Synchronization problems in multihop wireless networks

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Synchronization problems in multihop wireless networks

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Motivation

Sensor networks

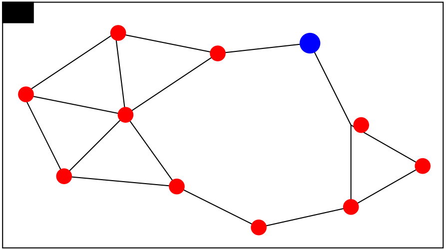
Ad hoc networks

Embracing asynchrony

SICS

Target tracking

Sensors report to sink



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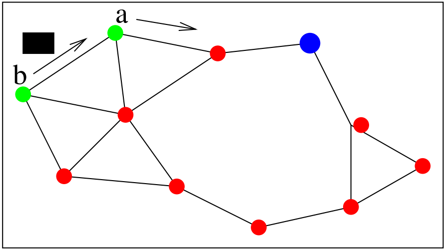

sensors detect target

SICS

Target tracking

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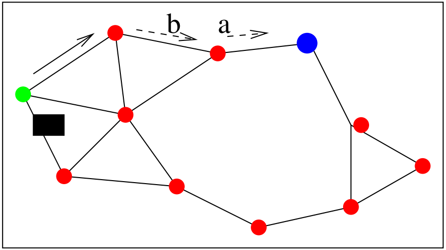
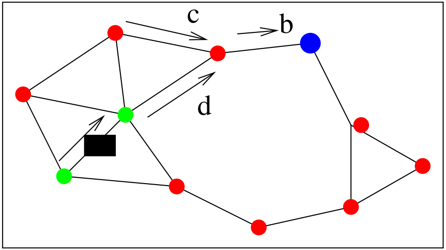


old and new messages in transit

Target tracking

Sensors report to sink



data compression (c-d)?

Target tracking

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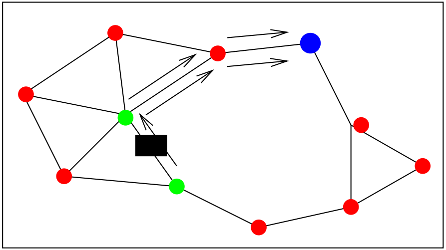

is $t_a > t_b$ or $t_b < t_a$?

Target tracking

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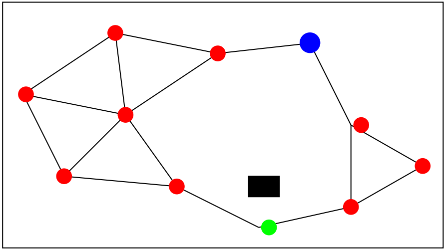

calculating velocity of target

Outline

introduction

- motivation

strictest requirements

- sensor networks

relax some requirements

- ad hoc networks

embracing asynchrony

- asynchronous protocols

Motivation

Why should I bother to discuss the problem?

Motivation

Why should I bother to discuss the problem?

(why should you bother to listen?)

Practical problem

Solutions depend on synchronized clocks

- secure protocols
- distributed protocols
    - channel access
    - group communication
- energy management
- sensor data analysis

Easy to get wrong...

Simulators are (necessary) evil

- simulations have poor communication models
  - RSS varies predictably with position ($1/R^{-\alpha}$)
  - RSS doesn't vary over time
- unrealistically reliable communication (esp. broadcast)

Easy to get wrong...

Simulators are (necessary) evil

- common simulation environments are implicitly synchronous
  - nodes turn on at time 0 and have identical clocks
  - periodic events are magically synchronized across the network
  - even under partition and merge...

Easy to get wrong...

Solving the right problem...

- What kind of synchronization is needed?
  - “new regime” - Elson and Römer
- global synchronization
- local (pairwise) synchronization
- on-demand synchronization
- periodicity
- virtual clocks

Hard problem

Assumptions don't hold...

