

# CSMA

Carrier sense multiple  
access

No external  
reference

# TDMA

Time Division Multiple  
Access

More predictable  
communication

**What is possible?**

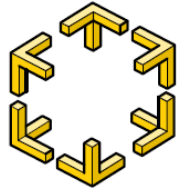
More predictable  
communication

?

No external  
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**What is impossible?**

# Chalmers University of Technology



Distributed Computing and Systems  
**Chalmers university of technology**

## Self-stabilizing TDMA Algorithms for Wireless Ad-hoc Networks without External Reference

**Elad Michael Schiller**

Joint work with Thomas Petig and Philippas Tsigas

IEEE VTS Workshop on Wireless Vehicular Comm., Halmstad, Nov. 20, 2013

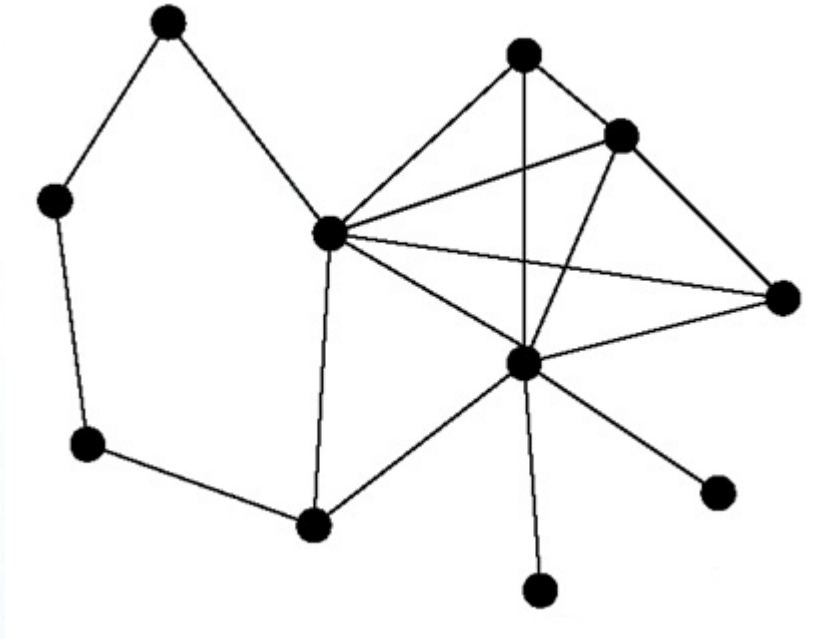
Also appeared in SSS'13.

# Outline

- The Problem
- Our Contribution
- Lower Bound
- Algorithms
- Extensions and Implementation
- Conclusions

# The Problem

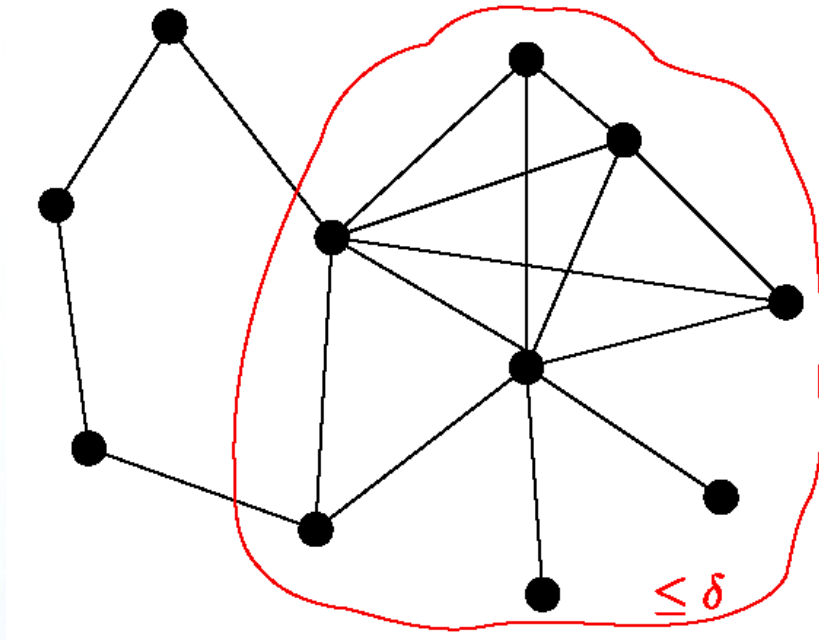
Given a communication graph:



- construct a self-stabilizing, distance-2 coloring for TDMA slot location.

