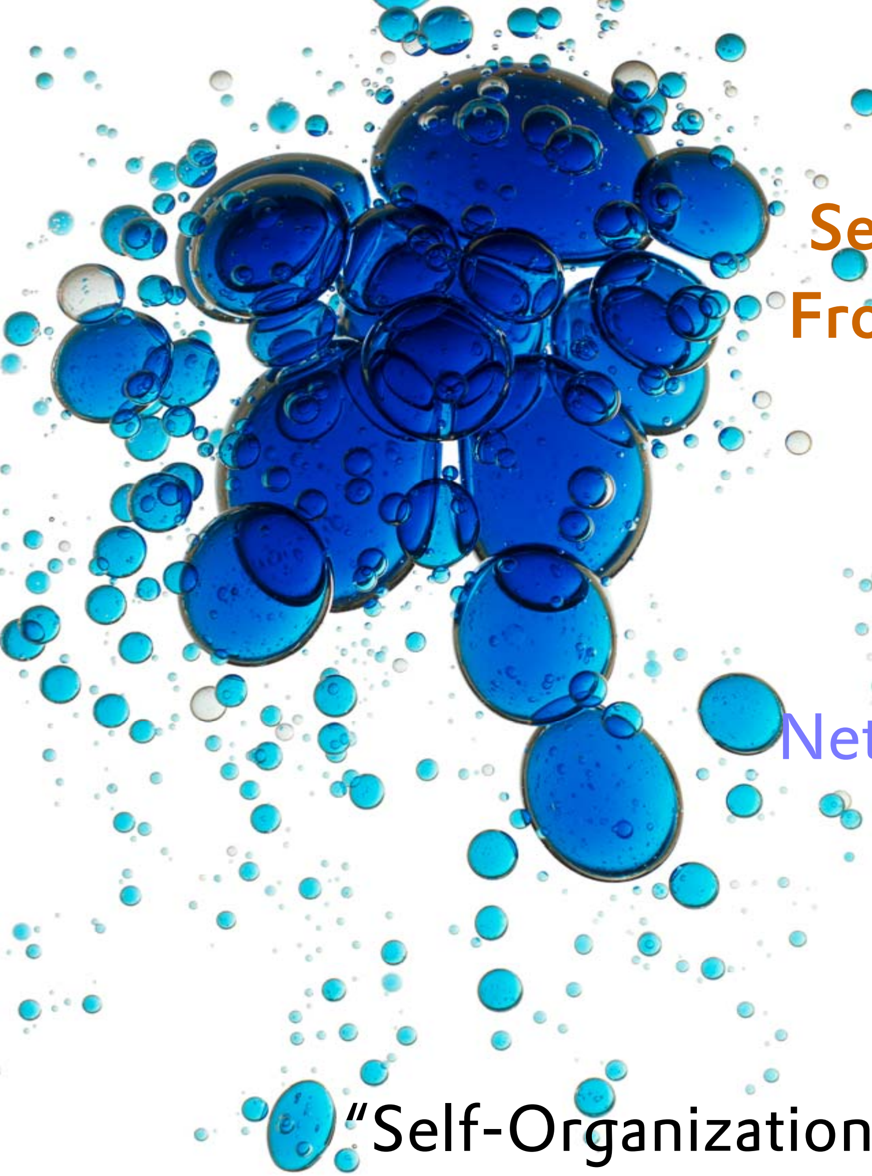


Self-Organizing Synchronization: From Fireflies to Wireless Systems

Christian Bettstetter

University of Klagenfurt
Networked and Embedded Systems

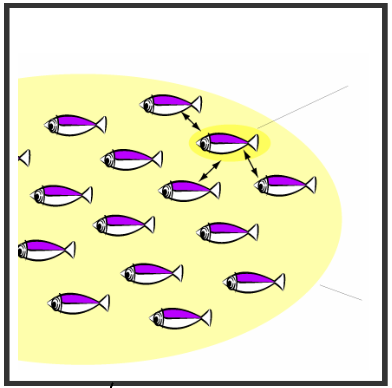
Lakeside Labs GmbH

Talk at ITG Workshop
“Self-Organization: Opportunities and Challenges“
Stuttgart; October 7, 2010

ALPEN-ADRIA
UNIVERSITÄT
KLAGENFURT

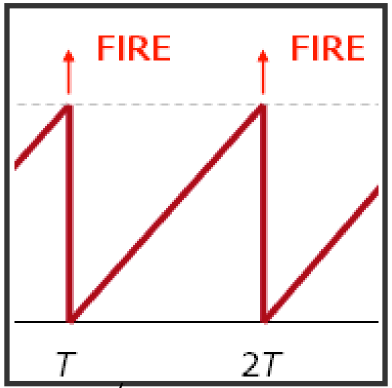
Lakeside Labs

Outline



Self-Organization

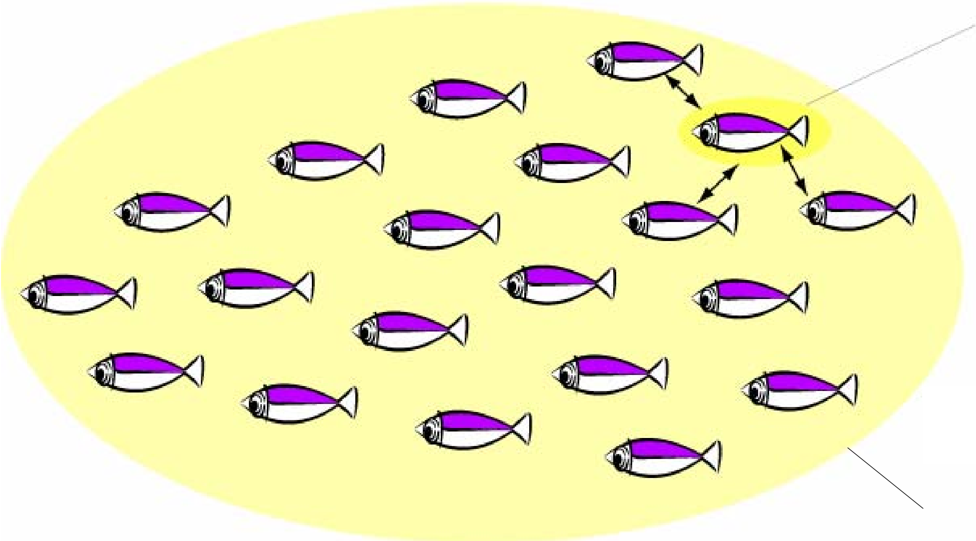
Synchronization



Fireflies

Wireless systems

What is Self-Organization?



Individual Entity („Fish") *many*

- Simple behavior rules
- Local view
- Distributed operation

⇩ Emergence

Entire System ("Shoal")

- Solves a complex task
- Is adaptive to changes
- Is very scalable

- No commonly accepted definition
- Basic concept is quite old

C. Prehofer, C. Bettstetter: Self-Organization in Communication Networks: Principles and Design Paradigms. *IEEE Communications Magazine*, Feature on Advances in Self-Organizing Networks, July 2005.

Bird Swarming

A video is shown here.

Trend Toward Self-Organization in Computing & Communications

- Self-configuration in the Internet (addresses, services, …)
- Infrastructureless wireless networks (ad hoc networks)
- Peer-to-peer networking
- Web 2.0, Wikis, social online networks

- Networked embedded systems (pervasive computing):

Increased dynamics and complexity

Raises requirements:
- Adaptability
- Distributed operation
- Autoconfiguration

Discussion Issues

- To what extend can **today's systems** be **replaced or complemented** by self-organizing systems, taking into account
  - constraints and acceptance of the technology and
  - risks for users?
- How to **design and engineer** technical self-organizing systems?
  - What are building blocks or paradigms for the design?
  - Are traditional approaches for system and software engineering suited?

These are difficult questions ...

What is Synchronization? Experiment with Metronomes

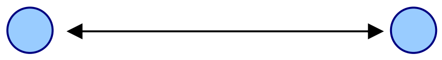
Synchronization in Communications and Computing

- Carrier frequency synchron.
- Symbol or bit synchronization
- Slot synchronization
- Frame synchronization
- Packet synchronization

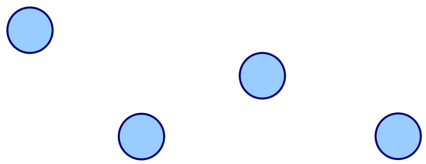
- Clock synchronization
- Data or file synchronization
- Multimedia synchronization

- ...

