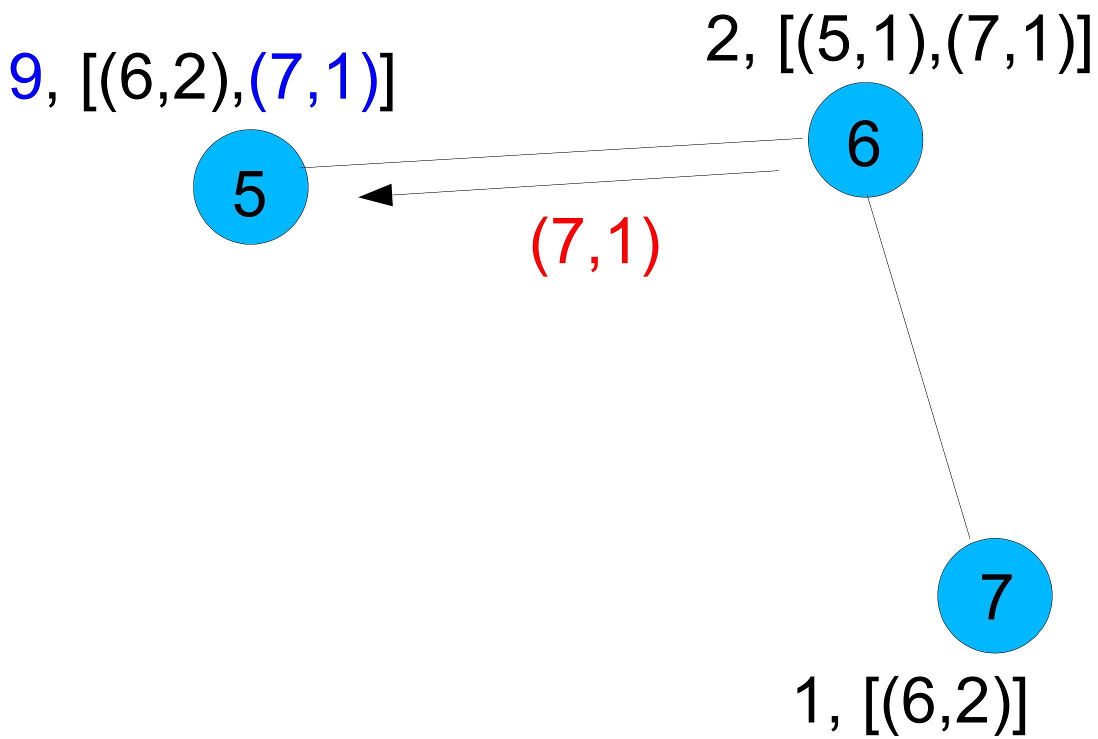
Neighborhood-unique naming

- After round 2:



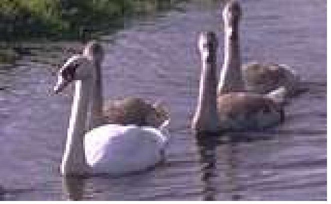
Neighborhood-unique naming

- After round 3:



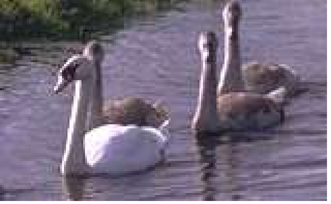
Neighborhood-unique naming

- And so on...
- Once the name of a node is established (=unique) in all 3-neighborhoods a node is part of, it stays fixed!
- Algorithm self-stabilizes with probability 1 and has constant expected local convergence time
  - What about propagation of name changes through the whole network?



Leaders via Maximal Independent Set

- Simple distance-two coloring algorithms use too many colors, so leaders dictate color of nearby nodes.
- A Maximal Independent Set of the graph gives the leaders.
- An independent set *I* of a graph *G* is a set of nodes such that no two nodes in *I* are neighbors.



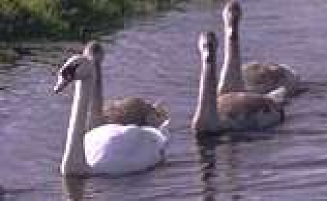
Leaders via Maximal Independent Set

Algorithm for a node p:

(Flag Lp: leader flag of node p)