# The Problem

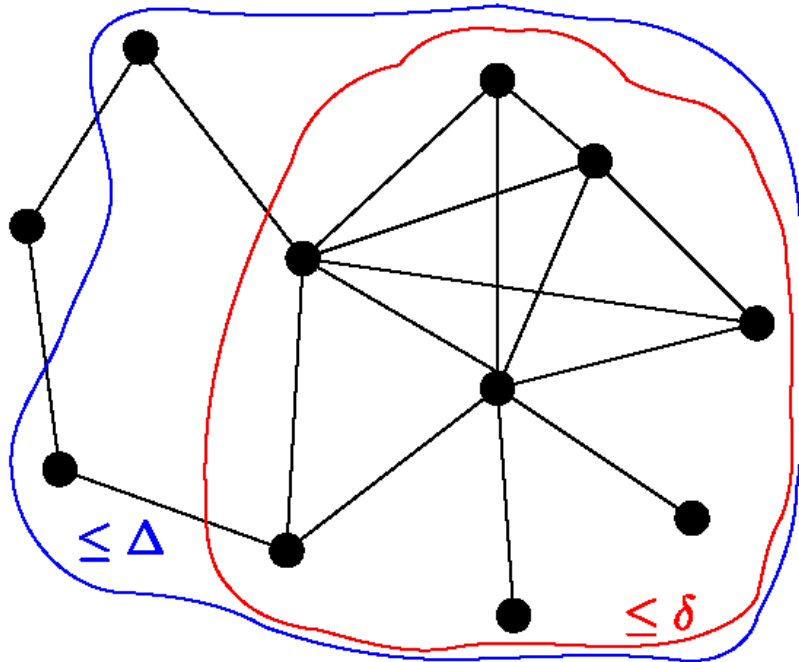
Given a communication graph:



- construct a self-stabilizing, distance-2 coloring for TDMA slot location.

# The Problem

Given a communication graph:



Note that:  $\Delta \in O(\delta^2)$

- construct a self-stabilizing, distance-2 coloring for TDMA slot location.



# The Challenge

- **Collisions**: concurrent transmissions might lead to packet omission.
- We do **not** consider:
  - external **time** reference [Herman-Tixeuil'04, STDMA, MS- Aloha],
  - external **location** reference [Viqar-Welch'09, STDMA],
  - **collision detection**,
  - **base stations** for scheduling transmissions.

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# Our Approach

We focus on self-stabilizing algorithms that their converges considers both:

- clock synchronization, and
- time slot assignment.
  
- Our algorithmic design does **not** cluster, leader election or centralistic time slot registration.

# Self-Stabilization

- **Transient faults**

- Failures are hard to predict
  - Can never model all of them
- Probabilistic assumptions
  - Implies eventual failure
- Temporary violation of assumptions

# Self-Stabilization

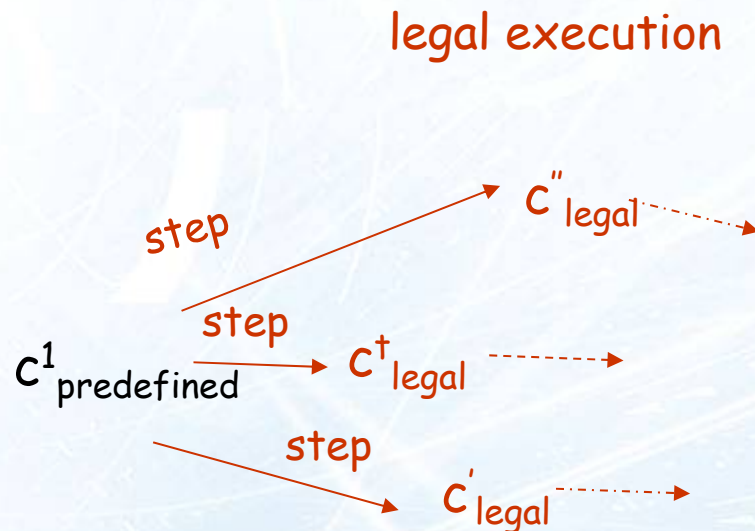
- Transient faults
- **Examples**

- Concert hall clapping
  - Eventually synchronized
- Routing Information Protocol
  - The internet routing protocol

# Self-Stabilization

- Transient faults
- **Definition**

- Set of **Legal Execution (LE)**
  - Encodes correct system behavior
- Non-self-stabilizing algorithms
  - Consider predefined starting configurations



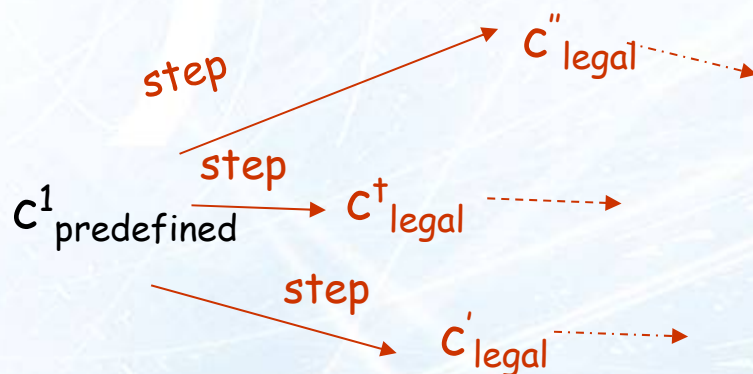
- Configuration  $C_{\text{safe}}$  is said to be **safe** if any execution that starts from it is a legal one
- In other words, correct system behavior is guaranteed when starting from  $C_{\text{safe}}$

