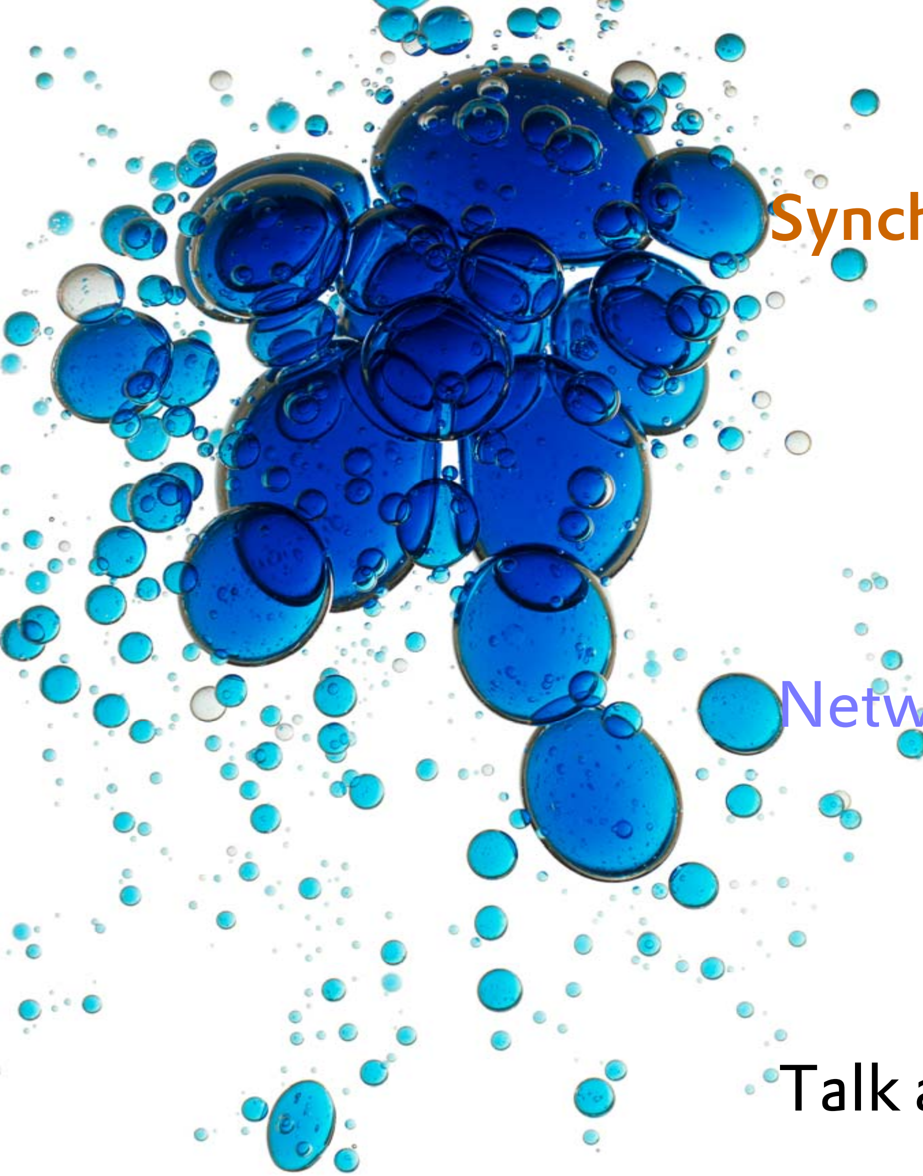


Synchronization and Dissemination in Self-Organizing Communication Networks

Christian Bettstetter

Networked and Embedded Systems

University of Klagenfurt

Lakeside Labs GmbH

Talk at the Vrije Universiteit Brussel

October 1, 2009

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT

Lakeside Labs

Visions from the past …

The Wireless Century

The citizens in 2010 will walk around with wireless trans-ceivers attached at hats or somewhere else.

The transceiver will react to myriads of vibrations trying to find connections.

Robert Sloß: Das drahtlose Jahrhundert.
In: *Die Welt in hundert Jahren*, Berlin, 1910.

… become reality.

- Computers become **embedded** into everyday objects.
- Computers become **invisible** to us.
- Objects are being networked.
  The **Internet of things** is evolving.
- **Sensors** play an important interface: they link the real to the virtual world.

These trends are likely to continue.

What is the Problem, if "Every Thing" is Networked?

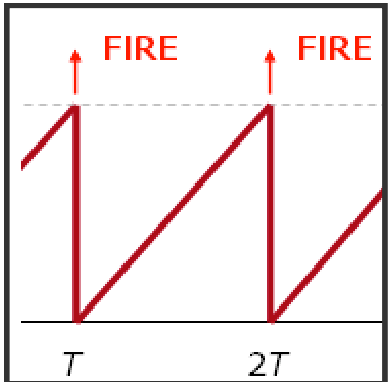
- Decentralized organization
- More dynamics
- More adaptability needed
- More administrative burden on users and administrators

Trend toward self-organization in communication networks:

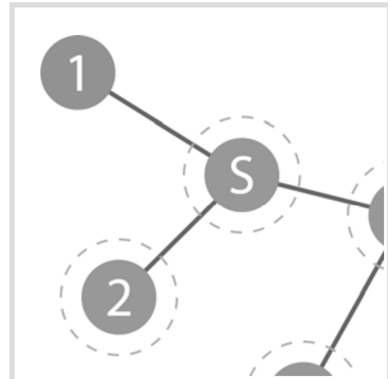
- Infrastructureless wireless networks (ad hoc networks)
- Internet autoconfiguration (fixed → stateful → stateless)
- Peer-to-peer overlay networks
- Web 2.0, Wikis