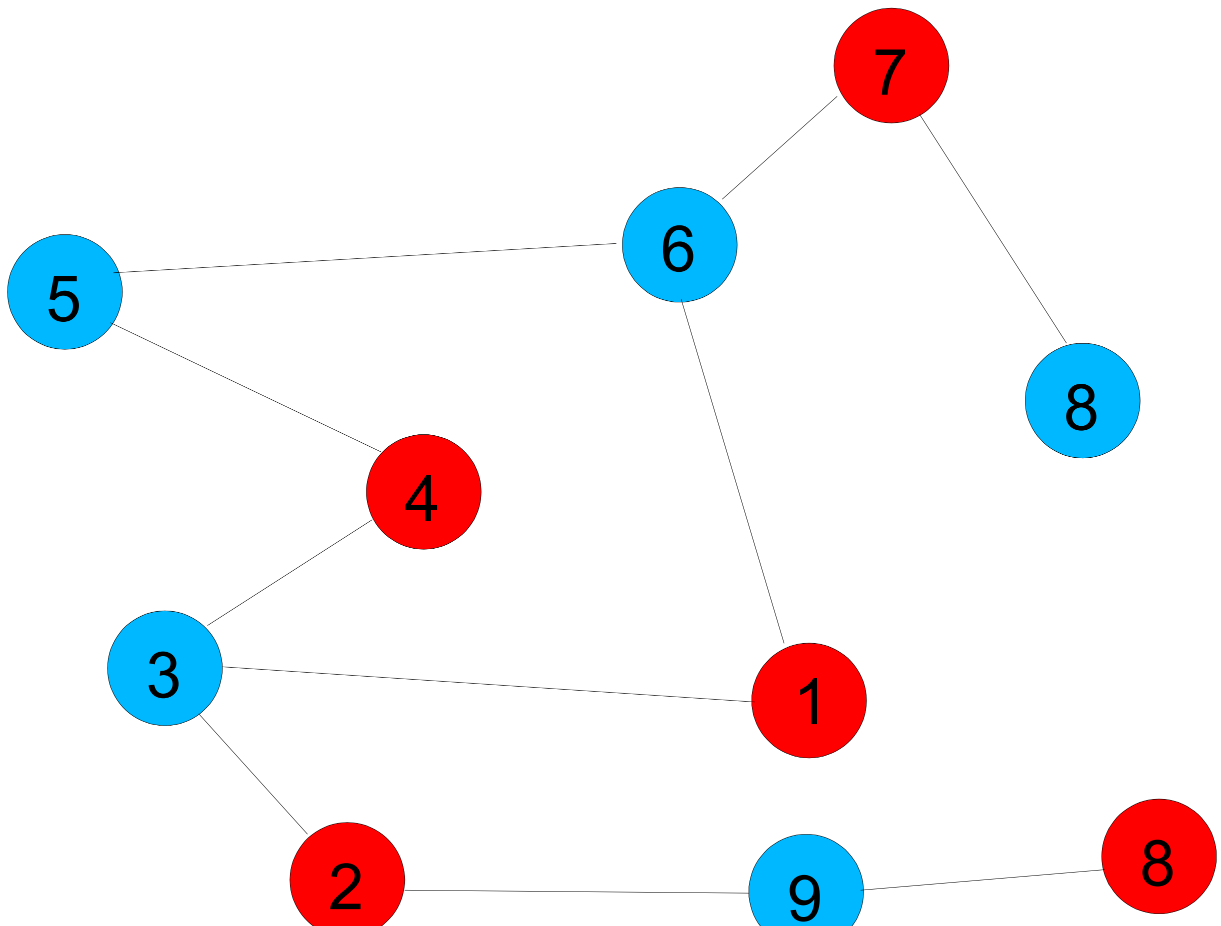
- Set *Lp* to true if all neighbors have larger id.
- If there is a neighbor which is leader and has smaller *id*, set *Lp* to false.
- If all neighbors with smaller id have their leader flag cleared, set *Lp* to true.

Solution converges to a maximal independent set.



