Self-Organizing Time Synchronization of WSNs with Adaptive Value Trackers

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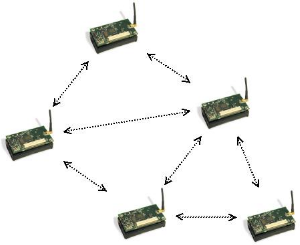
Need for "Time" Synchronization in Wireless Sensor Networks (WSN)

Tiny sensor nodes with **limited** battery, memory, computation capability.



- **read-only hardware clock**
  - provides **local time notion**
  - frequently **drifts apart** due to aging, battery level, temperature etc.

- WSN applications such as **target tracking** require **global time notion**.

There is a need for *time synchronization* where...

- a *logical clock* value (representing the **global time**) is calculated

Why Self-Organization for Time Synchronization in WSNs?

- When frequent topological changes & node failures in WSNs are considered
  - **local** interactions (peer-to-peer)
  - **decentralized** control (no reference node)
  - **simple** behaviors (no hierarchical topology)
  - **global** organization (network-wide synchronization)
  - **dynamic** adaptivity (reaction to topological changes)

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and these are...

...the properties of **self-organizing systems!** [Serugendo et al., 2011]

- **Several** self-organizing synchronization solutions in the literature! [Babaoglu et al., 2007, Tyrrell and Auer, 2008, Leidenfrost and Elmenreich, 2009, Tyrrell et al., 2010, Pagliari and Scaglione, 2011, Klinglmayr and Bettstetter, 2012, Zhang et al., 2012]
  - either **not designed** for WSNs
  - or provide **only synchronicity,** not **Global Time Notion = Sychronized "Time"**

Why we should want a new protocol?

- Besides, there are **practical** synchronization protocols
  - **a special node acting as a time reference** [Elson et al., 2002, van Greunen and Rabaey, 2003, Ganeriwal et al., 2003, Dai and Han, 2004, Maróti et al., 2004, Sun et al., 2006, Kusy et al., 2006, Lenzen et al., 2009, Schmid et al., 2009, Schmid et al., 2010, Ferrari et al., 2011, Yildirim and Kantarci, 2013b, Yildirim and Kantarci, 2013a]
  - **building a communication infrastructure** (e.g., **a spanning tree**) [van Greunen and Rabaey, 2003, Ganeriwal et al., 2003, Dai and Han, 2004, Sun et al., 2006]
  - **can only provide synchronicity** [Werner-Allen et al., 2005, Yu and Tirkkonen, 2008]
  - **keeping track of** the **time information** of **neighboring nodes** [Sommer and Wattenhofer, 2009, Schenato and Fiorentin, 2011]
    - causes **memory overhead**
    - which neighbors **to track**? which ones **to discard**?
    - a big problem especially in **densely connected** networks [Dousse and Thiran, 2004]

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What we want is to achieve ...

self-organizing time synchronization **without keeping track of neighbors**.

Self-Organizing Time Sychronization Protocol (STSP)

STSP Algorithm

- Periodically **broadcast the logical clock value to the neighbors (beacon period)**
- **Upon receiving the logical clock value of a neighbor**
  1. **calculate the difference (clock skew)** between my logical clock and the received value
  2. **add clock skew / 2** to my logical clock
  3. **if clock skew** is **lower than** the **max possible skew**
     1. **if clock skew > 0, speed up** my logical clock
     2. **if clock skew < 0, slow down** my logical clock
     3. **else the speed** of my logical clock is said to be **good**

But how this speed adjustment is done?

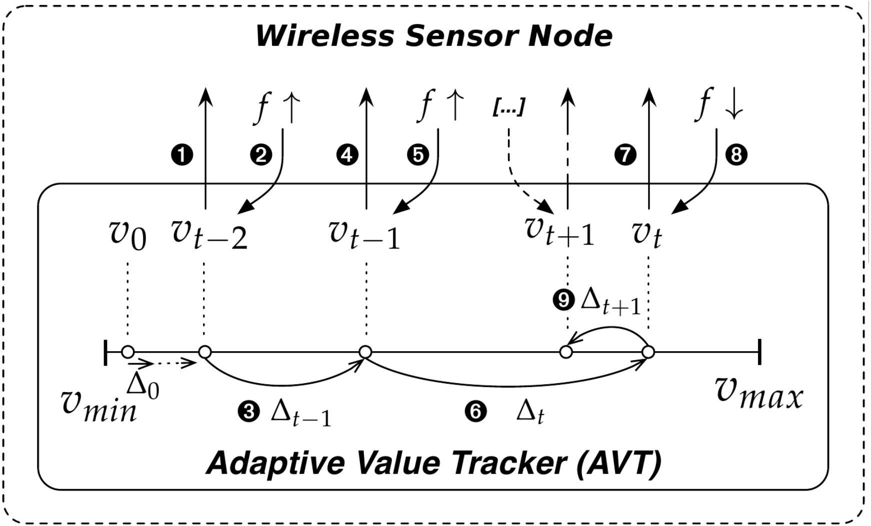

Figure: Let's begin with v_0 and try to find the best value between v_{min} and v_{max}.