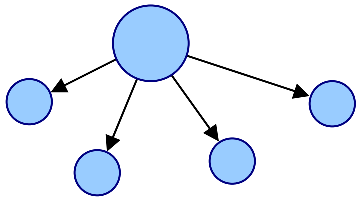
Point-to-point synchronization:



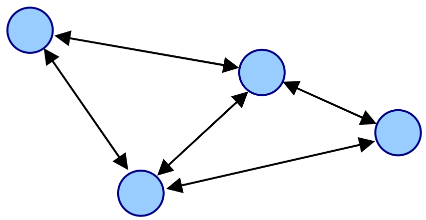
Network synchronization:



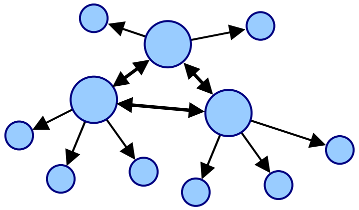
Network Synchronization Strategies: Basic Categorization



Master-slave synchronization
(monarchy)

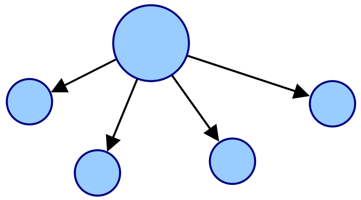


Mutual synchronization
(base democracy)



Mix of master-slave and mutual synchronization
(oligarchy)

Network Synchronization Strategies: Basic Categorization



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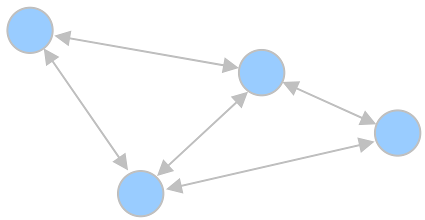
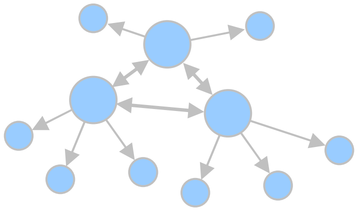
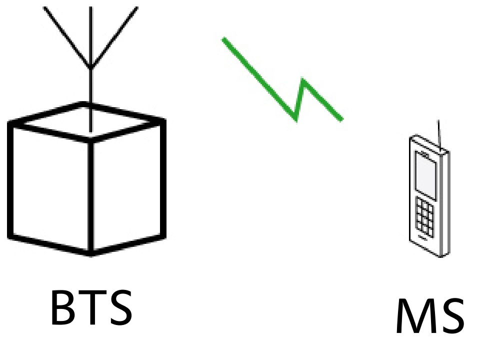


Mutual synchronization
(base democracy)



Mix of master-slave and mutual synchronization
(oligarchy)

Synchronization in GSM (between BTS and MS)



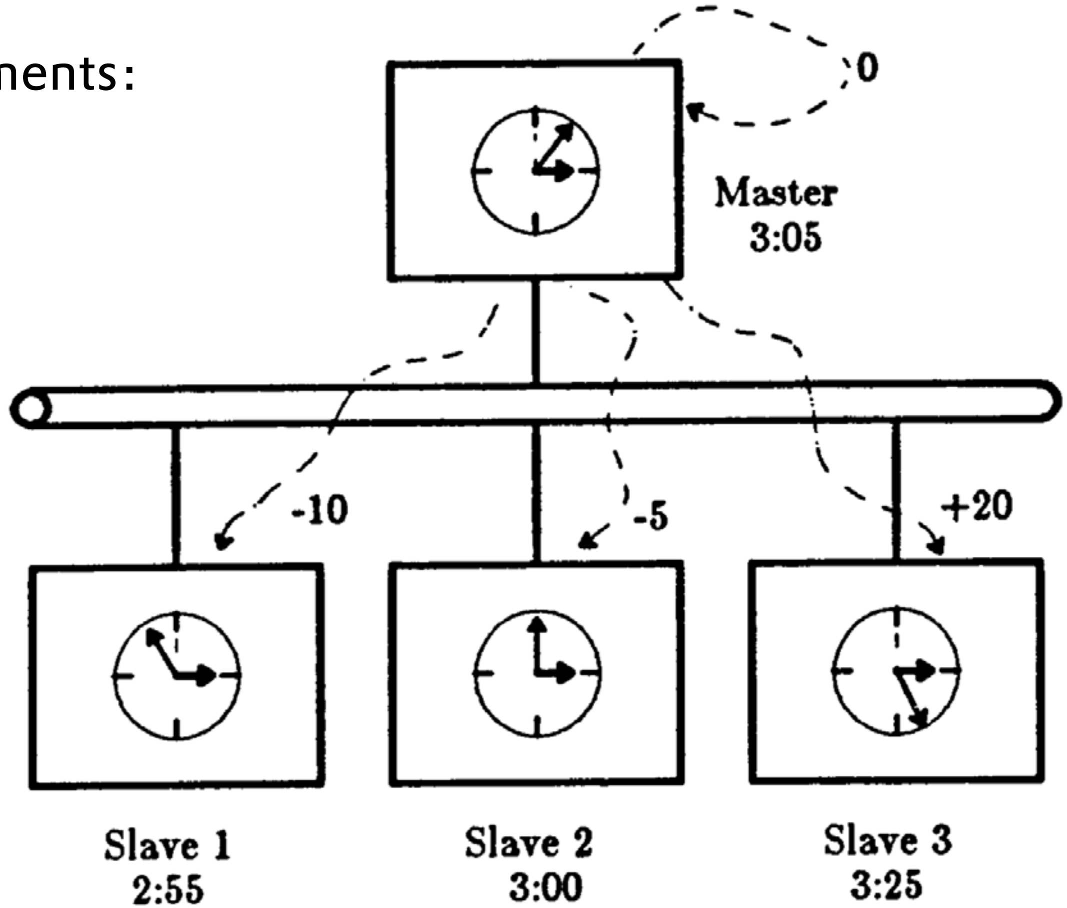
The BTS sends signals on the *Broadcast Control Channel (BCCH)* to enable the MS to synchronize itself to the BTS.

- Carrier frequency synchronization (*frequency correction bursts*): Adjustment of the sending and receiving frequencies of a MS to the frequencies of the BTS
- Time synchronization (*frequency correction, synchronization bursts*):
  - Frame synchronization: Adjustment of the start of a periodically repeating transmit frame
  - Bit synchronization

Synchronization in LANs: Berkeley algorithm (1980s)

Step #1:

Measurements:

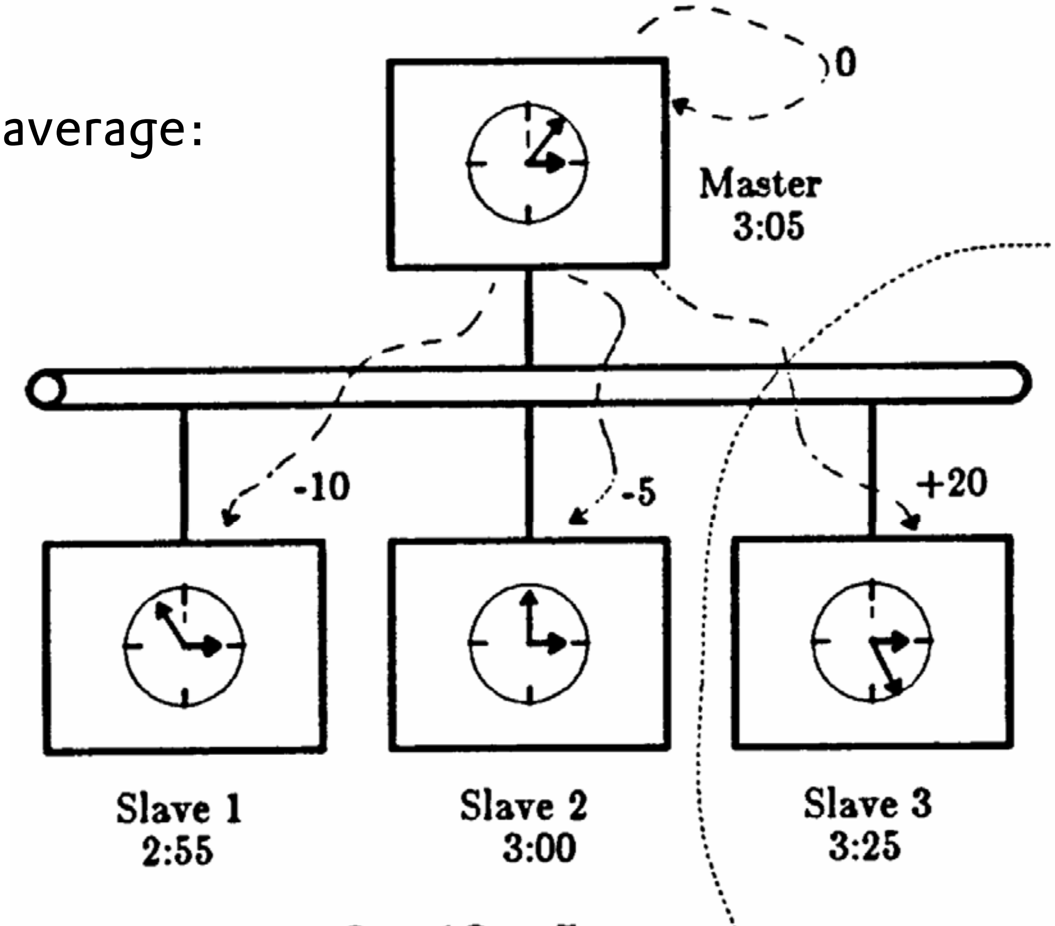


R. Gusella and S. Zatti: The accuracy of the clock synchronization achieved by TEMPO in Berkeley UNIX 4.3BSD, *IEEE Trans. on Software Engineering*, 15 (7): 847–853, 1989.

Berkeley algorithm (1980s)

Step #2:

Compute average:



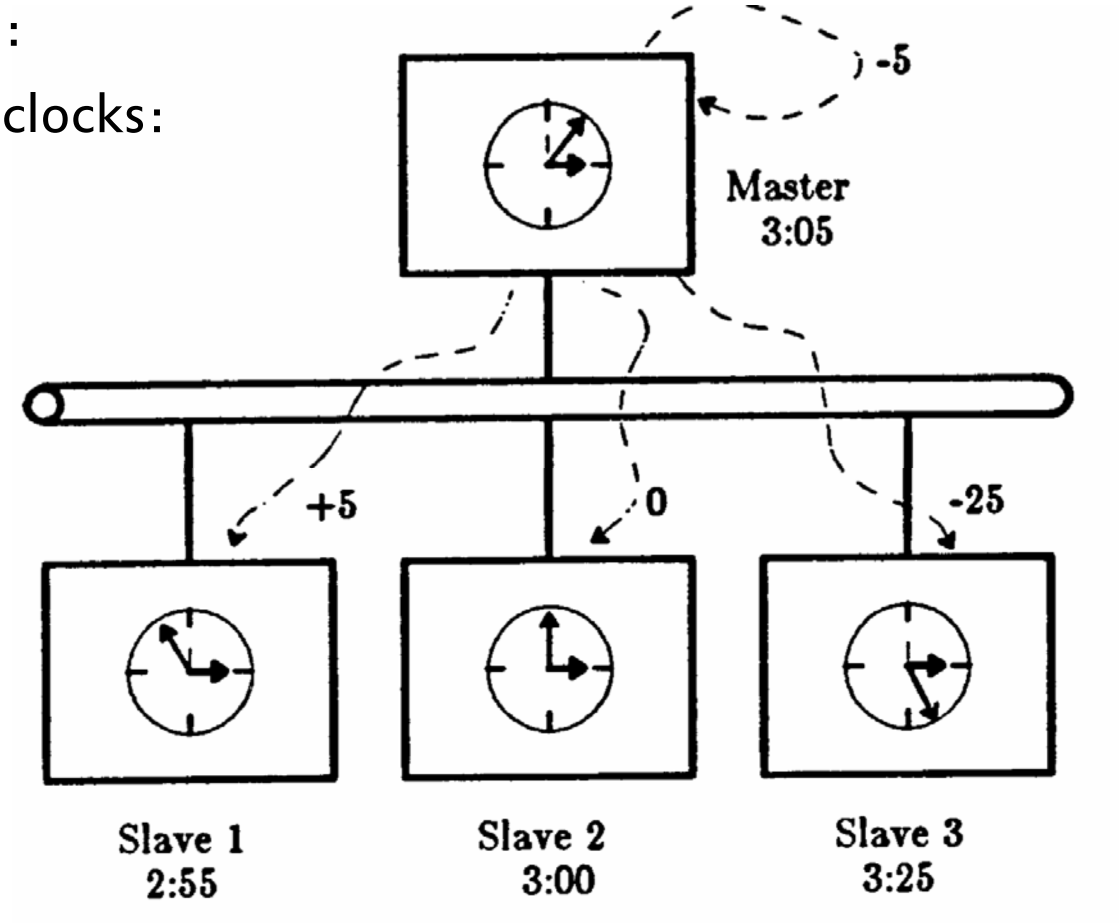
$$Av = \frac{0 - 10 - 5}{3} = -5$$

R. Gusella and S. Zatti: The accuracy of the clock synchronization achieved by TEMPO in Berkeley UNIX 4.3BSD, *IEEE Trans. on Software Engineering*, 15 (7): 847–853, 1989. © 1989 IEEE. Figure used with kind permission from the IEEE IPR Office.

Berkeley algorithm (1980s)

Step #3:

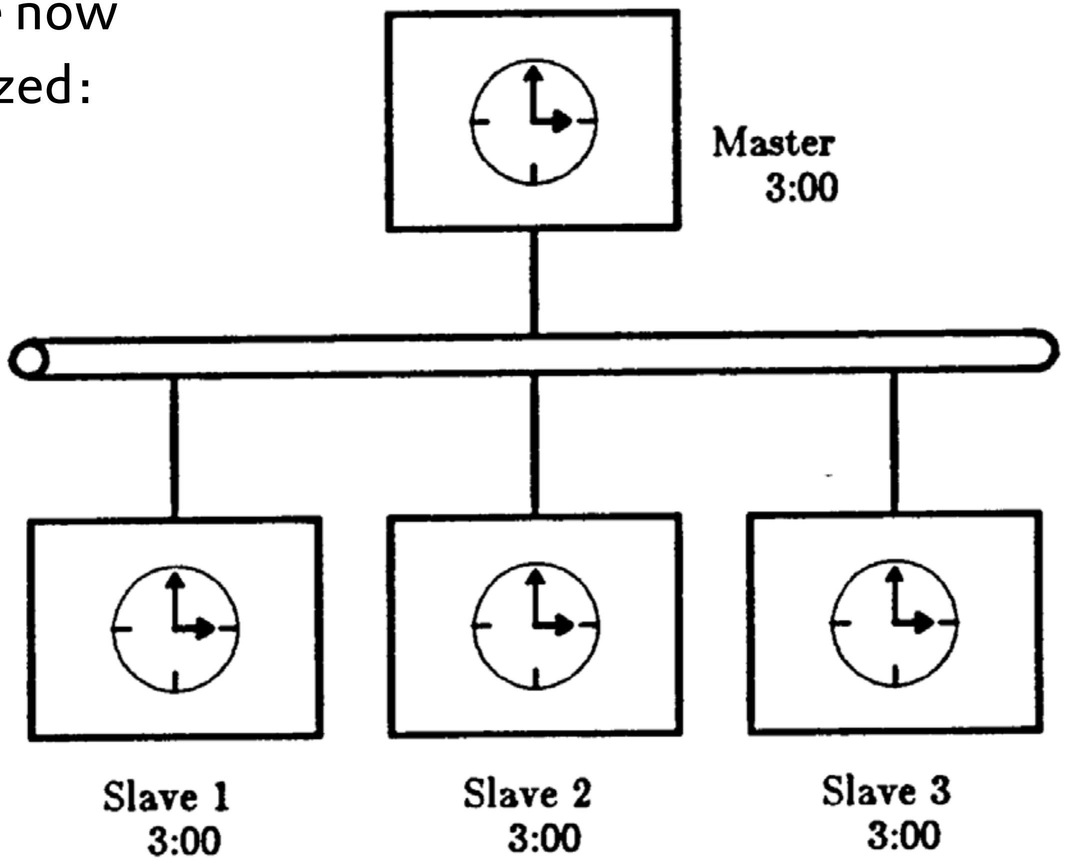
Correct clocks:



R. Gusella and S. Zatti: The accuracy of the clock synchronization achieved by TEMPO in Berkeley UNIX 4.3BSD, *IEEE Trans. on Software Engineering*, 15 (7): 847–853, 1989.