Leaders via Maximal Independent Set

An example graph with marked leaders



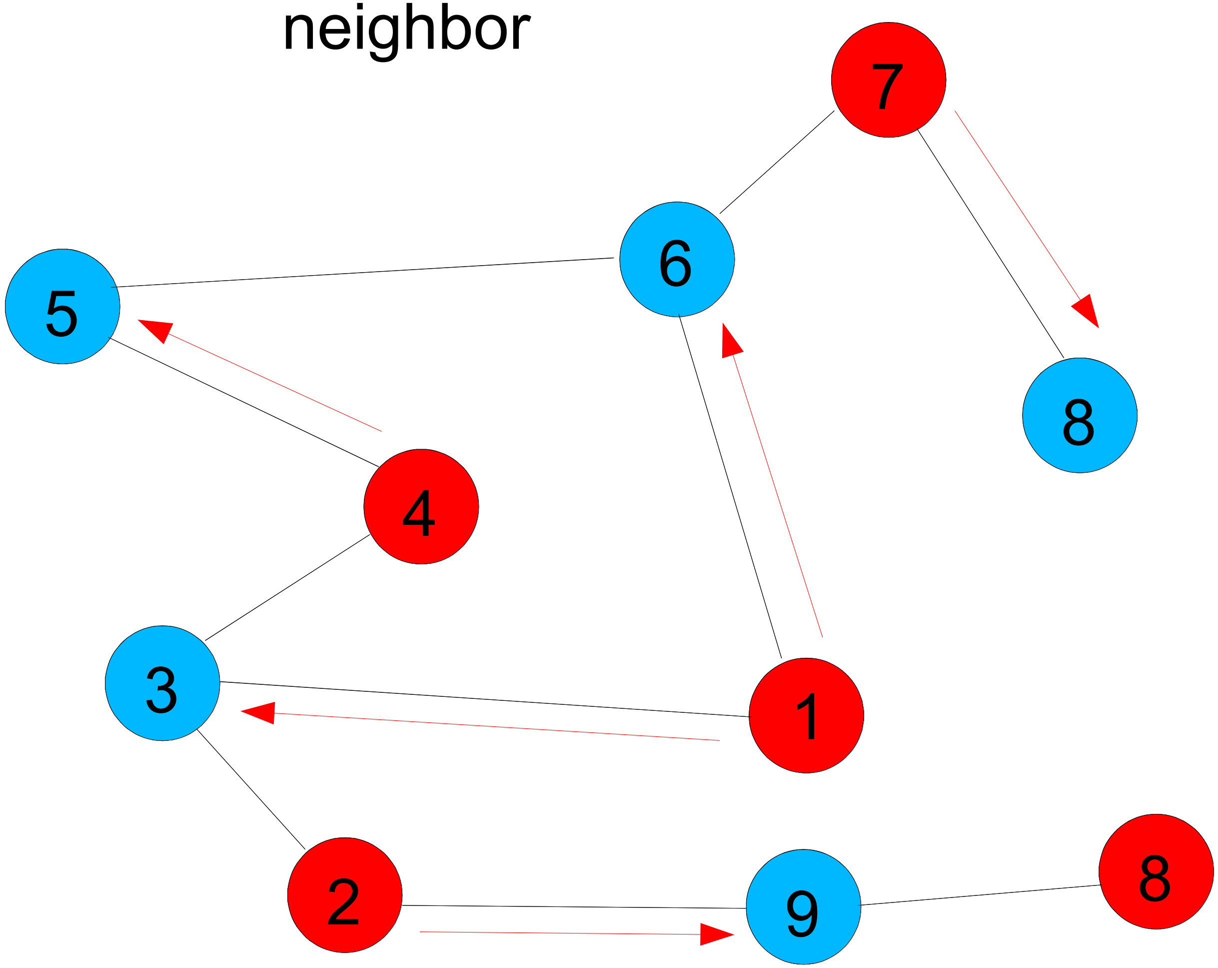
Leader assigned coloring

- Leaders assign colors to their neighbors and themselves.
- Each leader has list of preferred colors for each node in its neighborhood (shared variable).
- A node chooses a color in the cached color list of the leader with the smallest id in its neighborhood.
- Leader chooses color for a node from colors which haven't already been assigned by leaders with smaller id's somewhere in 2-neighborhood.
  - every non-leader stores colors of its neighbors and leader id which assigned them in a shared variable

