Adaptive Synchronization of Robotic Sensor Networks

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What time is it?

- Low-cost built-in clocks - \textit{local time notion}
  - A \textit{read-only} counter register
  - A \textit{low-cost} crystal oscillator
    - temperature, voltage level and aging of the crystal
    - \textit{clock drift} - does not generate ticks at the exact speed of real-time.
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**Time Synchronization**

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

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- **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    - reception of outdated time information due to delays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 \(\leftrightarrow\) 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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Adaptive Value Tracking - adaptive and dynamic value searching
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Adaptive Value Tracking - adaptive and dynamic value searching

AVTS - STSP [Gürcan 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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  - 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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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

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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  - **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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  - does not require to keep track of the information of the neighboring robots
  - update their time information regardless of the identity of the sender
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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!
References

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