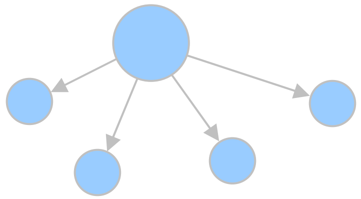
Berkeley algorithm (1980s)

Clocks are now synchronized:

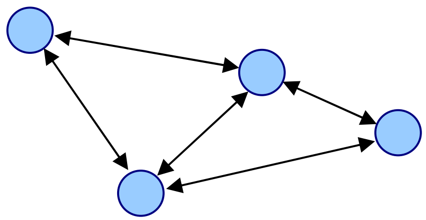


R. Gusella and S. Zatti: The accuracy of the clock synchronization achieved by TEMPO in Berkeley UNIX 4.3BSD, *IEEE Trans. on Software Engineering*, 15 (7): 847–853, 1989. © 1989 IEEE. Figure used with kind permission from the IEEE IPR Office.

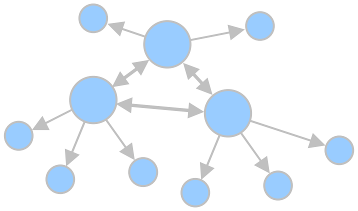
Network Synchronization Strategies: Basic Categorization



Master-slave synchronization
(monarchy)



Mutual synchronization
(base democracy)



Mix of master-slave and mutual synchronization
(oligarchy)

Synchronous Flashing of Fireflies in South-East Asia

A video is shown here.

Synchronous Flashing of Fireflies in South-East Asia

A video is shown here.

Synchronous Flashing of Fireflies in South-East Asia

Early hypotheses of the mechanism

- Environment (e.g. wind, thunder) triggers the synchronization
- Some "leader" firefly controls the synchronized flashing

Experimental work (1960s to 80s)

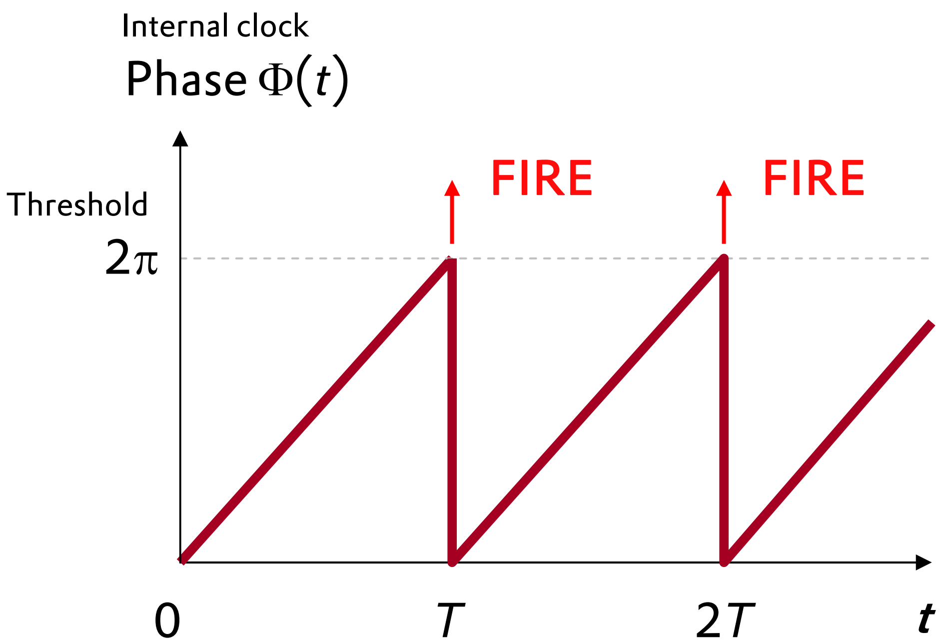
- Firefly in a dark room flashes with quite constant frequency
- Exposed to generated light flashes, it responds to these stimuli

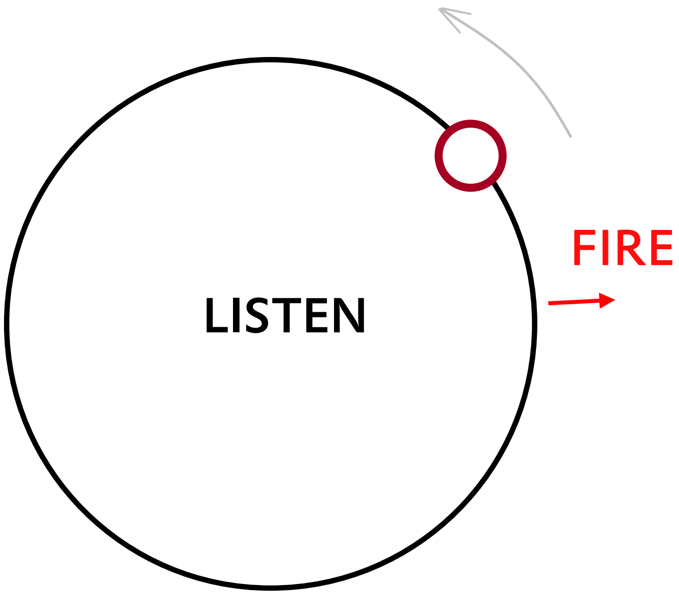
Values in ms

A: no influence
B: delay in flashing
C: earlier 2nd next flash

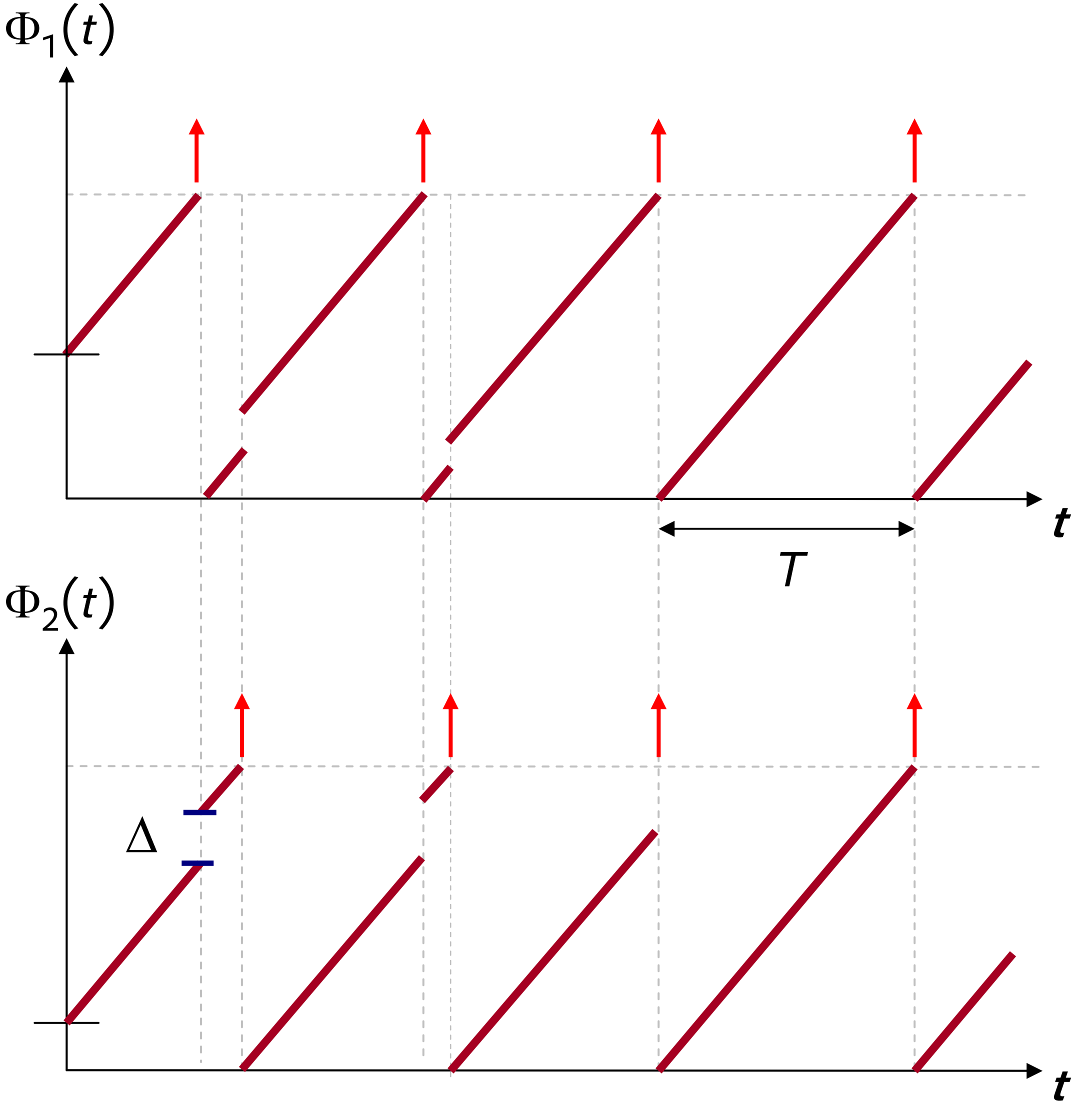
J. Buck *et al.*: Control of Flashing in Fireflies V. *Journal of Comparative Physiology A*, 144:630–633, 1981.