Outline

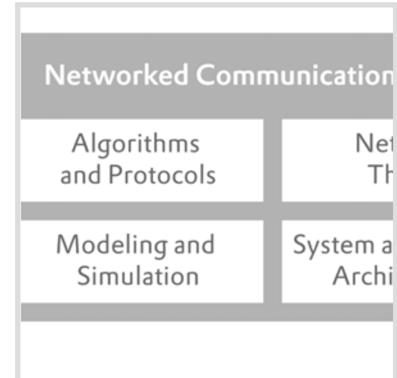
Introduction



Synchronization



Dissemination



Portfolio

Joint work with Alexander Tyrrell and Gunther Auer

NTT docomo
DOCOMO Euro-Labs

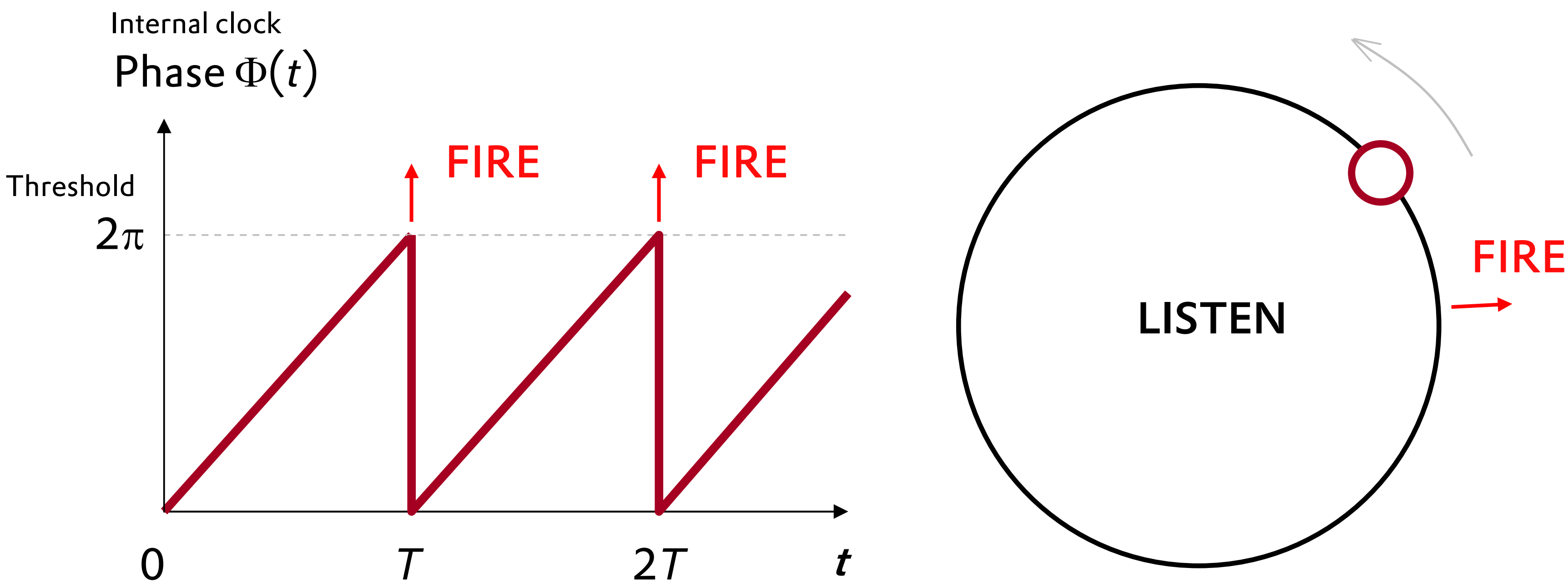
Design and assess a completely distributed time synchronization technique for wireless communication networks.

Time Synchronization of Fireflies in South-East Asia

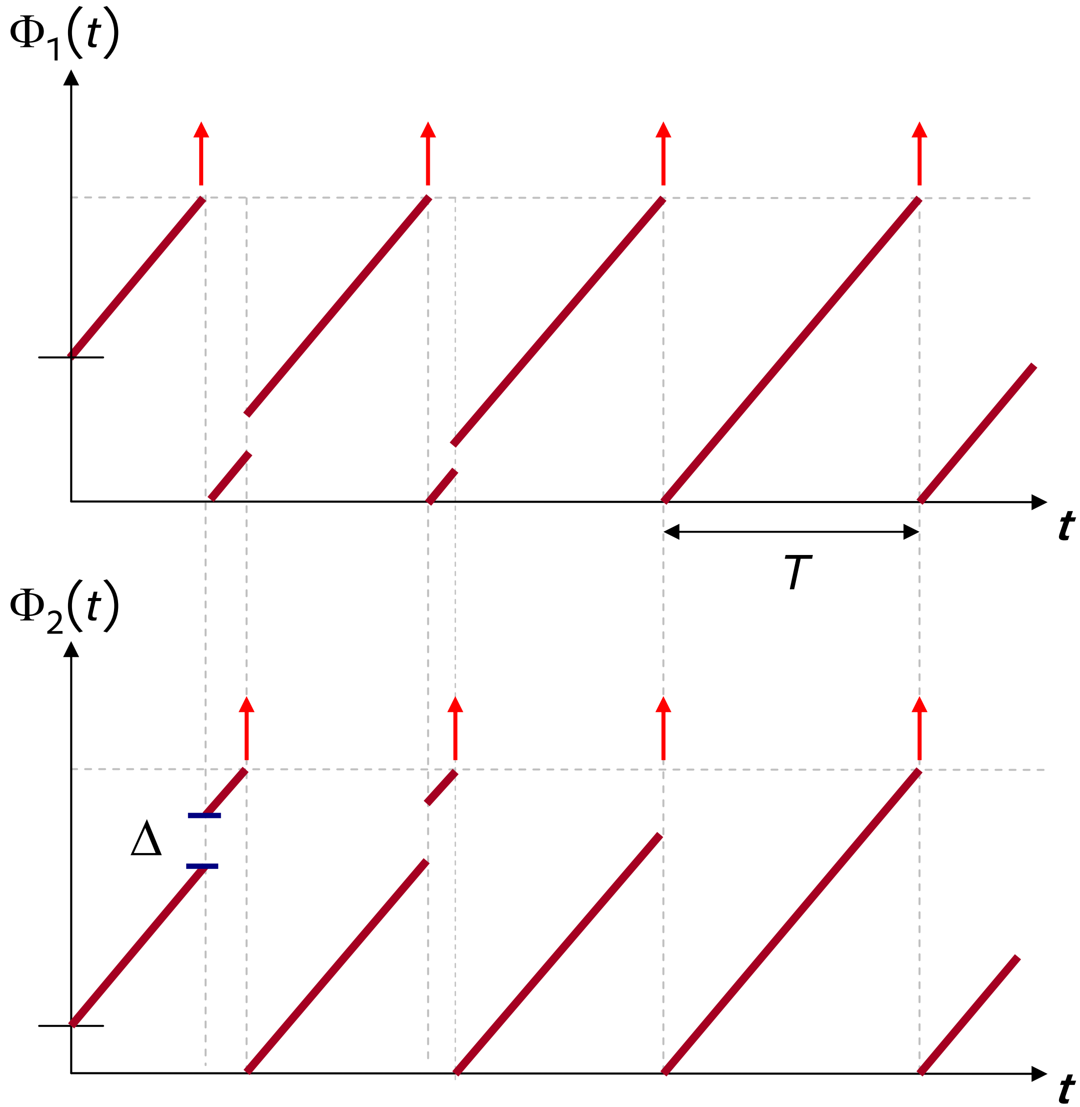
BBC video "Trials of Life"

"I could hardly believe my eyes. I saw .. a synchronal .. flashing of fireflies."
(P. Laurent, *Science*, 1917)

