Adaptive Synchronization of Robotic Sensor Networks

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What time is it?

- Low-cost built-in clocks - **local time notion**
  - A **read-only** counter register
  - A **low-cost** crystal oscillator
    - temperature, voltage level and aging of the crystal
    - *clock drift* - does not generate ticks at the exact speed of real-time.
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Exchange information to calculate a logical clock - common time
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**Time Synchronization**

Exchange information to calculate a **logical clock** - **common time**

- Sources of errors
  - *transmission delay*
    - composed of deterministic and non-deterministic components
    - reception of outdated time information due to delays
  - *frequency* of the built-in clock
    - *quantization errors* - low-frequency built-in clocks
Exchange of Time Information

- **Flooding Time Information**
  - A **reference** node *floods* its current time - **periodically**
    - built-in clock \( \text{relationship} \leftrightarrow \text{reference time} \)
    - broadcast predicted time - **network-wide synchronization**

- **Peer-to-Peer Communication**
  - No special **reference** node
    - Communicate with and synchronize to direct neighbors.
Calculation of the Logical Clock

Least-Squares Regression - PulseSync [Lenzen et al., 2009]
Distributed Averaging - GTSP [Sommer and Wattenhofer, 2009]
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**AVTS - STSP** [Gürçan and Yildirim, 2013, Yildirim and Gürcan, pear]

**Algorithm 1.** Speed tracking code for robot $u$
1: if error $> 0$ then avt$_u$.adjust($f \uparrow$)
2: else if error $< 0$ then avt$_u$.adjust($f \downarrow$)
3: else avt$_u$.adjust($f \approx$)
High Dynamics of the Network Topology

- Aforementioned protocols
  - periodical and almost reliable communication among the nodes.
    - more noise, collisions and packet losses?
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  - more noise, collisions and packet losses?
- performance evaluation on *static* and *non-mobile* topologies.
  - instantaneously start to receive time information from *badly synchronized* nodes?
  - dense and sparse areas?
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- It is still unknown whether the existing solutions are still applicable under **mobile network dynamics** or not:
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**Our Question**

Are networked robots still be able to adapt themselves and self-adjust their logical clocks while meeting the pre-defined synchronization performance?
Simulations

- Implemented PulseSync, GTSP, AVTS and STSP in our simulator.
- 300x300 meter square area, Transmission range - 25 meters.
- Probabilistic radio model (Gaussian wireless channel) with CSMA based MAC layer.
- Beacon period of 30 seconds.
- Random Waypoint Mobility Model
- 1 MHz built-in clocks with **constant drift clock model** (drift is uniformly distributed within the interval of ± 100 ppm).
- The least-squares regression tables are **composed** of 8 entries and each node tracks at most 10 neighbors.
Results

K.S. Yildirim, O. Gurcan
Adaptive Synchronization of RSNs

Flooding-based AVT

PulseSync

Peer-to-peer AVT

GTSP

Maximum Global Skew — Average Global Skew
Lessons Learned

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  - all of the network *should be connected* at pulse times
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- **GTSP**
  - *keep track* of their neighboring robots
    - which neighbors to *keep track* and which ones to *discard* in *dense* areas
  - detection of the *neighborhood change* is another crucial problem
    - *not suitable* for mobile robotic networks and exhibits a poor performance

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- **Peer-to-peer** approaches are expected to have a better performance in mobile networks.
- However, **flooding-based options perform better** and **establishes** network-wide synchronization **faster**!
Future Questions

- What happens if the reference node **dies**?
  - Reference node **election**?

- How to achieve gradient time synchronization **faster** and **better**?

- How to separate **stable** and **unstable** nodes?
  - Synchronize to **well-synchronized nodes**?
THANK YOU!
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