# Self-Stabilization

- Transient faults
- Definition

- Set of **Legal Execution (LE)**
  - Encodes correct system behavior
- Non-self-stabilizing algorithms
  - Consider predefined starting configurations

Arbitrary starting configuration can be the result of transient faults



1. Starting from a **safe** configuration, the system stays in **LE**
2. Starting from an **arbitrary** configuration, the system reaches a **safe** one within a bounded time

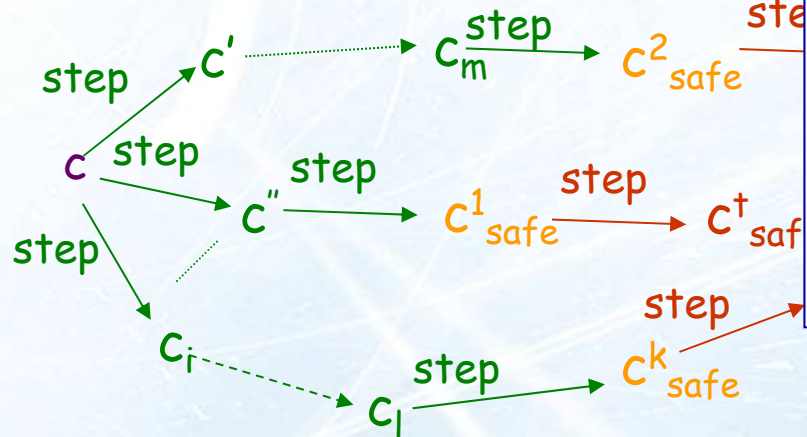
# Self-Stabilization

- Transient faults
- Definition

- Set of **Legal Execution (LE)**
  - Encodes correct system behavior
- Non-self-stabilizing algorithms
  - Consider predefined starting configurations

Self stabilizing systems:

1. Starting from a **safe** configuration, the system stays in **LE**
2. Starting from an **arbitrary** configuration, the system reaches a **safe** one within a bounded time





# Our Contribution

Basic limit on the TDMA bandwidth utilization in wireless ad hoc networks:

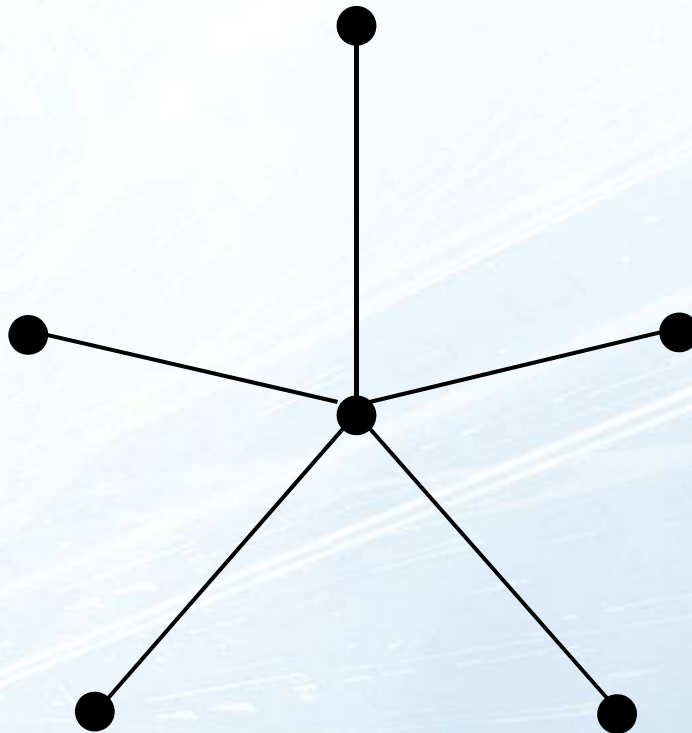
- $T < \max \{2\delta, \chi^2\}$ , where  $\chi^2$  is the chromatic number for distance-2 vertex coloring, and  $T$  is the TDMA frame size.

Existent proof of collision-free self-stabilizing TDMA without access to external reference.