Modeling One Firefly: Integrate-and-Fire Oscillator

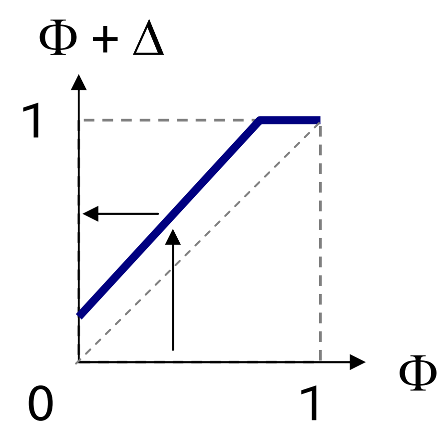


Modeling Two Fireflies: Coupled Integrate-and-Fire Oscillators

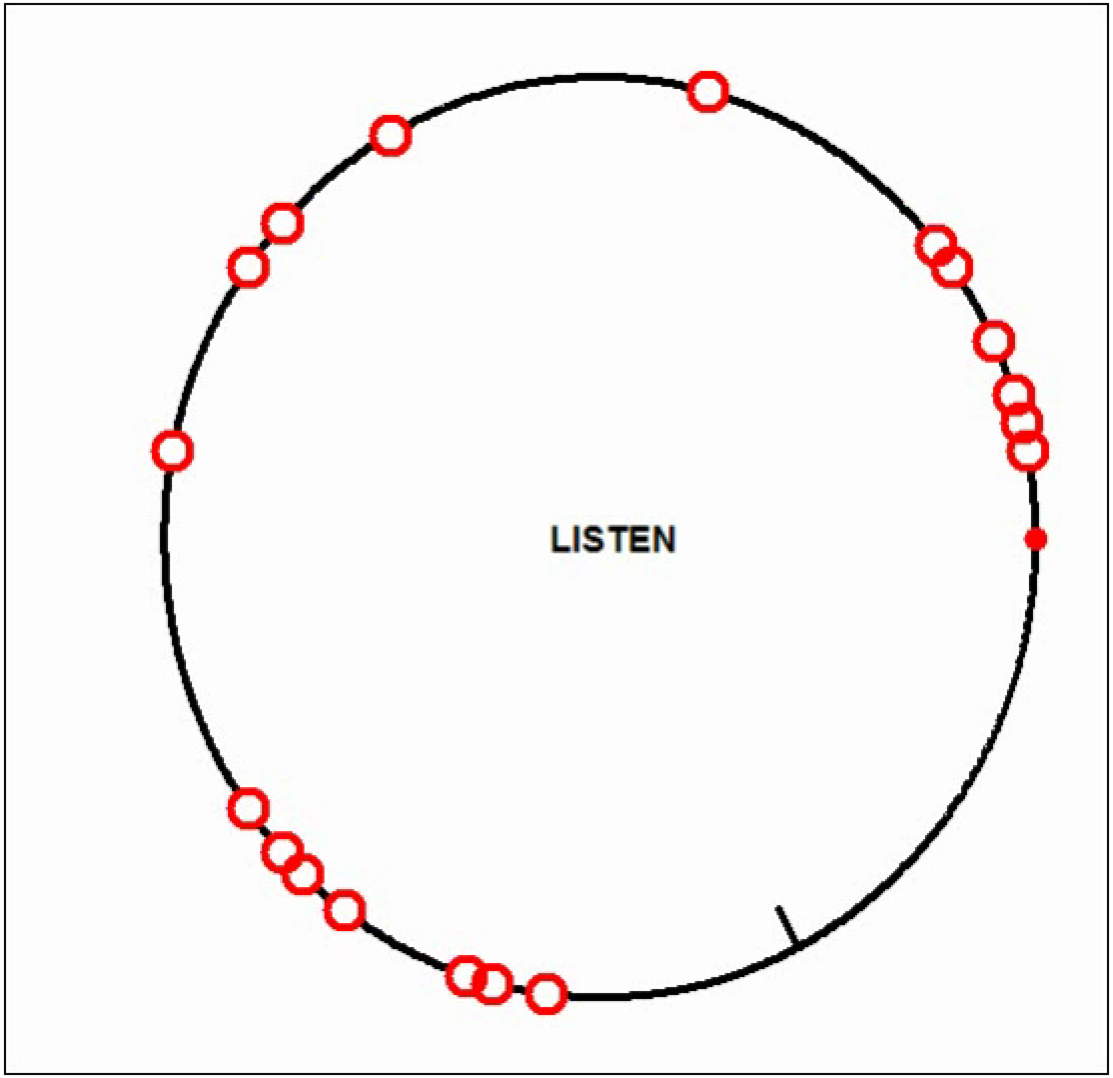


Firing of one oscillator causes other oscillator to increment phase $\Phi(t)$ by a value $\Delta(\Phi(t))$.

Phase jump: $\Phi \rightarrow \Phi + \Delta$



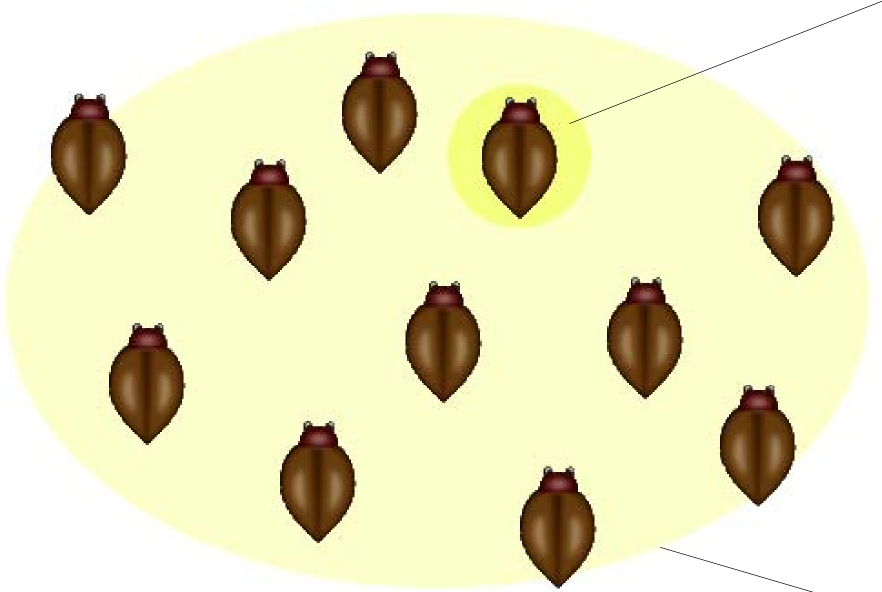
Several Coupled Integrate-and-Fire Oscillators



FIRE

Mathematically proven to lead to synchronization

Self-organizing Networked Systems



Individual Entity („Firefly“) *many*

- Local view
- Peer-to-peer communication
- No central entity
- Simple behavior rules

⇩ Emergence

Entire System (“Swarm”)

- Solves a complex task
- Acts in a coordinated manner
- Is adaptive and 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.

Our Research: Application to Wireless Networks

Problem statement: Can we apply this distributed algorithm to achieve slot synchronization in ad hoc networks?

Why is this algorithm appealing?