- no infrastructure (e.g. NTP clocks)
- partition and merge
- variable delays, changing routes
- limited resources

Very hard problem

Sensor network context

- centralized structure
- limited resources
- variable connectivity (less mobility?)
- unstable clocks

Very hard problem

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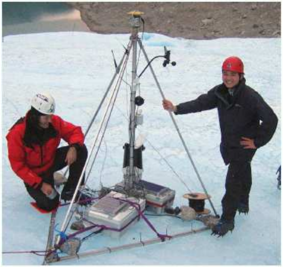

Very hard problem

Sensor network context

- centralized structure
- no resources
- variable connectivity (less mobility?)
- unstable clocks

Synchronization in sensor networks

Requirements are application-specific

- type of synchronization required
- accuracy

Two drivers

- sensor data analysis
- energy management

Synchronization

global (i.e. UTC) synchronization

- requires consistent access to UTC time
- functions across partition and merge
- federated sensor networks

local synchronization

- sensitive to partition and merge
- sufficient accuracy for many purposes

Synchronization

clock discipline

- clock offset vs clock drift
- continuous correction
- PLL (i.e. NTP) very expensive

Synchronization

clock discipline

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open(?) problem: merging clocks

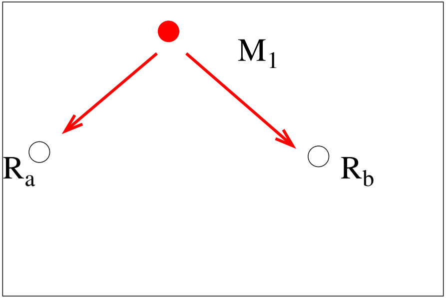
- "easily extended"

Synchronization in sensor networks

- receiver-receiver synchronization
  - Reference Broadcast Synchronization (Elson et.al.)
- sender-receiver synchronization
  - Lightweight Tree-based Synchronization (van Gruenen et.al.)
- on-demand synchronization
  - "post-facto" synchronization (Elson et.al.)

RBS (simplified)

receiver-receiver synchronization



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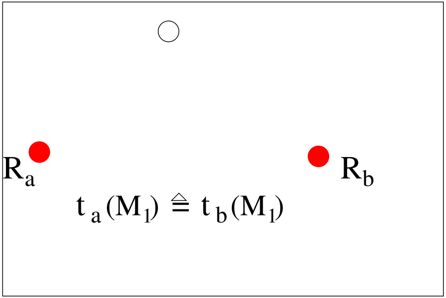

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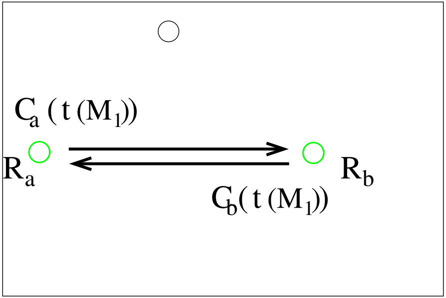

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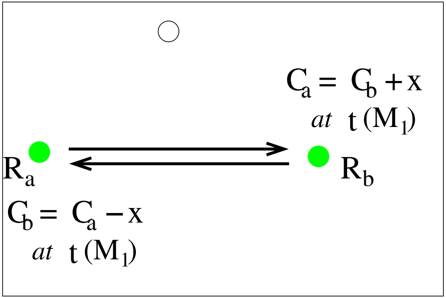
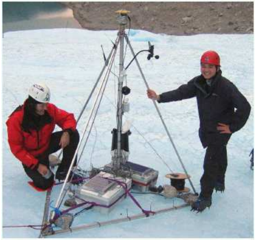


RBS (extensions)

- multiple broadcasts to minimize receiver variation
- statistical analysis to estimate clock skew (!)
- multi-hop synchronization
- on-demand synchronization

state of the art: 1's-10's μsec on mote hardware

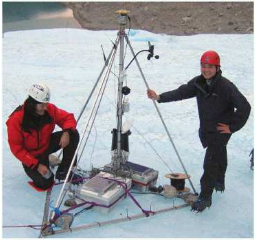
Intermittent connectivity



photo, K.Martinez

eight probes embedded in Norwegian glacier

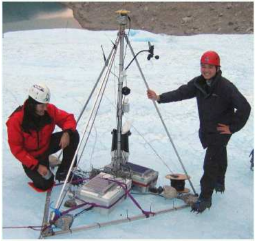
Intermittent connectivity



photo, K.Martinez

intended lifetime ≈ 1 year

Intermittent connectivity



photo, K.Martinez

probes: 6 readings/day (15 sec)