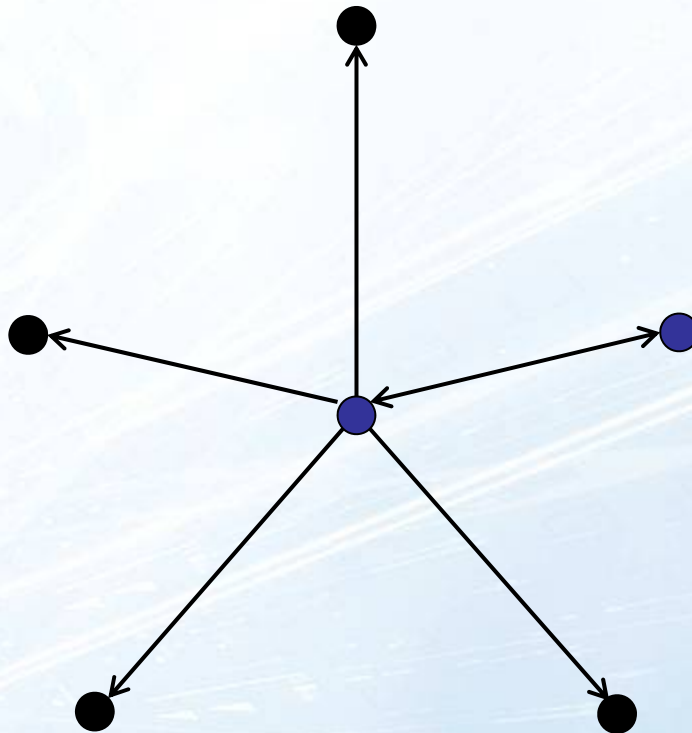
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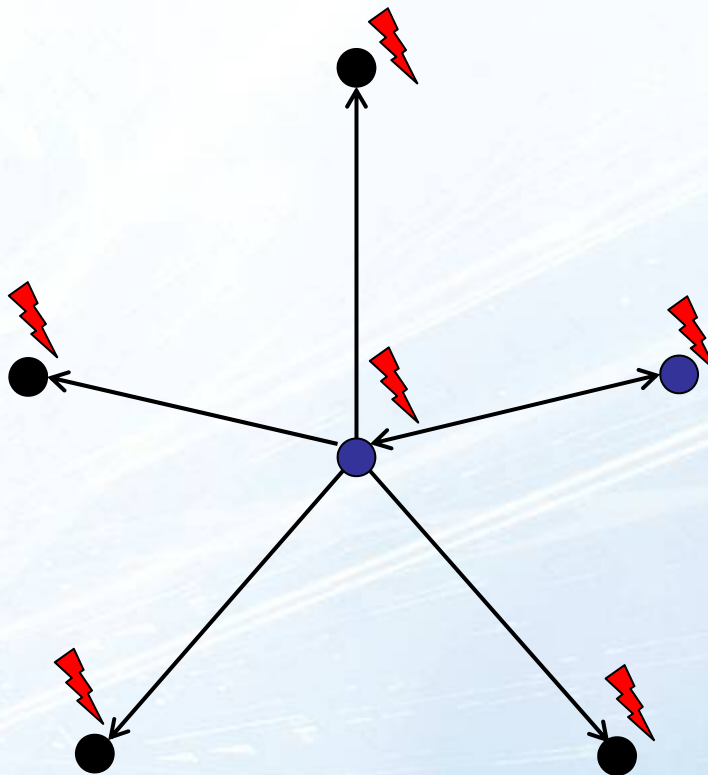
# Lower Bound