- Simple local behavior leads to synchronization of the entire network
- Algorithm is scalable and adaptive to changes in the topology
- Nodes do not need to distinguish between transmitters

Why do we need slot synchronization?

- Essential building block for functions in communications and control e.g. for medium access, distributed sensing, scheduling of sleep phases, and cooperative diversity

Can Firefly Synchronization be Applied to Wireless Systems?

Firefly algorithm assumes:

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

Removing one or more of these assumptions causes severe problems → Direct transfer to wireless systems is **infeasible**

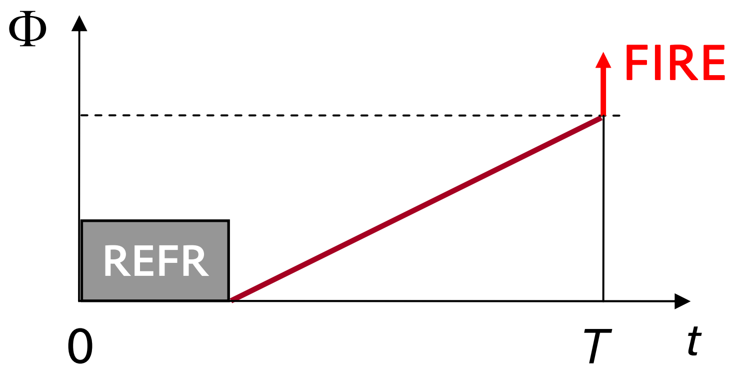
A. Tyrrell, G. Auer, C. Bettstetter: Biologically Inspired Synchronization for Wireless Networks. In *Advances in Biologically Inspired Information Systems: Models, Methods, and Tools*, Series: *Studies in Computational Intelligence*, Springer, 2007.

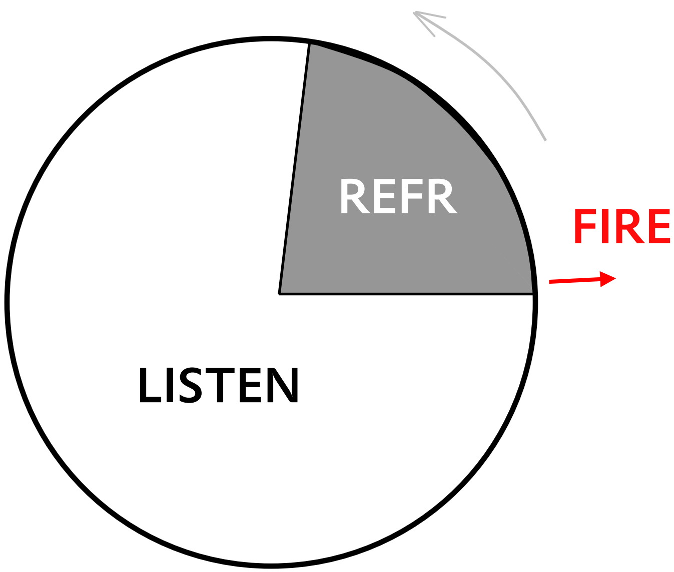
Example: Synchronization with Delays

Problem:

- Nodes may receive "echos" of their own firing, causing them to fire immediately again
- System becomes unstable

Solution:

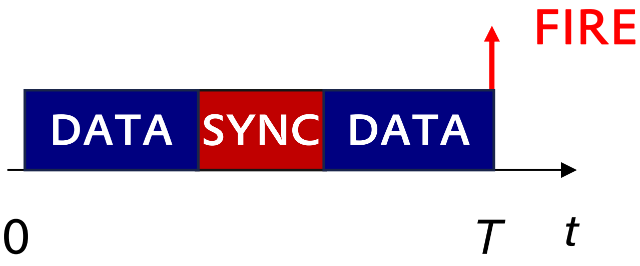




After a node has fired, pulses of other nodes are ignored for a certain REFRACTORY period.

Meshed Emergent Firefly Synchronization (MEMFIS) (1/4)

- Solution taking into account the **technological constraints** of wireless systems while maintaining nice properties of firefly sync.
- A **synchronization word** that is common to all nodes is **embedded** into each payload packet.
- This synchronization word is detected at the receiver using a cross-correlator.



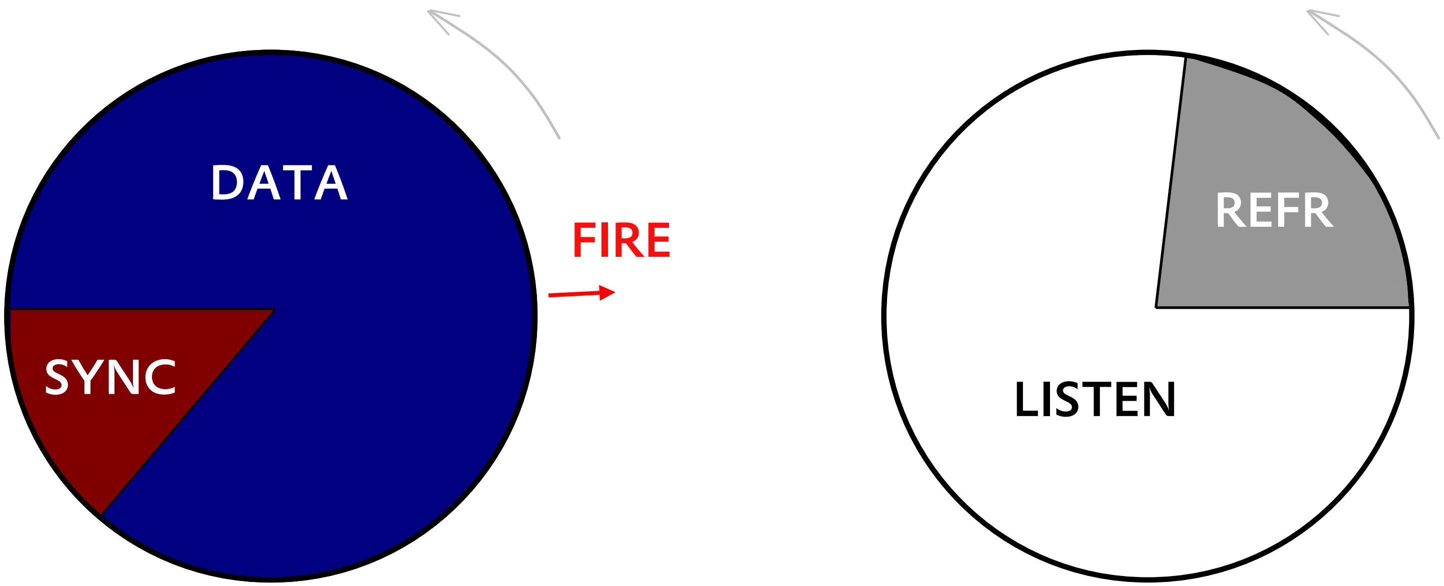
- Synchronization **emerges** gradually as nodes exchange packets randomly, hence avoiding a dedicated synchronization phase