STSP Simulation Setup

- **networks consisting of 100** sensor nodes
  - with **densities 10**, **20** and **50**
- **clock drifts** - uniformly distributed [-10^{-4}, 10^{-4}]
- **delays** on the communication links - gaussian random variable
- beacon period of **30** seconds.
- AVT params: $v_{min} = -10^{-4}, v_{max} = 10^{-4}$, $\Delta_{min} = 10^{-10}, \Delta_{max} = 10^{-5}$

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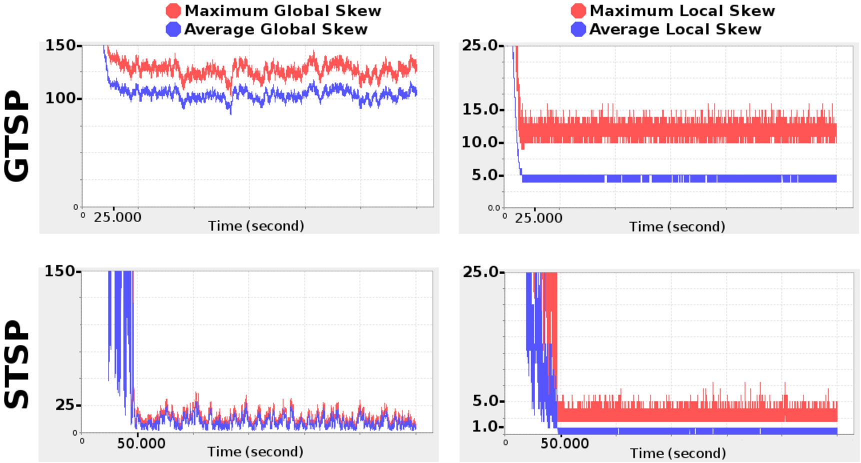
compared with Gradient Time Synchronization Protocol (GTSP) [Sommer and Wattenhofer, 2009]

- converges to the average clock value/speed of all neighbors
- allocates memory to keep track of each neighboring node
- lots of computation for each neighbor

Evaluation metrics: instantaneous synchronization errors

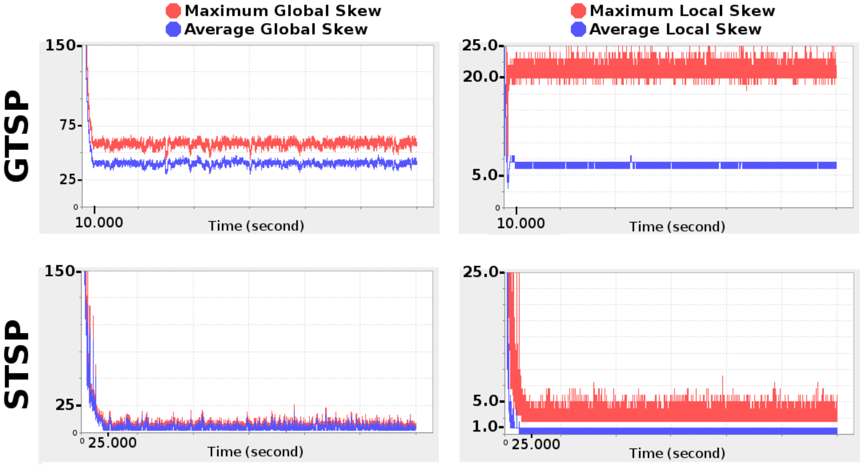
- global skew (arbitrary nodes)
- local skew (neighboring nodes)

Low Density Results - 100 nodes 10 neighbors



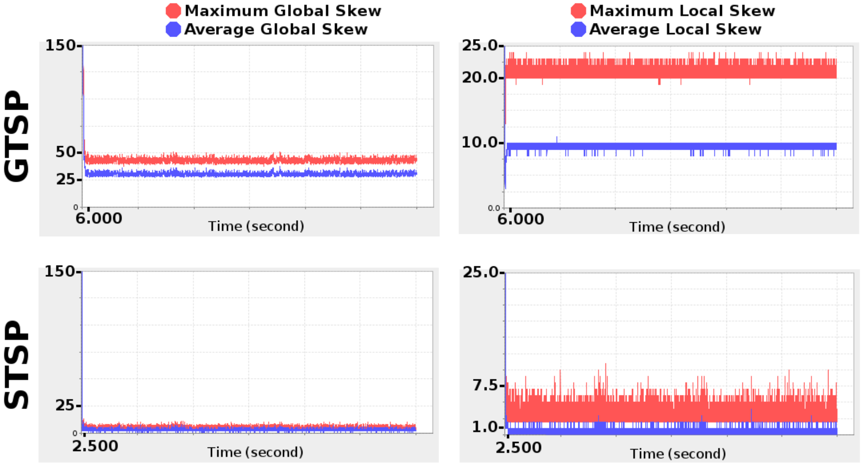
Tighter synchronization :-), worse convergence time :-(

Midium Density Results - 100 nodes 20 neighbors



Tighter synchronization :-), worse convergence time :-(

High Density Results - 100 nodes 50 neighbors



Tighter synchronization :-), better convergence speed :-)

Why STSP is meaningful for you?

- **Scalable**
  - the **denser** the network, the **tighter** the synchronization was
  - **memory & CPU requirements remain the same**.
- **Adaptive**, not **adaptable**.
  - **adaptive** - maintains **some** stable states (e.g., **any** global time value)
  - **adaptable** - maintains **particular** organization (e.g., a **specific** global time value)
- **Adaptivity** is provided using **Adaptive Value Trackers (AVTs)**
  - requires **quite a few arithmetic operations**
  - parameters to be set **carefully**, e.g. high precision (Δ_{min}) is **not good**

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Can AVTs improve robustness against faulty behavior?

- **Yes**. Because the Δ values converge Δ_{min}
- But **successive erroneous feedbacks** would increase the Δ values **exponentially**

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