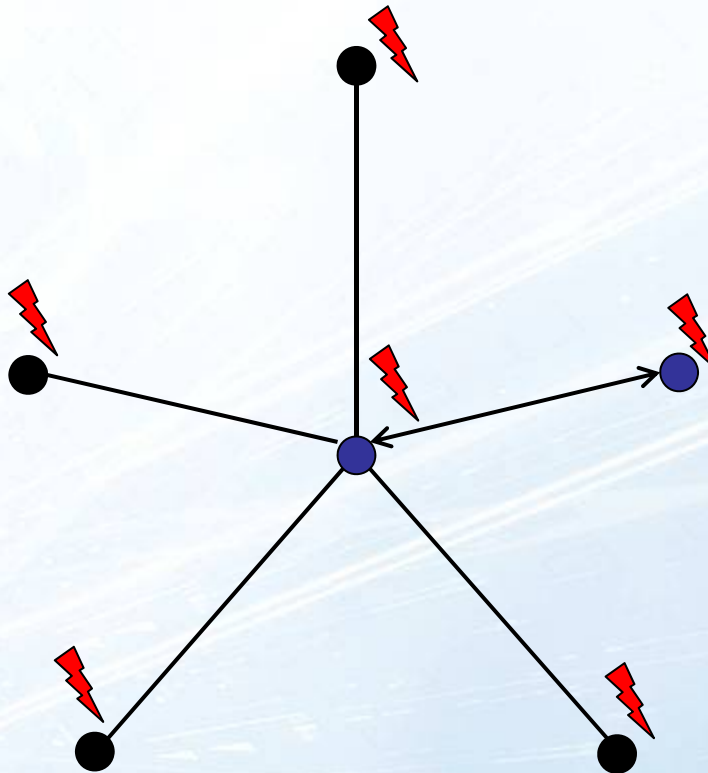
# Lower Bound



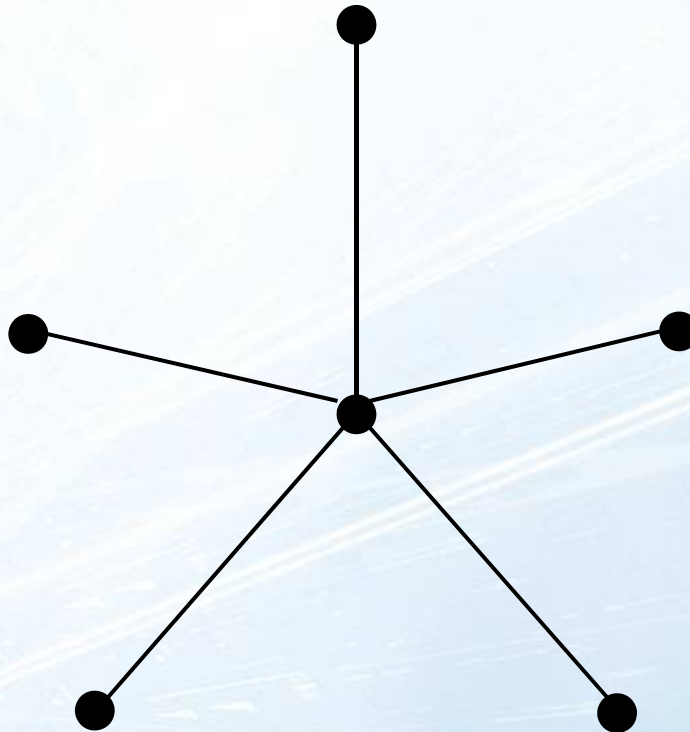
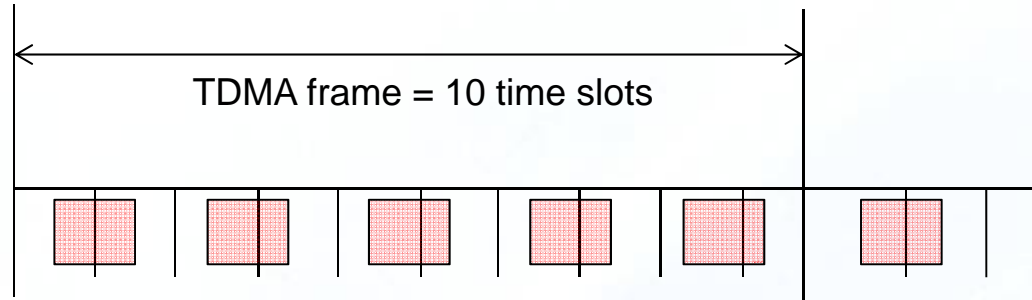
# Lower Bound



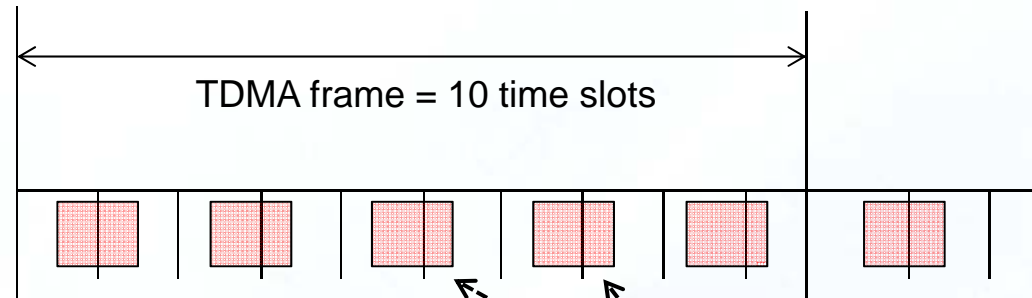
# Lower Bound



# Lower Bound



# Lower Bound



- $\delta$  leaves can block  $2\delta$  slots
- $2\delta$  is our lower bound
  - rather than  $2\Delta$  [Busch, et al.'08], where  $\Delta \in O(\delta^2)$