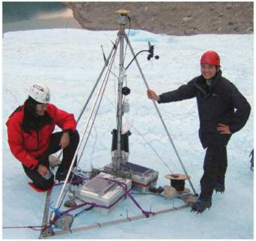
probes: 1 upload/day (3 min)

base: 1 wakeup/day (5-15 min)

base: 1 GPS/week (10 min)

intended lifetime $\approx$ 1 year

Intermittent connectivity



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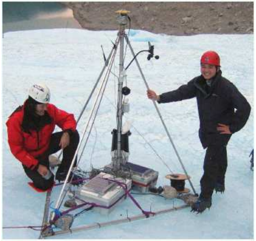
some probes not recovered after base station failure

Intermittent connectivity



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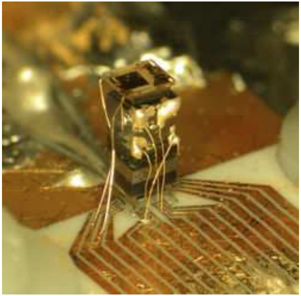
University of Southampton, UK
http://envisense.org/glacsweb/index.html

The future


photo, US NIST

chip-scale atomic clock (1cm, 75mW)
http://tf.nist.gov/ofm/smallclock/

Synchronization in adhoc networks

Relax requirements

- global synchronization
- resource availability

Energy management

- idle interface consumes energy
- maximize time in sleep state

Synchronous protocol

Distributed election of topological cover

- clustering
- dominating-set

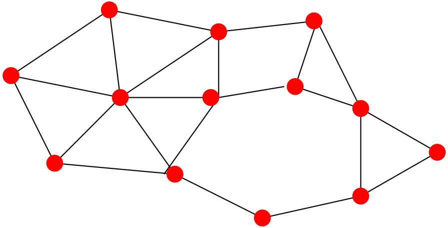
Mimics operation of base station

- clusterhead nodes buffer traffic
- non-clusterhead nodes sleep
- e.g. Chen et.al. 2001

Topology discovery is synchronous...

Example

Power save protocol



nominate a “covering set”
(minimum dominating set)

Example

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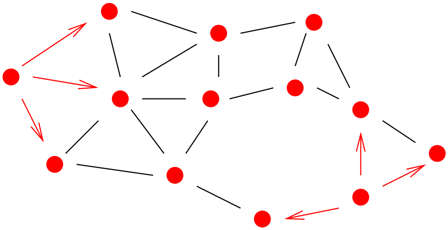

broadcast messages for topology discovery

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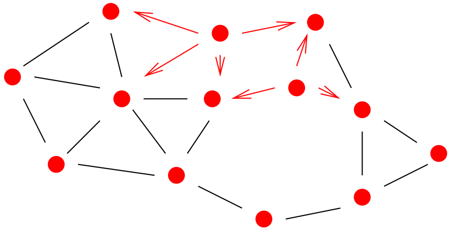

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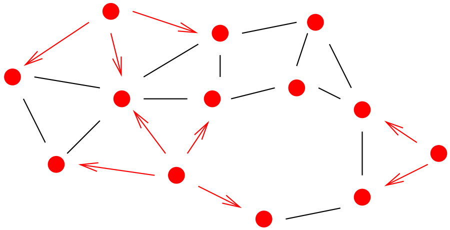

CSMA prevent many (not all) collisions

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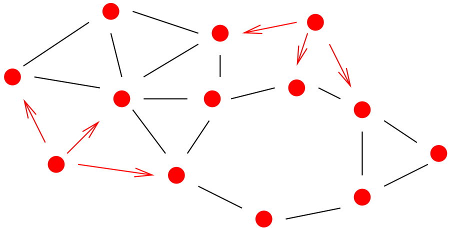

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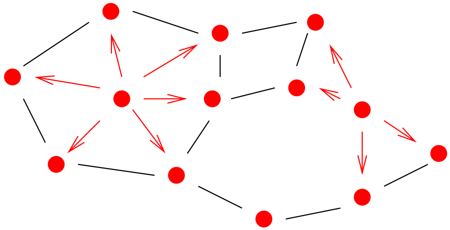

given 2-hop topology, nodes estimate their suitability

Example

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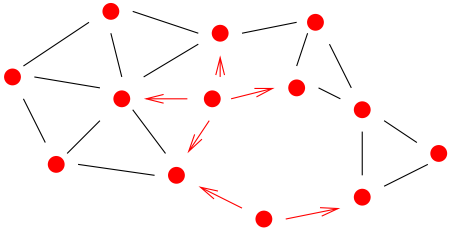