Modeling One Firefly: Integrate-and-Fire Oscillator



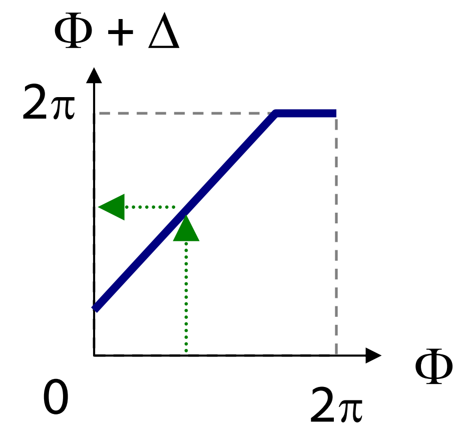


Modeling Two Fireflies: Coupled Integrate-and-Fire Oscillators



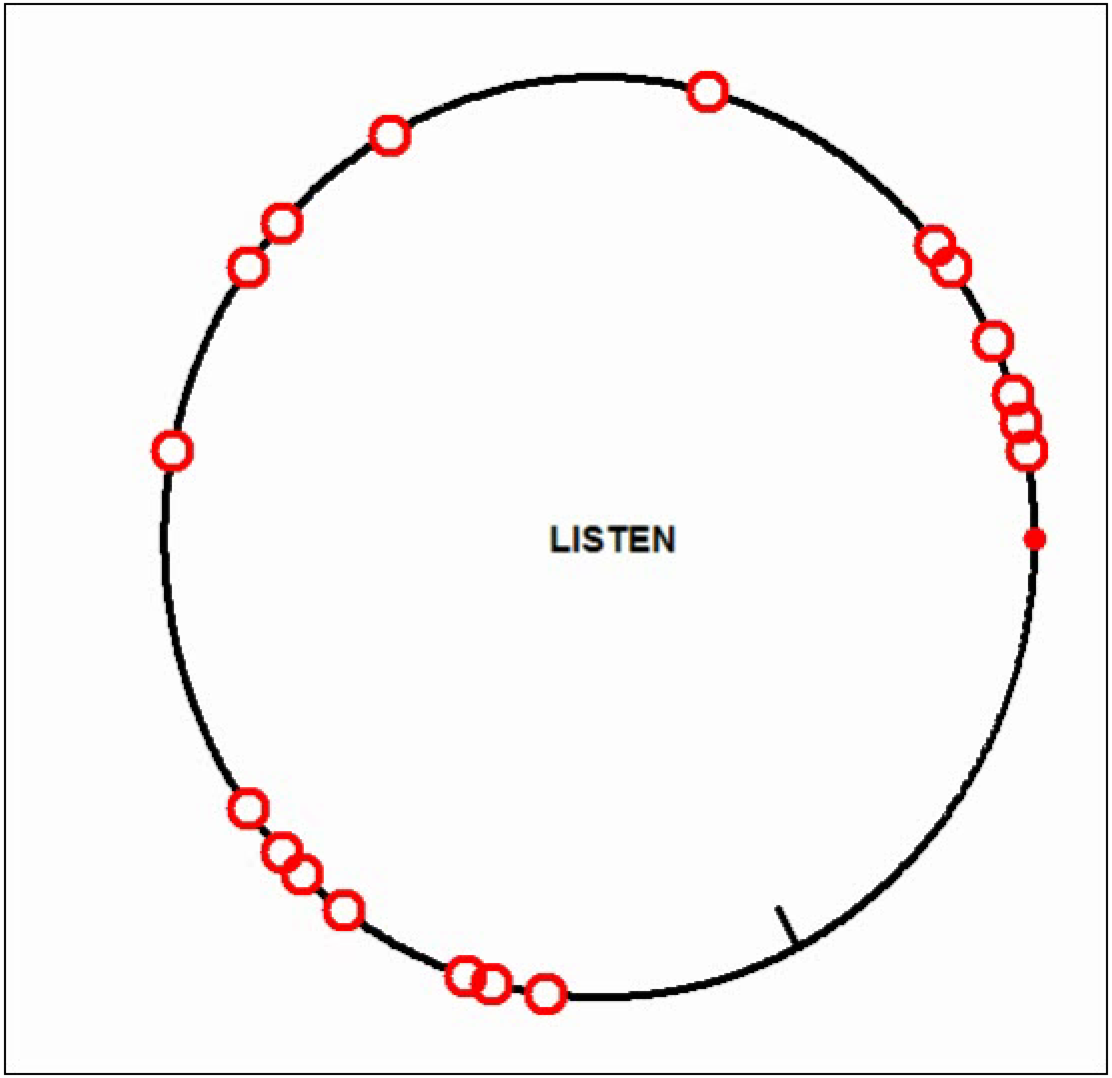
Phase jump upon reception of a pulse:

$$\Phi \rightarrow \Phi + \Delta$$

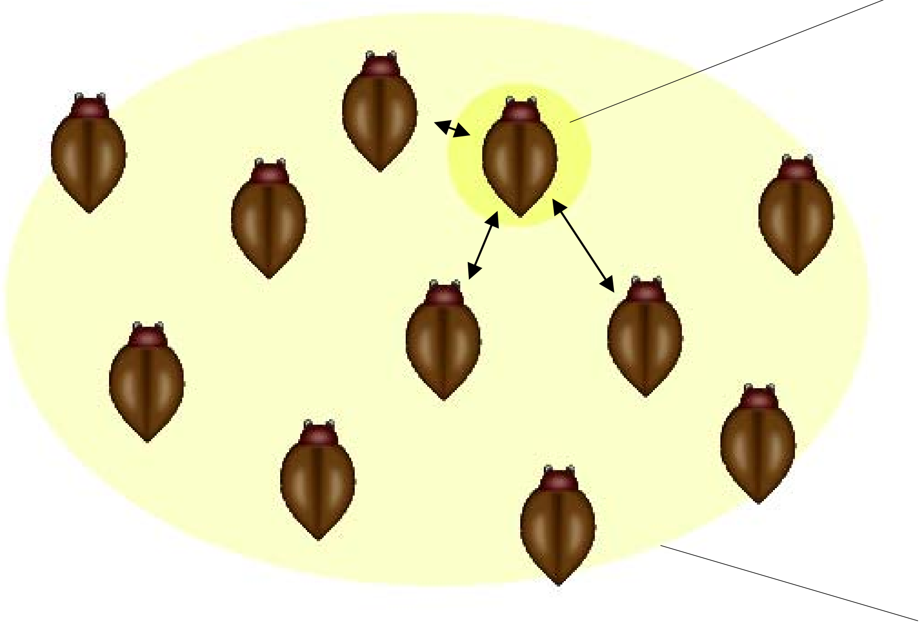


Proven to lead to synchrony

Several Coupled Integrate-and-Fire Oscillators



Why is this algorithm appealing?