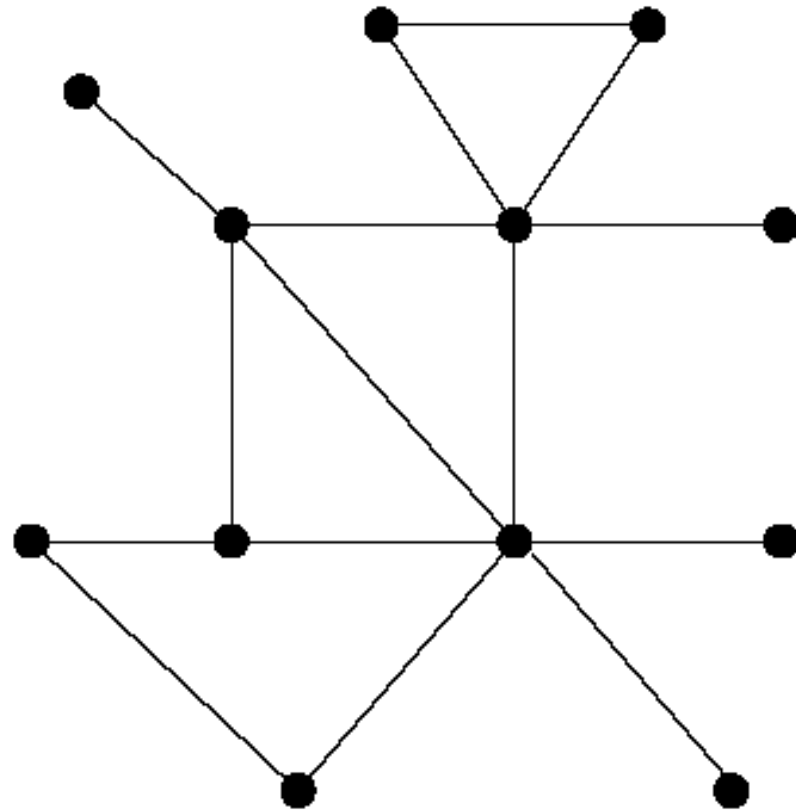


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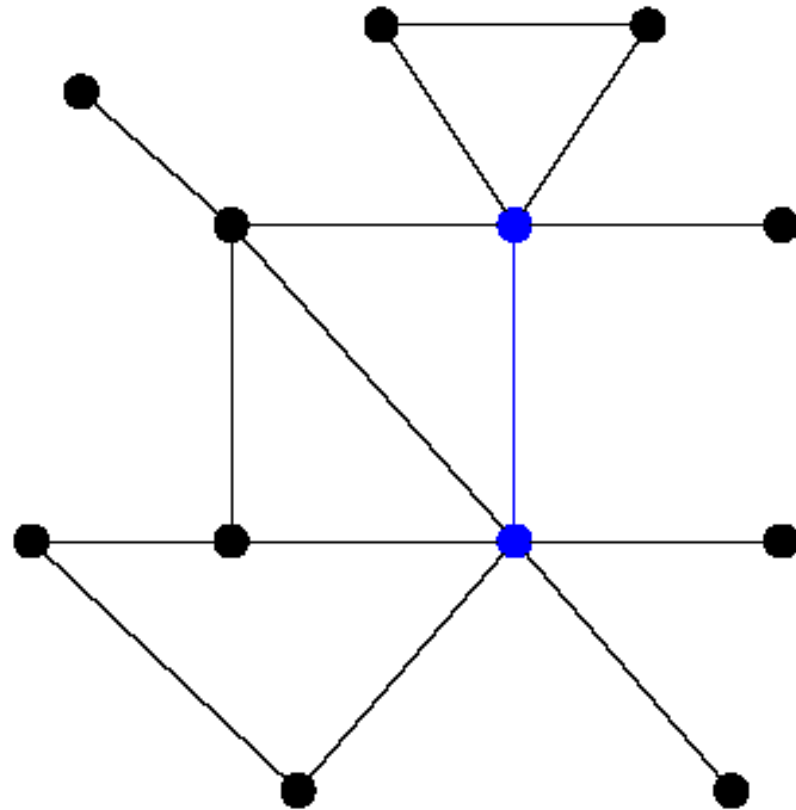
# The Algorithm

- We focus on the communication to a single neighbor.