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

Meshed Emergent Firefly Synchronization (MEMFIS) (2/4)

Node in transmit modus:

Node in receive modus:



A. Tyrrell, G. Auer, C. Bettstetter: Emergent Slot Synchronization in Wireless Networks.
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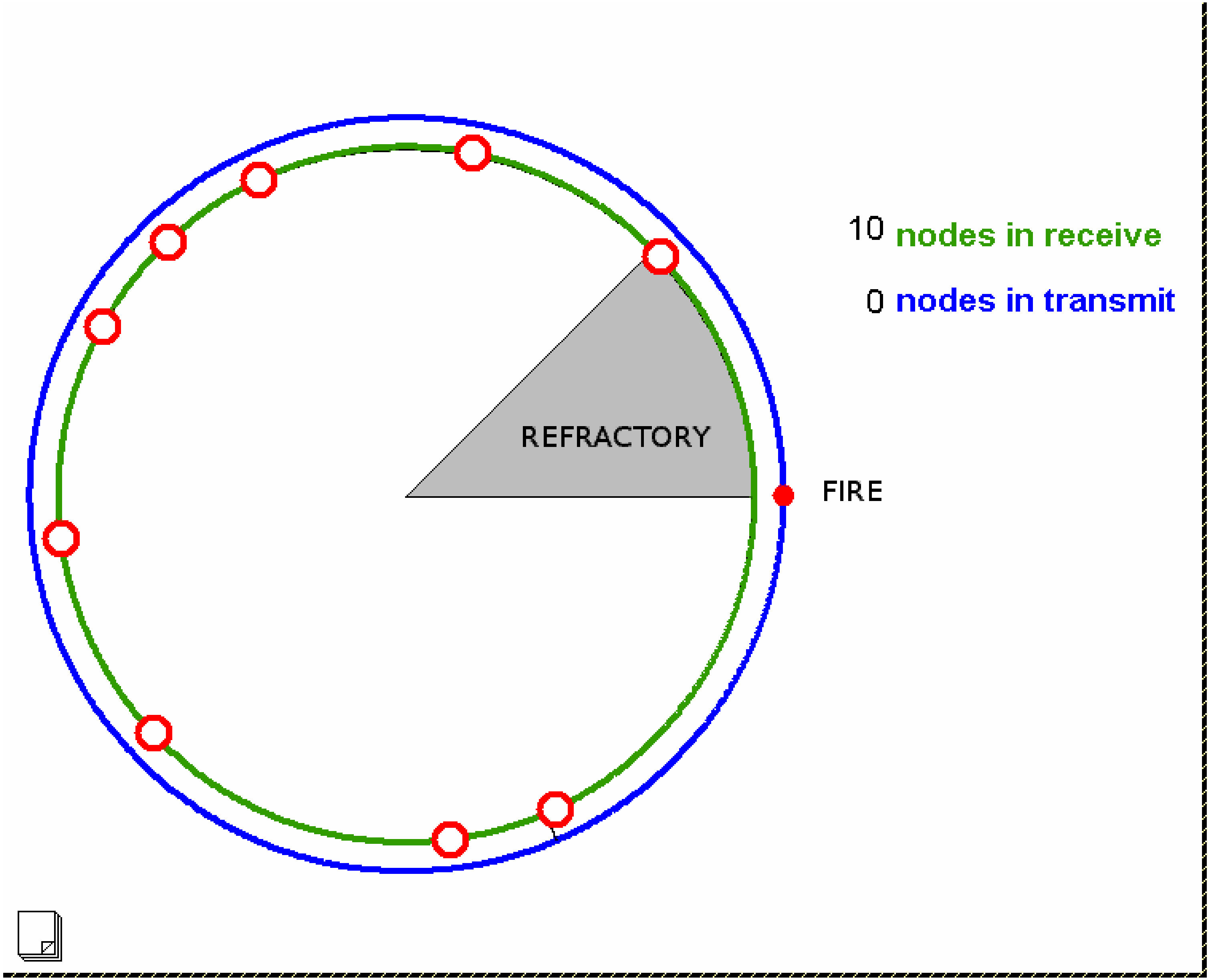
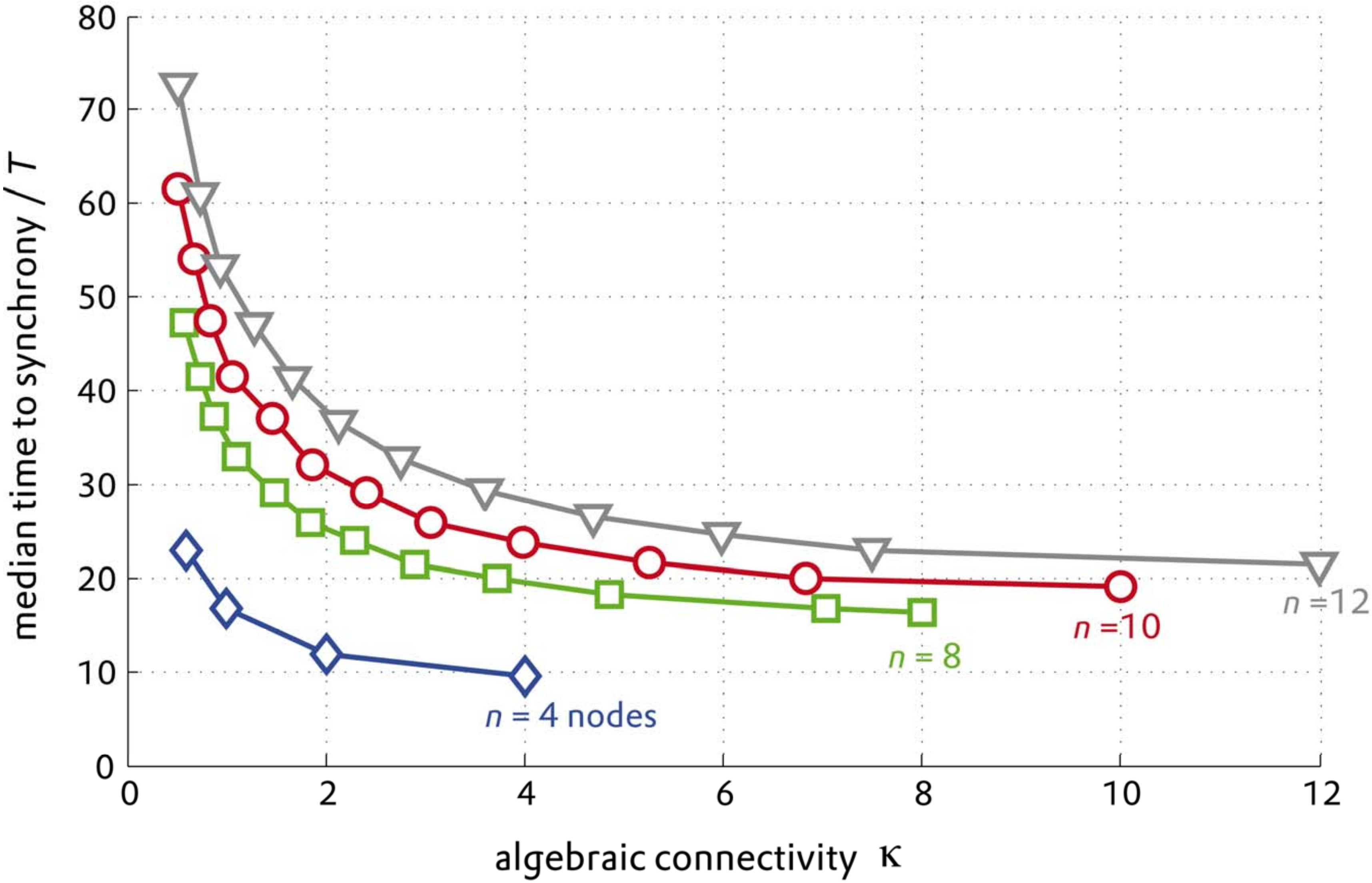
Meshed Emergent Firefly Synchronization (MEMFIS) (3/4)