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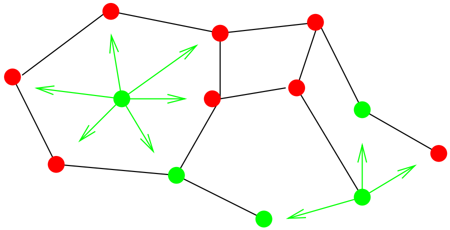

clusterheads elect themselves
(adaptive backoff)

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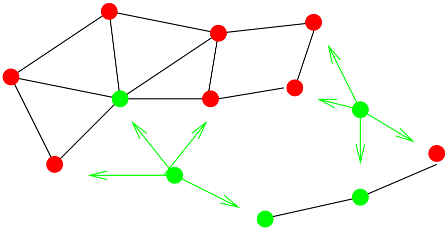

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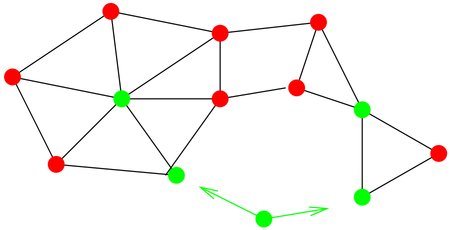

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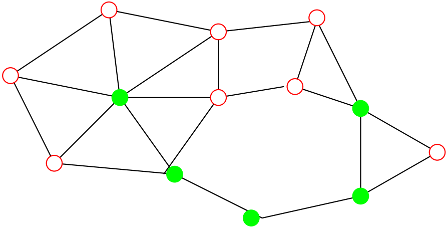
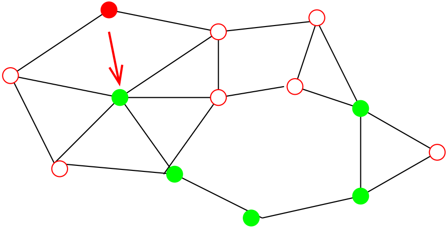


non-clusterheads periodically wake up

Example

Power save protocol



clusterheads buffer traffic for non-clusterheads

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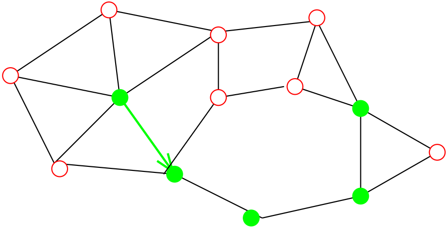

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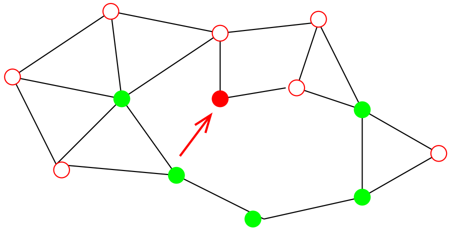

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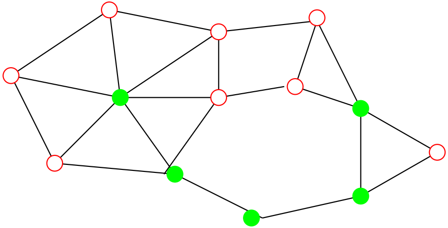

topology discovery must(?) be synchronous

Synchronization problems in multihop wireless networks

Laura Marie Feeney

Motivation

Sensor networks

Ad hoc networks

Embracing asynchrony

Example

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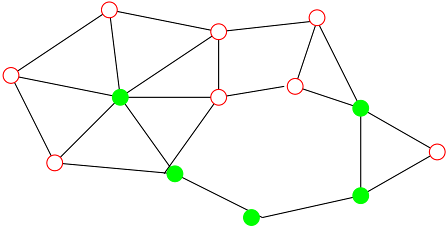


open(?) problem: conditions for asynchronous discovery/election to converge?

Asynchronous protocols

No synchronized sleep/wake

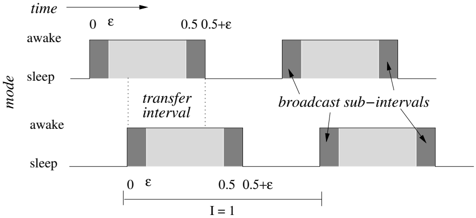
- PHY layer
  - energy sampling
  - preamble sampling (low-traffic networks)
- probabilistic
  - eventually communicate with some neighbor (with high probability) (dense networks)

Asynchronous protocols

No synchronized sleep wake

- asynchronous schedules
  - well-known, periodic wakeup schedule
  - unknown offset to neighbors' schedules
  - deterministic overlap of wake intervals
- use overlapping intervals
  - traffic announcement (wake up message)
  - discovery of offset to neighbor's schedule

Simple deterministic protocol



nodes are awake ϵ more than 50%

guaranteed to overlap with neighbors

Feeney('02), Tseng,Jiang('02,'05)

Complex protocols

More complex periodic schedules have lower duty cycles

- quorum schedule (Tseng, Jiang et.al.)
- block schedule (Zheng et.al.)
- hybrid probabilistic (Hurni et.al.)