Leader assigned coloring

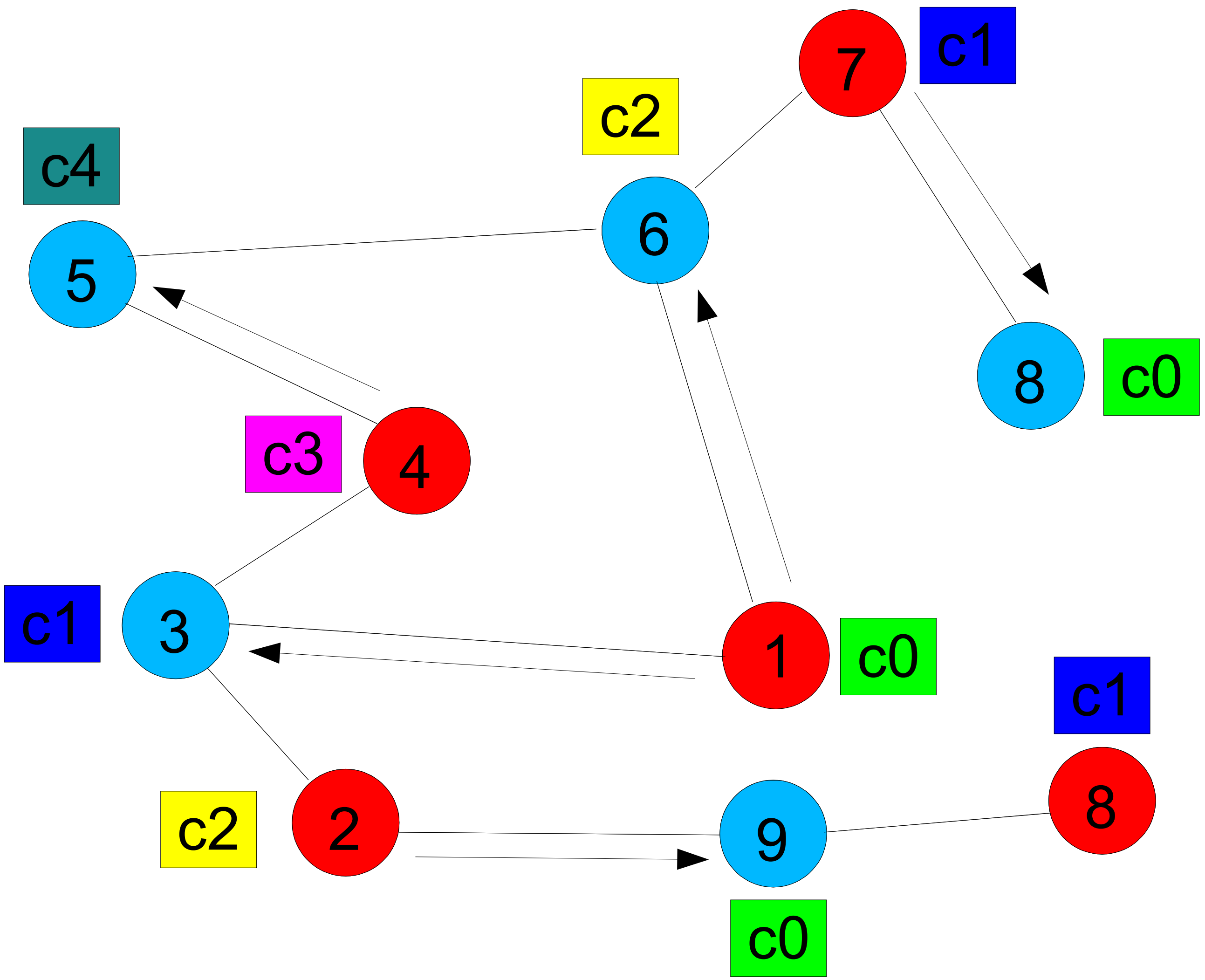
Example

Arrows: assignment of color from minimum leader to a neighbor



Leader assigned coloring

Example Coloring which needs 5 colors from c0 to c4

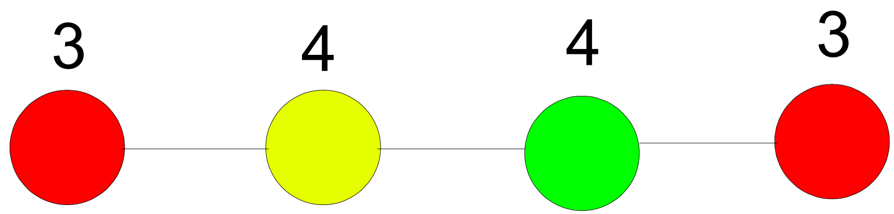


Assigning Time Slots from Colors

- Actual number of colors used is not available in a global variable
- Each node should have about as much bandwith as any other node in 2-neighborhood → fairness
- Allocate slots to nodes beginning with the most constrained to the least constrained in order not to waste bandwith

Assigning Time Slots from Colors

2-neighborhood:



Max. Bandwith:	1/3	1/4	1/4	1/3
Assignment in correct order:	[2/3,1]	[0,1/4]	[1/4,1/2]	[2/3,1]
Assignment in wrong order:	[0,1/3]	[1/3,1/2]	[1/2,2/3]	[2/3,1]

Assigning Time Slots from Colors

Algorithm (iterative)

- **Count number of colors in 2-neighborhood and store it in „*base*“** (gives upper bound on available time)
- Learn about time intervals chosen by nodes in 2-neighborhood which have larger „base“
- Choose as much time intervals which haven't already been assigned to reach maximum „1/base“

Conclusion

- 5 algorithms running in combination
- Probalistically self-stabilizing solution to the problem
- O(1) local convergence time for every algorithm and consequently whole process in expectation
- Global convergence time? Suspected to be sublinear

Conclusion

- Relies on synchronized clocks
- How to decide on the length of the CSMA / CA slot?
  - And: percentual size of the CSMA / CA slot?
- Algorithm assumes bidirectional communication
- Simulation would be nice:
  - Length of CSMA / CA slot could be ascerted.
  - No statements about actual amount of energy which is saved

Thank you for your attention

Please feel free to ask question!