Meshed Emergent Firefly Synchronization (MEMFIS) (4/4)



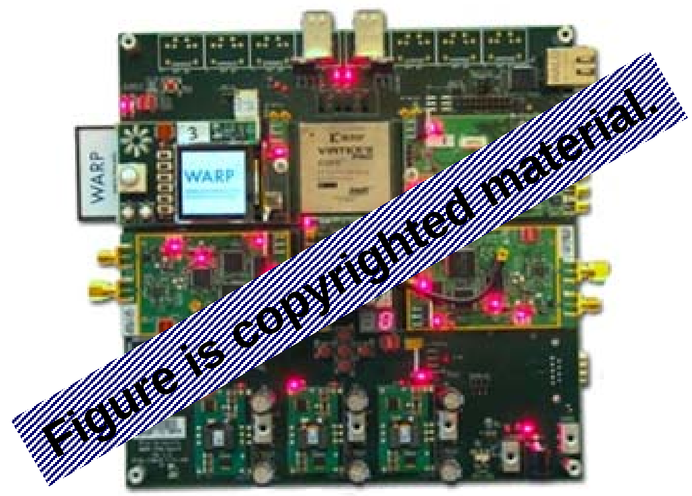
Ongoing and Future Work

Basic Research

- Robustness of synchronization against faulty and malicious nodes

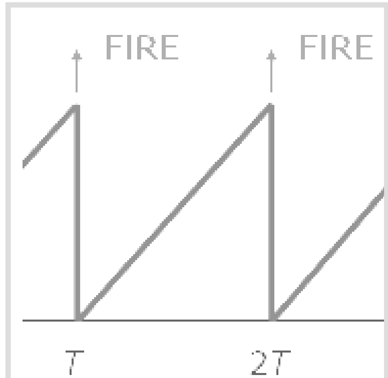
Demonstration and Prototyping

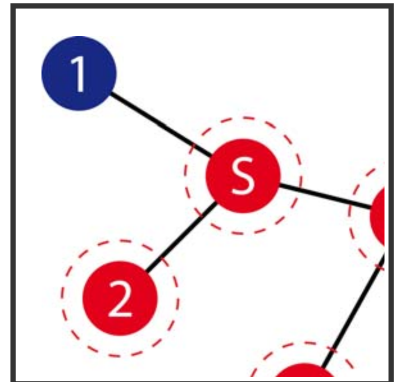
- Demo applications with
  - light and
  - audio signals
- Prototyping on the programmable radio platform WARP

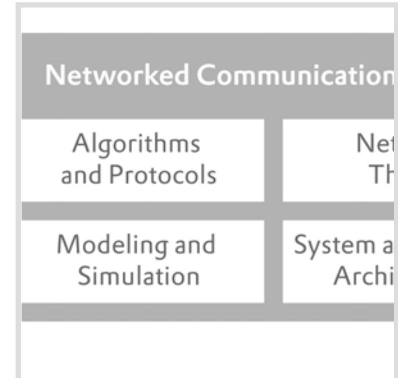


A. Tyrrell, G. Auer, C. Bettstetter: How Does a Faulty Node Disturb Decentralized Slot Synchronization over Wireless Networks? Submitted to *IEEE Intern. Conf. on Communications (ICC),* Cape Town, South Africa, May 23-27, 2010

Outline







Introduction   Synchronization   **Dissemination**   Portfolio

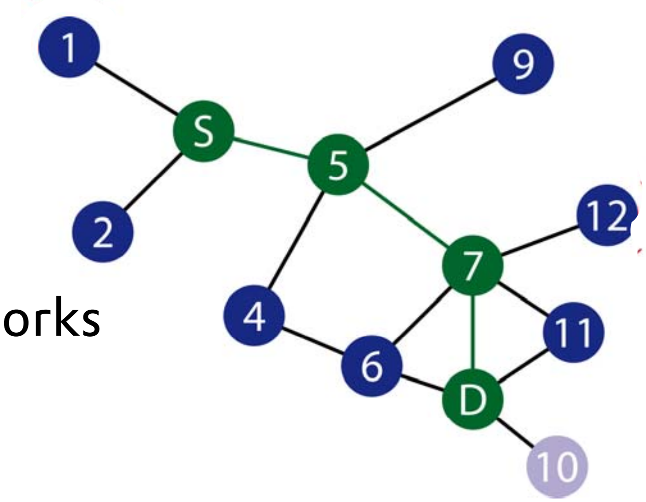
Joint work with Sérgio Crisóstomo, João Barros and Udo Schilcher

Gain deeper insight into information propagation in complex networks using techniques from stochastics and graph theory.

Motivation

Flooding is a basic technique for information dissemination.

- Route discovery in ad hoc networks
- Query propagation in peer-to-peer networks



Approaches

- Pure flooding: several redundant messages
- Deterministic flooding
- Probabilistic flooding

Our Research

- Study various flooding techniques in different types of networks
- Gain better understanding and propose improvements

Probabilistic Flooding in Random Networks

Probabilistic Flooding

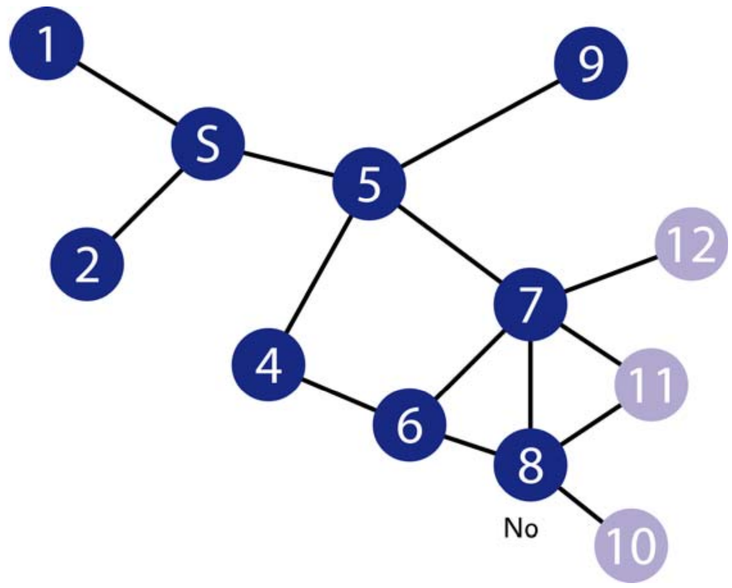
- Each node transmits a received message with given probability t
- A node only transmits a message not received before
- All neighbors of a node receive the message (broadcast medium)