Intuition

Nodes discover their neighbors' schedules.

Transmission window when both nodes are awake.

Intuition

Intuitively, some wakeup schedule distributions will be “friendlier” than others.

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- How much friendlier?
- Can we ensure friendliness?

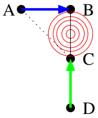
Intuition

Intuitively, some wakeup schedule distributions will be “friendlier” than others.

- How much friendlier?
- Can we ensure friendliness?
- Without solving distributed STDMA...

Wakeup schedule distributions

transmit $A \longrightarrow B$ and $D \longrightarrow C$



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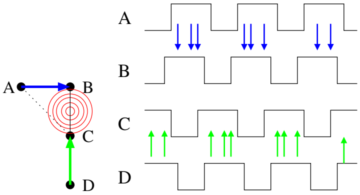

wakeup distribution reduces contention

Wakeup schedule distributions

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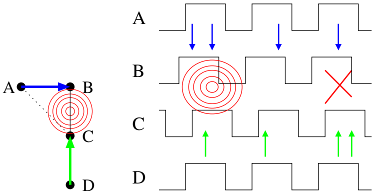
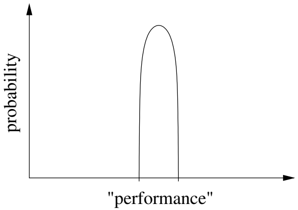


wakeup distribution increases contention

Thought experiment

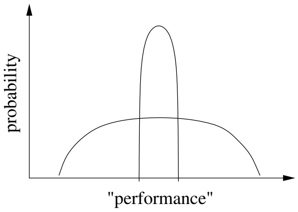
- fix topology/traffic scenario
- measure network "performance" for many wakeup schedule distributions
- performance measurements define probability distribution

Thought experiment



a narrow distribution implies that wakeup schedule distribution has little overall impact

Thought experiment

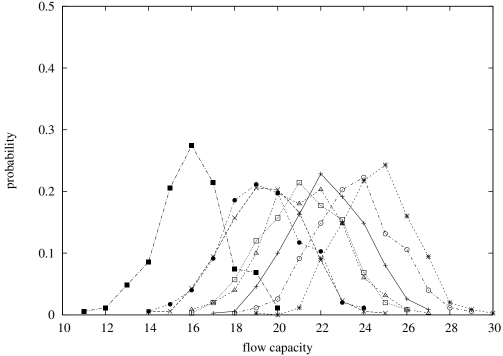


a flat distribution implies high sensitivity
randomized strategies may be useful

Non-thought experiment

For each topology, the flow capacity measurements form a probability distribution, showing sensitivity to wakeup schedule distribution.

Non-thought experiment



8 topologies (large rectangle, 100 nodes)

Non-thought experiment

"Friendly" wakeup schedule distributions provide almost twice as much capacity as "unfriendly" ones.

Friendly distributions

Asynchronous system

- easy to change the distribution
- for the better?
  - randomization?
  - feedback loops?

wakeup overlaps define coarse grain, variable length transmission opportunities (“slots”)

Hypothesis

(quasi-)periodic emergent behavior provides

- soft structure
- (quasi-)predictability

leverage these patterns for higher layer (approximate) traffic management

Biological models?

Question: Do "biological" models apply?

Most "biological" protocols assume lowest level functionality

- e.g. assumes CPU, OS, packet transmission
- "ant-based" ad hoc routing uses packets

Distributed emulation of biological process

Biological models?

A "biological" MAC or L2.5 approach would be quite different.

What does a "biological" PHY look like?

Biological models?

A “biological” MAC or L2.5 approach would be quite different.

What does a “biological” PHY look like?

Very open problem:

- non-packetized PHY/MAC for sensor network?

Thanks!

ACM Workshop on Real-World Wireless Sensor Networks

REALWSN'06

http://www.sics.se/realwsn06/