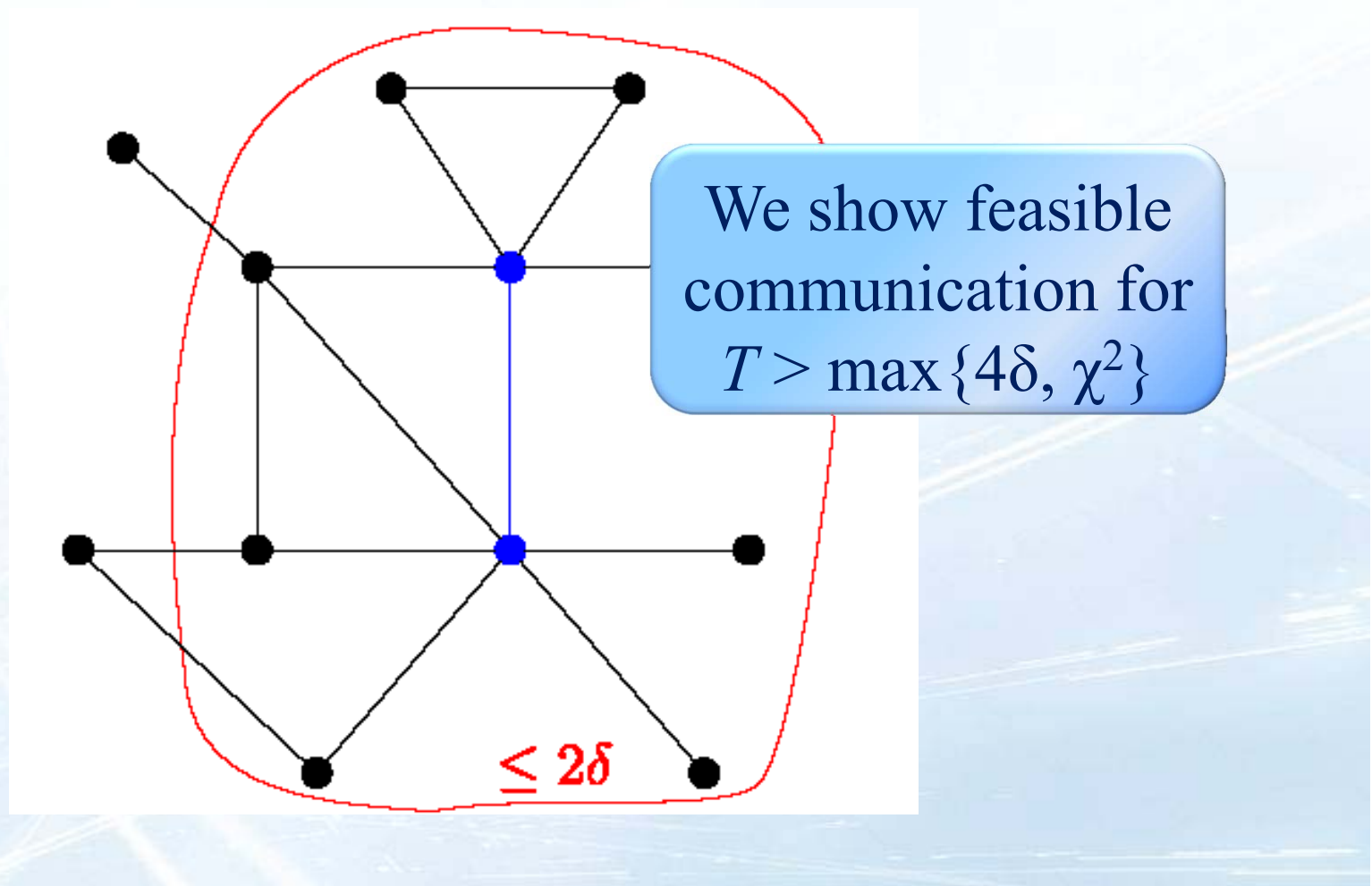
# The Algorithm

- We focus on the communication to a single neighbor.



# The Algorithm

- We focus on the communication to a single neighbor.

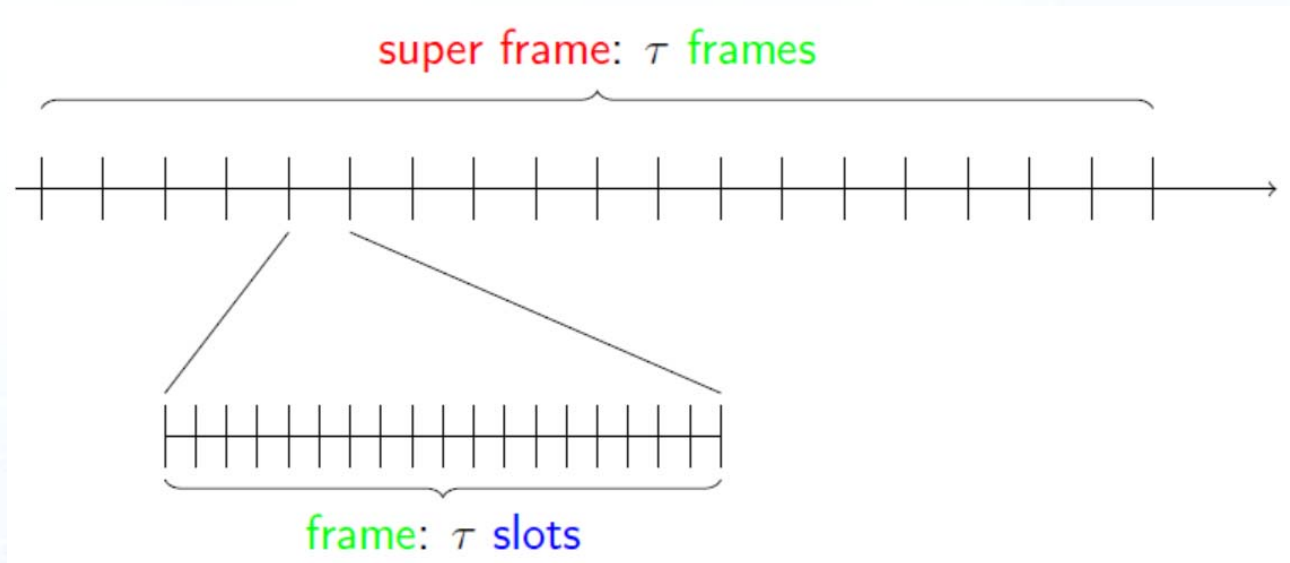


# The Algorithm

- Aim at **data** packet transmission within  $\tau$  time slots
- Use **control packets** to exchange frame information
  - detect (and inform) about collisions,
  - request data time slot allocation,
  - synchronization, and TDMA time slot alignment.