Network Model

Erdös Renyi Random Graph $G(n, p)$

- n nodes
- Link between any pair of nodes exists with probability p

Example



Random Network

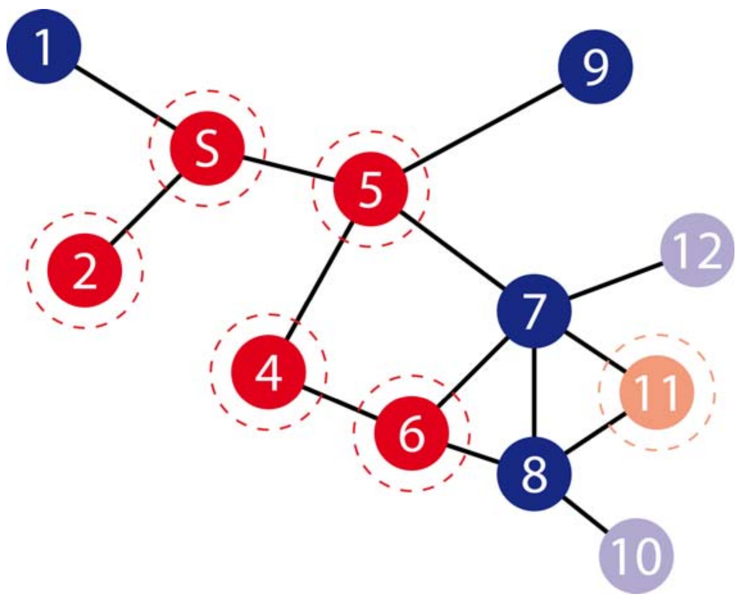
- $n = 12$ nodes
- Link probability $p = 0.1$

Probabilistic Flooding

- Source node S
- Node becomes forwarding node with probability $t = 0.3$

Problem statement (outreach probability): What is the probability Ψ that all nodes obtain the message for given n, p, and t?

Approach: Graph Sampling



A node can decide beforehand whether to become a forwarding node or not.

↓

Each node is chosen with probability t as a forwarding node independently of other nodes.

How should the forwarding nodes be located in the graph, to make the flooding process reach all nodes?

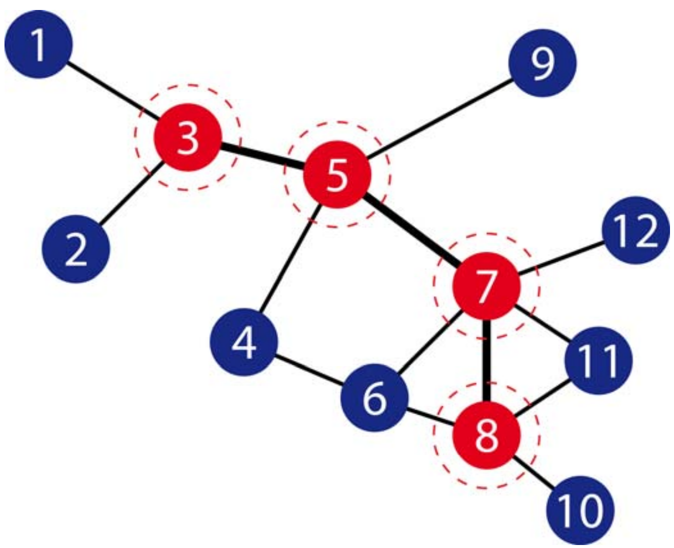
S. Crisóstomo, U. Schilcher, C. Bettstetter, J. Barros: Analysis of Probabilistic Flooding: How do we Choose the Right Coin? In Proc. *IEEE Intern. Conf. on Communications (ICC)*, Dresden, Germany, June 14-18, 2009.

Conditions for Outreach

The flooding process reaches all nodes only if both of the following conditions apply:

(1) The forwarding nodes **dominate** the graph G.

(2) The forwarding nodes are **connected**.



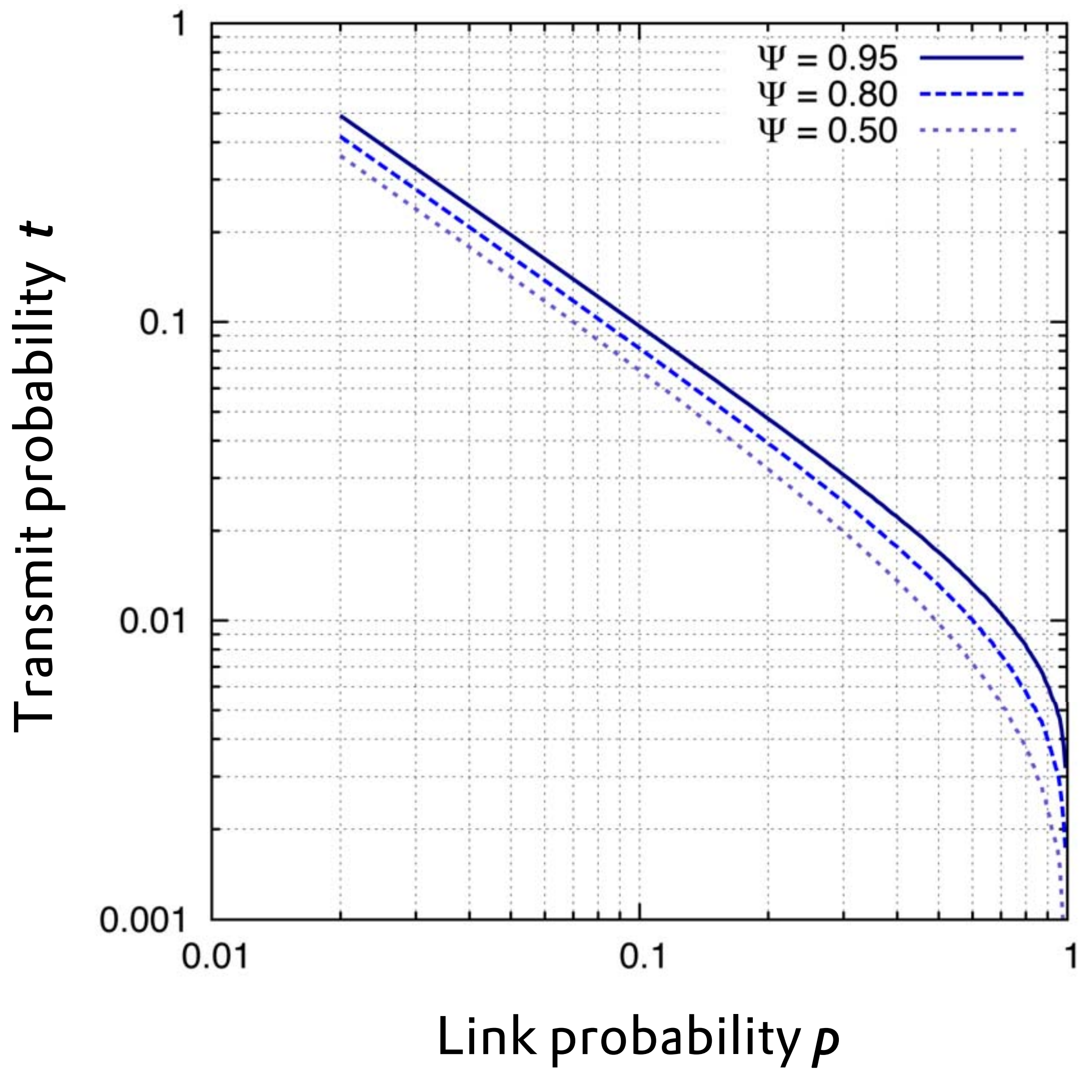
Connected dominating set G'