Individual Entity („Firefly“) *many*

- Simple behavior rules
- Local view
- Distributed operation

⇩ Emergence

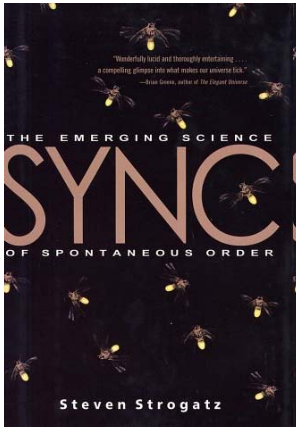
Entire System (“Swarm”)

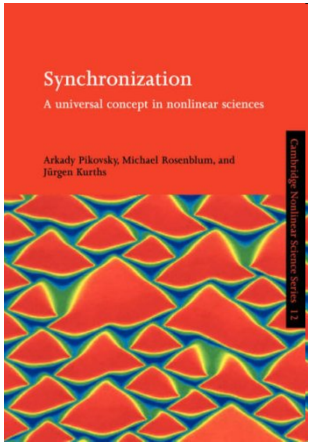
- Solves a complex task
- Is adaptive to changes
- Is very scalable

C. Prehofer, C. Bettstetter: Self-Organization in Communication Networks: Principles and Design Paradigms. *IEEE Communications Magazine*, Feature on Advances in Self-Organizing Networks, July 2005.

Applications of Coupled Oscillator Synchronization

- Synchronization of heart cells
- Synchronous firing of neurons
- Formation of earthquakes
- Forest fires
- Mass extinctions
- Sleep cycles
- …
- Bridge vibrations
- …





Millenium Bridge (London)

Source: Wikimedia Commons

Our Research: Application to Wireless Networks

Problem statement:

Can we apply this algorithm for frame or slot synchronization in wireless multihop networks?

Why do we need such synchronization?

Building block for various functions in communication and control systems, e.g.:

- medium access,
- distributed sensing, and
- scheduling of sleep phases.

Joint effort of

- Klinglmayr & Bettstetter
- Tyrrell & Auer
- Timme

NTT docomo
DOCOMO Euro-Labs

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut
für Dynamik und Selbstorganisation

Can Firefly Synchronization be Applied to Wireless Systems?

Firefly algorithm assumes:

- Synchronization pulses are infinitely short
- No delays
- Nodes listen and transmit at the same time
- All nodes form a fully meshed network

Removing one or more of these assumptions makes synchronization unstable. → Direct transfer to wireless systems is **infeasible.**

Example: With delays, nodes may receive "echos" of their own fire pulse.

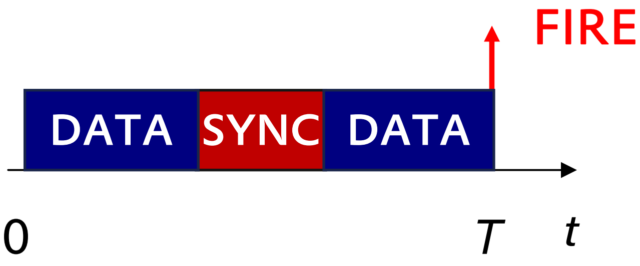
A. Tyrrell, G. Auer, C. Bettstetter: Biologically Inspired Synchronization for Wireless Networks. In *Advances in Biologically Inspired Information Systems: Models, Methods, and Tools*, Series: *Studies in Computational Intelligence*, Springer, 2007.

Meshed Emergent Firefly Synchronization (MEMFIS) (1)

Solution taking into account the **technological constraints** of wireless systems while maintaining nice properties of firefly sync.

Key design characteristics:

- A common **synchronization word** is **embedded** in each payload packet.
- This synchronization word is detected at the receiver using a cross-correlator.



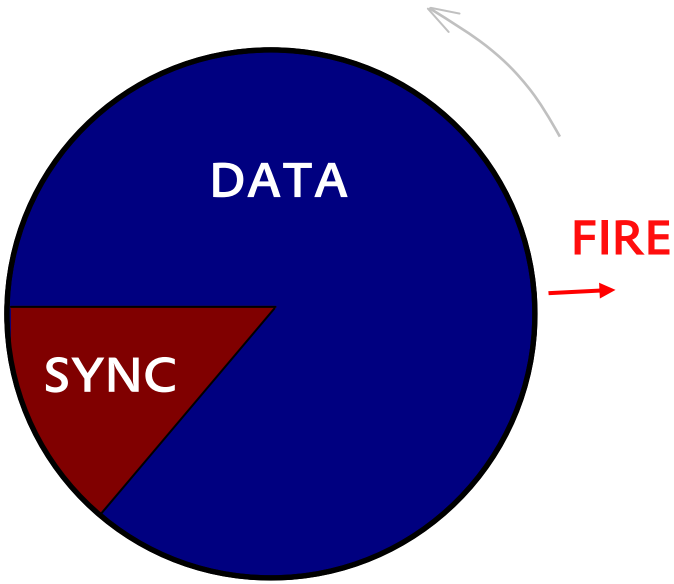
- **Delays** are handled by enhancing the synchronization algorithm.

Result: Synchronization **emerges** gradually as nodes exchange packets randomly. No dedicated synchronization phase needed.

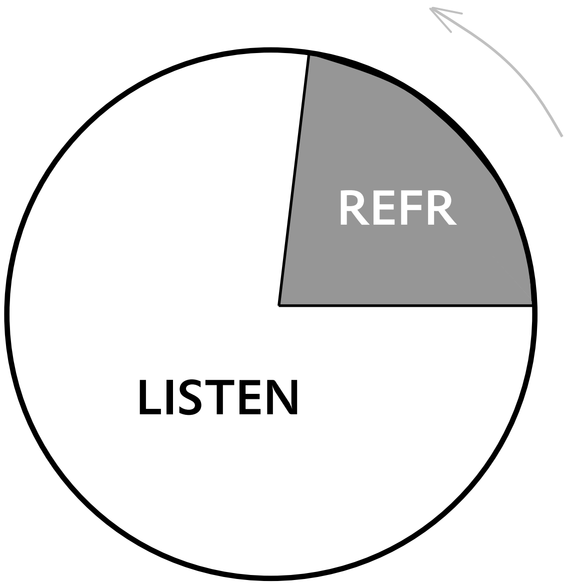
A. Tyrrell, G. Auer, C. Bettstetter: Emergent Slot Synchronization in Wireless Networks. *IEEE Transactions on Mobile Computing*, May 2010.

Meshed Emergent Firefly Synchronization (MEMFIS) (2)

Node in transmit modus:



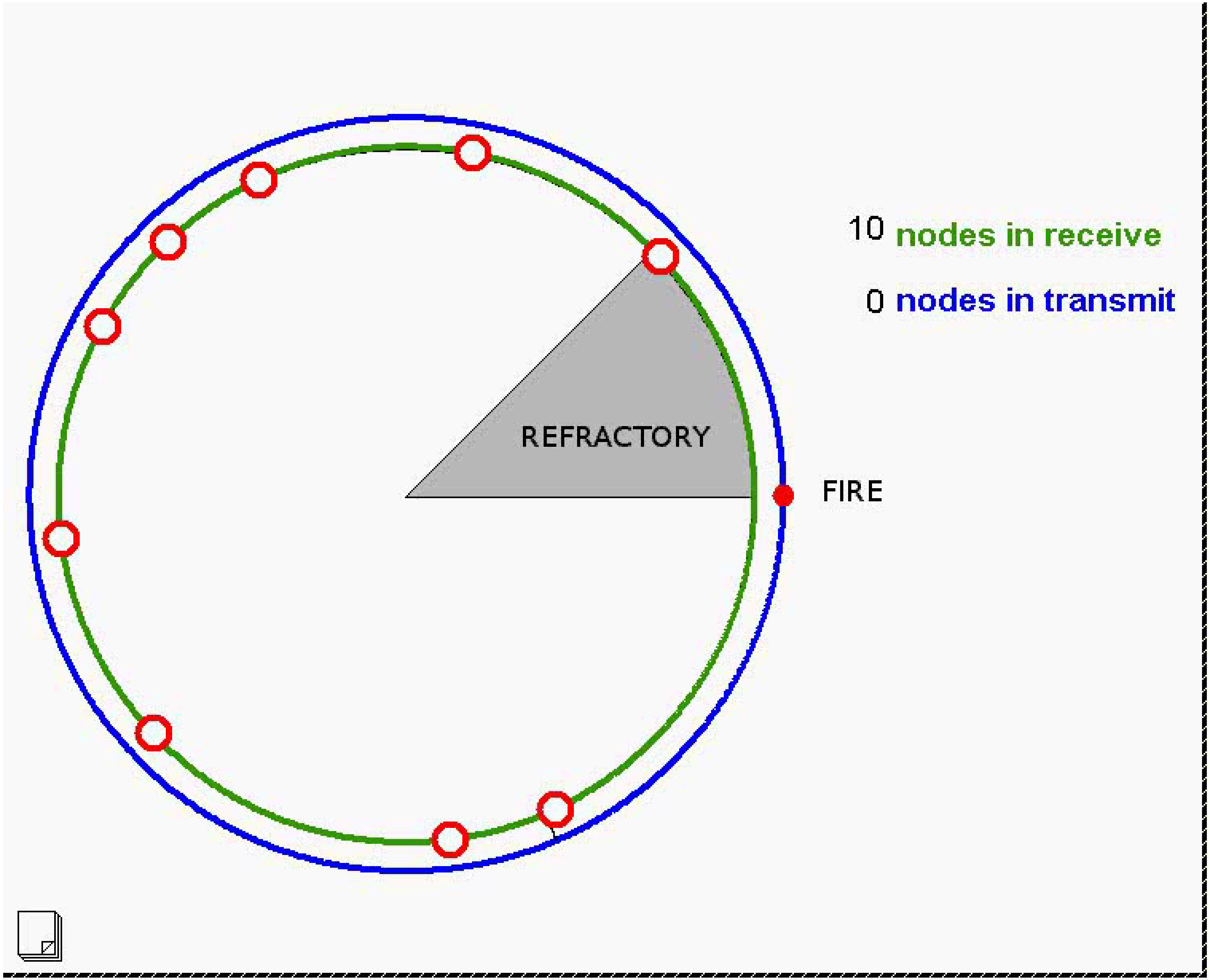
Node in receive modus:



During REFRACTORY period received SYNC words are ignored.

A. Tyrrell, G. Auer, C. Bettstetter: Emergent Slot Synchronization in Wireless Networks. *IEEE Transactions on Mobile Computing*, May 2010.

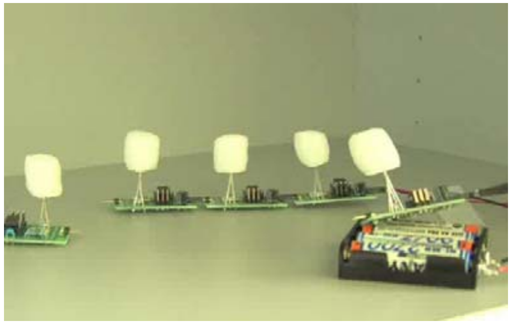
Meshed Emergent Firefly Synchronization (MEMFIS) (3)



***

Ongoing and Future Research

- Performance assessment
  - Time to synchrony
  - Synchronization precision
  - Impact of network topology
- Robustness against
  - Missed sync words and false alarms
  - Faulty & malicious nodes
- Negative phase jumps: Convergence proof
- Implementation on hardware platforms



A. Tyrrell, G. Auer, C. Bettstetter: A Synchronization Metric for Meshed Networks of Pulse-Coupled Oscillators. In *Proc. Intern. Conf. Bio-Inspired Models of Network, Information, and Comp. Sys. (BIONETICS),* Hyogo, Japan, Nov 2008.

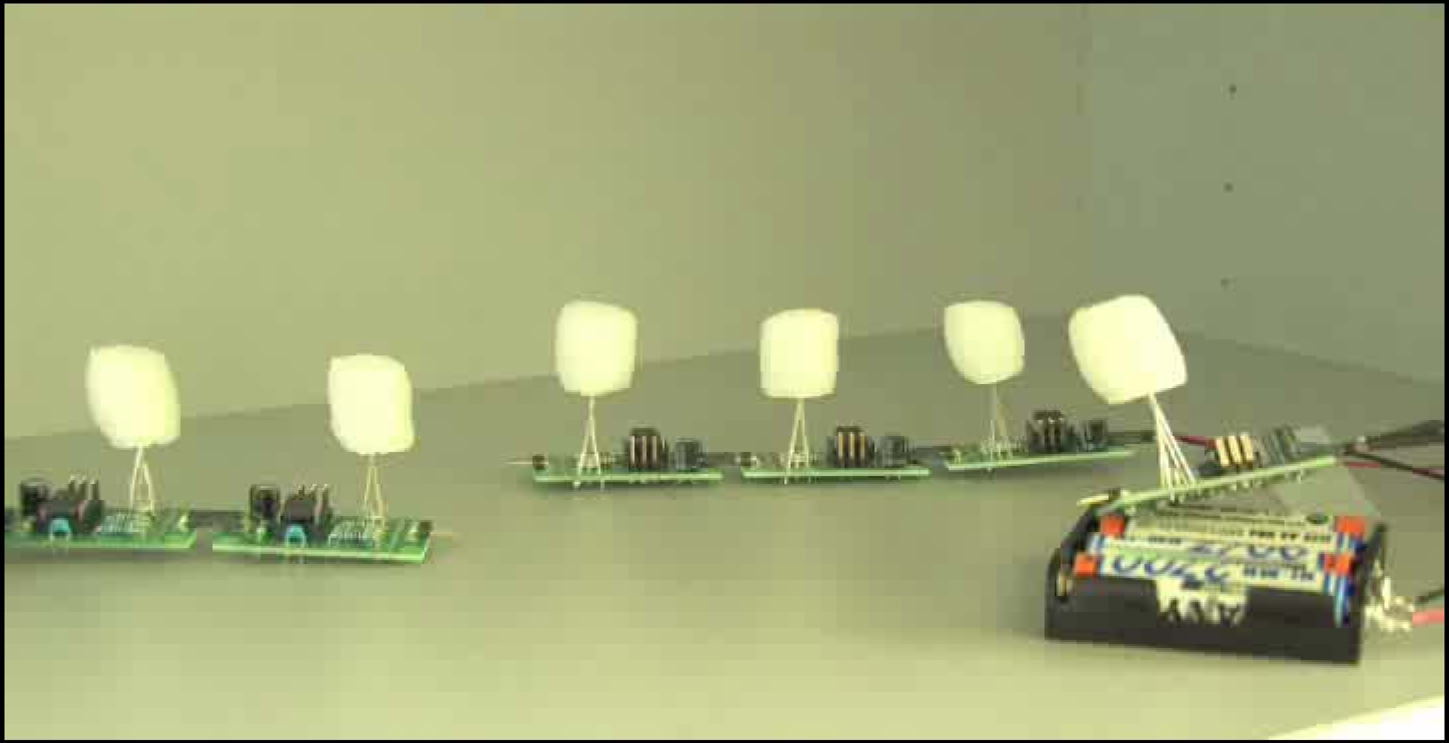
A. Tyrrell, G. Auer, C. Bettstetter: On the Accuracy of Firefly Synchronization with Delays. Best paper award. In *Proc. Intern. Symp. on Applied Sciences in Biomed. Commun. Techn. (ISABEL),* Aalborg, Denmark, Oct 2008.

J. Klinglmayr, C. Bettstetter, M. Timme. Globally Stable Synchronization by Inhibitory Pulse Coupling. Invited paper. In *Proc. Intern. Symp. on Applied Sciences in Biomed. Commun. Techn. (ISABEL),* Bratislava, Slovak Republic, Nov 2009.

A. Tyrrell, G. Auer, C. Bettstetter, R. Naripella: How Does a Faulty Node Disturb Decentralized Slot Synchronization over Wireless Networks? In *Proc. IEEE Intern. Conf. on Communications (ICC),* Cape Town, South Africa, May 2010.

J. Klinglmayr, C. Bettstetter. Synchronization of Inhibitory Pulse-Coupled Oscillators in Delayed Random and Line Networks. In *Proc. Intern. Symp. on Applied Sciences in Biomed. Commun. Techn. (ISABEL),* Rome, Italy, Nov 2010. Invited paper.

Electroflies: Sync via light signals



iPhone App "BUZZflies": Sync via audio signals

iPhone App "BUZZflies": Free for download at iTunes

App Store › Unterhaltung › Cam Lai Ngo

BUZZflies

Beschreibung

This application detects sounds from other iPhone devices and synchronizes them utilizing an synchronization algorithm inspired from the nature: the firefly synchronization algorithm.