# TDMA Frame

- Divide the radio time is into: slots, frames, super frames:



- A slot can be used for a data packet or a control packet.
- A data packet are send on a fixed slot within a frame.

# The Algorithm in a Nutshell

- Nodes are either be **Active** or **Passive**
  - Both **Active** nodes sends **control packets**
  - Only **Active** nodes sends data packets during data slots.
- **Active** → **Passive**: when data time slot has **collisions**
- **Passive** → **Active**: acknowledged **control packet**
- After convergence:
  - TDMA time slots are aligned,
  - each node successfully sends data packets once a frame,
  - control packets do not collide.

# The Convergence Proof

It shows that:

1. Show that every node can reach a neighbor within an expected time.
  2. A converge-to-the-max approach for clock convergence [Herman and Zhang'08].
  3. Each node gets a time slot that is unique within its neighborhood.
  4. There are no packet collisions.
- See TR <http://arxiv.org/abs/1308.6475>



# Outline

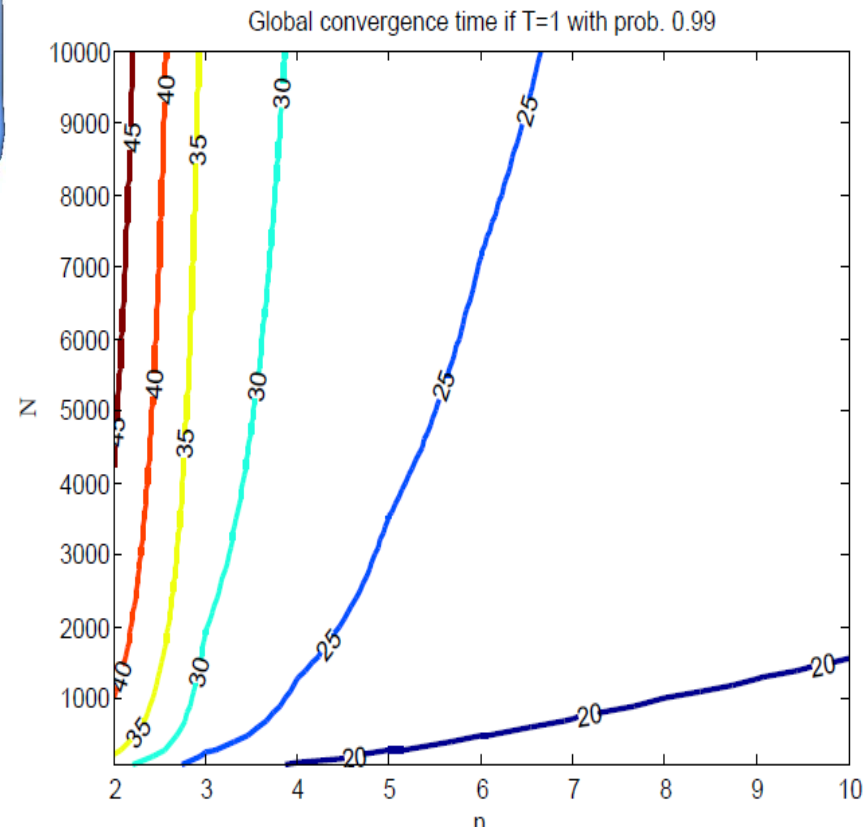
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# Version w. External Reference

With probability  $\alpha$  the network convergence time is bounded by  $k$ , where  $T$  is the frame size.

Leone-Schiller, JDSN'13  
SENSORNETS'12

$$k = 1 + \frac{\log(1 - \sqrt[N]{1 - \alpha})}{\log\left(1 - \left(\frac{n-1}{2n}\right)^{\frac{d}{T}}\right)}$$



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# Conclusions

- Our system settings do **not** consider: external time reference, location reference, collision detection, base station.
- Is it possible to combine the positive effects of TDMA and CSMA?

In our system settings:

- No, if the frame size  $\tau < \max\{2\delta, \chi^2\}$
- Yes, if the frame size  $\tau > \max\{4\delta, \chi^2\}$
- Future work: can the reference-free version serve as a fall back strategy to the synchronized one?

# Thank you for your attention!

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You find our technical report on arxiv:

- Self-stabilizing TDMA Algorithms for Wireless Ad-hoc Networks without External Reference <http://arxiv.org/abs/1308.6475>