Outreach probability Ψ of a probabilistic flooding message

— *is equivalent to* —

Probability that a subset of nodes, randomly uniformly selected with probability t, is a connected dominating set.

(p, t)–Pairs yielding a desired Outreach Probability Ψ



Network with $n = 1000$ nodes

Finished, Ongoing, and Future Work

Flooding techniques

- probabilistic flooding
- multipoint relay flooding
- network-coded flooding
- adaptive techniques

Types of Networks

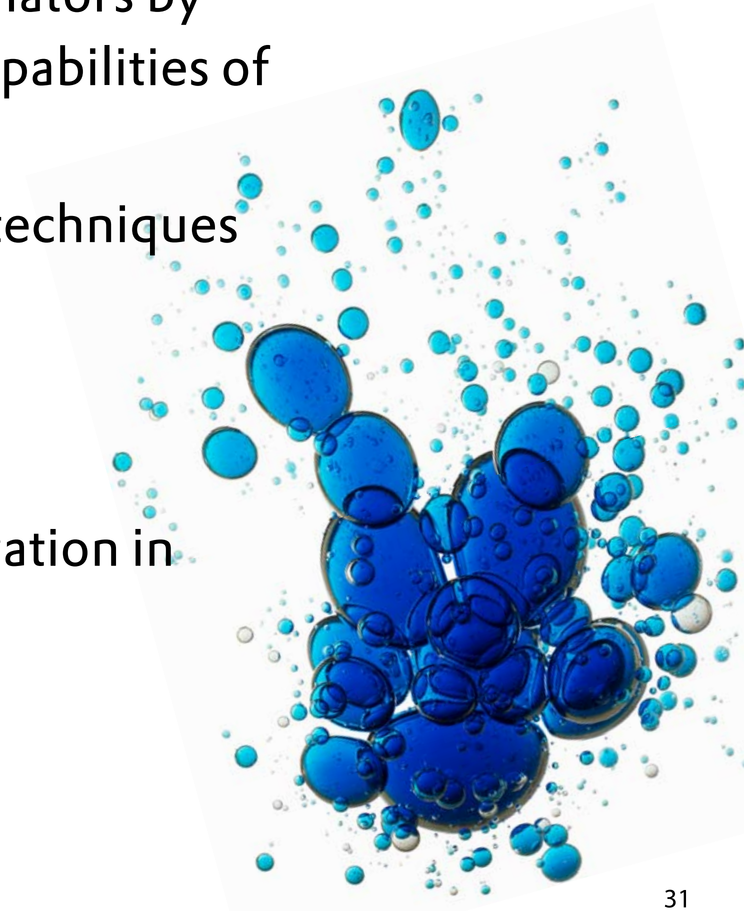
- random networks
- geometric random networks
- small world networks
- scale free networks

Summary

- Trend toward self-organization and cooperation at various layers of communication networks.
- Method for self-organizing **synchronization**, going beyond the theory of pulse-coupled oscillators by taking into account characteristics and capabilities of radio communications.
- Analysis of probabilistic **flooding**, using techniques from stochastics and graph theory.

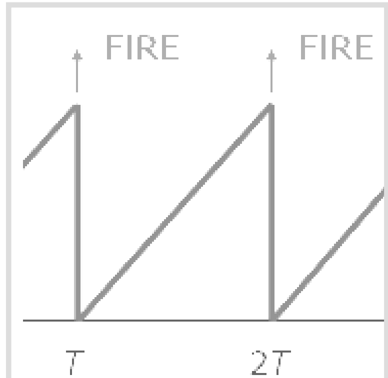
Outlook:

- General **design methods** for self-organization in networks.

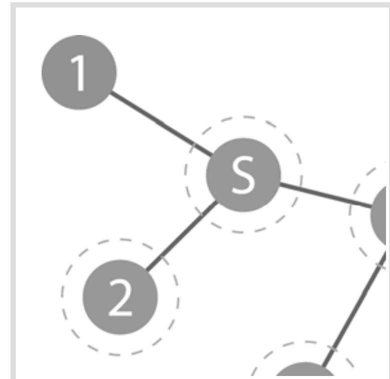


Outline

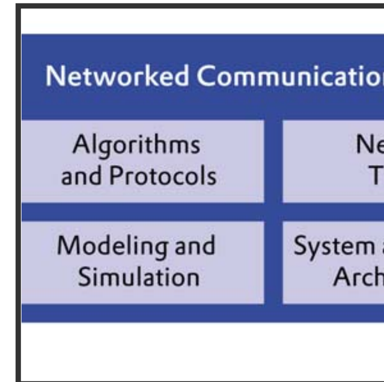
Introduction



Synchronization



Dissemination



Portfolio

Research Portfolio

Communication Networks
- Algorithms and Protocols
- Network Theory
- Modeling and Simulation
- System and Protocol Architectures

Focus on
- Mobile & Wireless Networking

Paradigms
- Self-organization
- Multihop relaying
- Cooperation
- Mobility

Funded Projects and Collaborators

Research projects

- Self-organizing synchronization in wireless systems (2 p)
- Flooding in complex networks (1 p)
- Cooperative relaying in wireless networks (4 p)
- Collaborative microdrones (1 p)
- Modeling of sparse networks (0.25 p)

DOCOMO Euro-Labs

Other projects

- Middleware for Network Eccentric and Mobile Applications (MiNEMA)
- Doctoral school „Interactive and Cognitive Environments“ (~75 p in total)

Thanks to the members of my team