Website von Cam Lai Ngo › **BUZZflies Support ›** ...Mehr

Gratis-App

Kategorie: Unterhaltung
Erschienen: 06. Januar 2010
Version: 1.0
4.8 MB
Sprachen: Englisch
Verkäufer: Cam Lai Ngo
© Cam Lai Ngo

Kennzeichnung: 4+

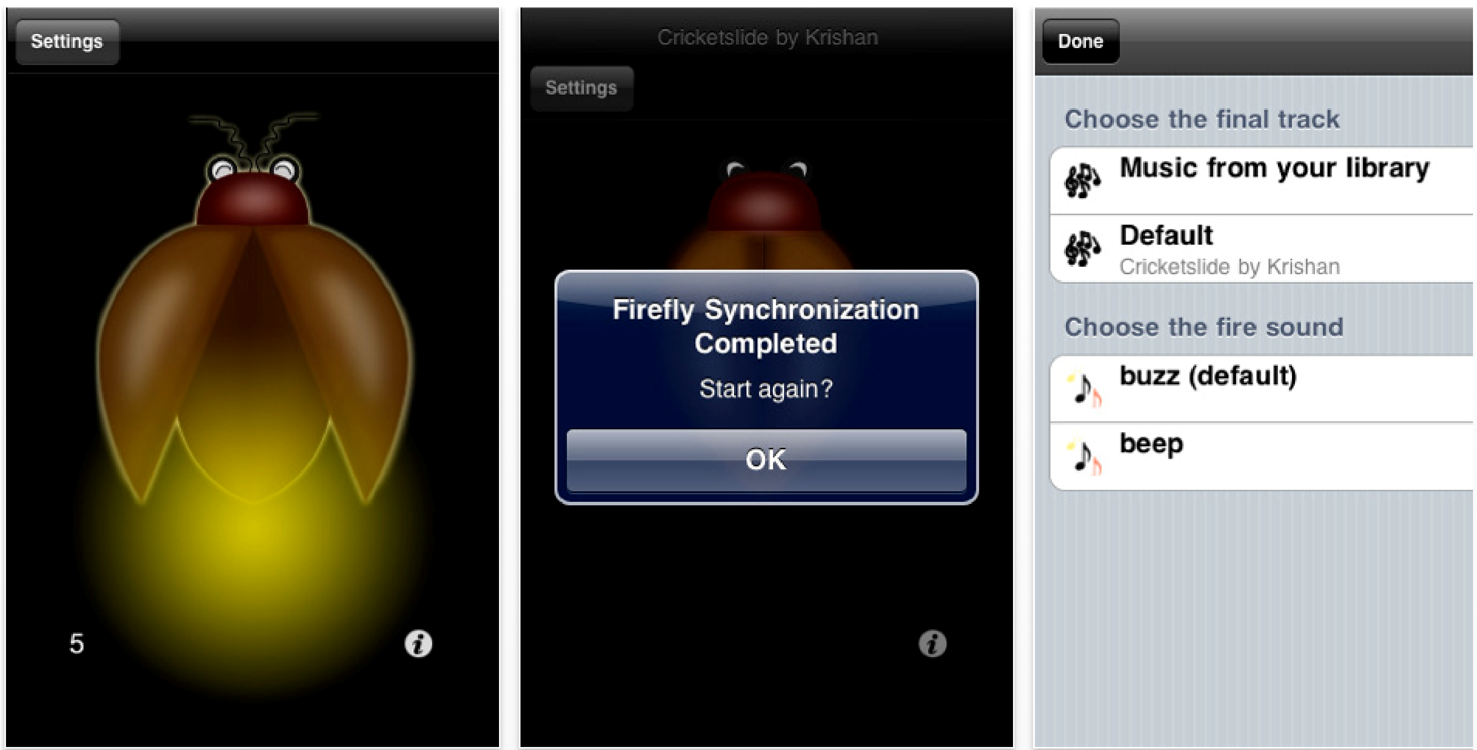
Voraussetzungen: Kompatibel mit iPhone. Erfordert iPhone OS 3.0 oder neuer.

Kundenbewertun...

Bewerten

Wir haben noch nicht genügend Bewertungen erhalten, um einen Durchschnittswert für die aktuelle Version von diesem/dieser application anzeigen zu können.

Screenshots



Literature: Synchronization

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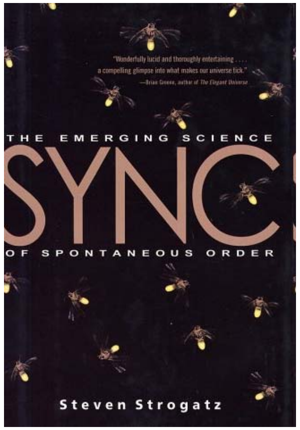
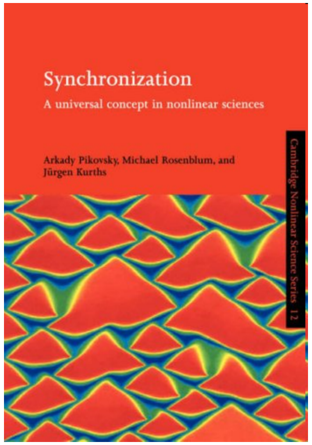
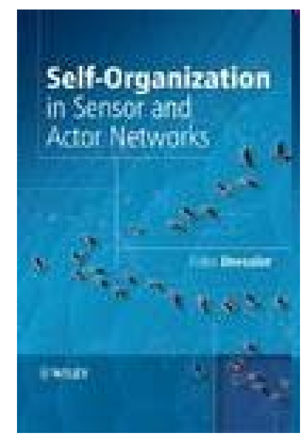
- S. H. Strogatz, I. Stewart: Coupled Oscillators and Biological Synchronization. *Scientific American*, Dec 1993.
- S. H. Strogatz: *SYNC: The emerging science of spontaneous order*, Hyperion, 2003.
- A. Pikovsky, M Rosenblum, J. Kurths: *Synchronization: A Universal Concept in Nonlinear Sciences*, Cambridge University Press, 2001.
- S. Bregni: *Synchronization of Digital Telecommunication Networks*, Wiley, 2002.
- A. Tyrrell, G. Auer, C. Bettstetter. Emergent Slot Synchronization in Wireless Networks. *IEEE Transactions on Mobile Computing*. May 2010.



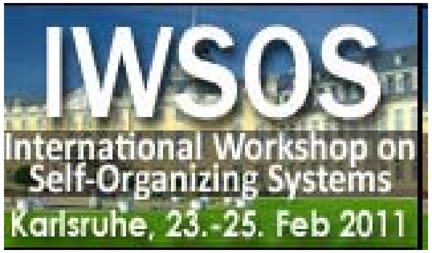


Literature: SO in Computer and Communication Networks

- S. Staab (Ed.): Neurons, Viscose Fluids, Freshwater Polyp Hydra—and Self-Organizing Information Systems, *IEEE Intelligent Systems*, July 2003.
- J. P. Hubaux *et al.*: Towards Self-Organizing Mobile Adhoc Networks: the Terminodes Project," *IEEE Communications Mag.*, January 2001.
- A. Sarma, C. Bettstetter, S. Dixit (Eds.): Self-Organization in Communication Networks. In *Technologies for the Wireless Future*, *Vol. 2,* Wiley, June 2006.
- C. Prehofer, C. Bettstetter: Self-Organization in Communication Networks: Principles and Design Paradigms. *IEEE Communications Mag.*, July 2005.
- F. Dressler: *Self-Organization in Sensor and Actor Networks*, Wiley, 2007.
- Q. H. Mahmoud (Ed.): *Cognitive Networks: Towards Self-Aware Networks*, Wiley, 2007.



International Workshop on Self-Organizing Systems (IWSOS)



Place: Karlsruhe, Germany

Date: February 23 - 25, 2010

Keynote speakers:

- Hermann Haken (U Stuttgart) – Synergetics
- Hod Lipson (Cornell Univ) – Evolutionary robotics

General and program chairs:

- Martina Zitterbart (U Karlsruhe)
- Hermann de Meer (U Passau)
- Christian Bettstetter (U Klagenfurt and Lakeside Labs)
- Carlos Gershenson (U Nacional Autónoma de México)