Time-of-Flight Aware Time Synchronization for Wireless Embedded Systems

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Motivation
Tight time synchronization is needed for applications such as localization or accurate control in distributed systems.

Sub-microsecond time synchronization for a distributed system can be achieved using GPS receivers. For many applications, this is not a feasible approach because
- GPS receivers are costly, both economically and power-wise, and
- they do not work in places without satellite reception, e.g. indoors.

To provide an economic solution, we aim to push the limits of state-of-the-art (> 2 µs) time synchronization using a low-power wireless multi-hop network.

Time Synchronization
Different techniques had been proposed in literature that either can be used to distribute time in a multi-hop network, or help to improve accuracy:
- Fast Network Flooding
- The faster the dissemination, the lower the accumulated error.
- Propagation delay measurement
- A two-way packet exchange allows to obtain an estimate of the propagation delay.

Can we combine this efficiently?
Other important techniques:
- Linear Regression
- MAC-Layer timestamps

Evaluation Setup
Hardware
CC430 SoC, MSP430 + sub-1GHz radio
13 MHz system clock

Testbed Experiments on FlockLab
Short
182 m / 22 hops

Long
283 m / 22 hops

Dynamic
31 nodes / 6 hops

- 1 s synchronization interval
- Regression over 80 samples
- Test duration: 1 h

8 nodes (●) equipped with GPS receivers for accurate time measurements.

Our time-of-flight aware time synchronization protocol has the same communication overhead as existing non-aware protocols (FTSP, PulseSync): One broadcast packet per round and node.

Time Synchronization Protocol
MAC-layer timestamping
Reference Node
Propagation delay compensation
Node 2
Node 3
Node 4
Node n
Linear regression over several rounds

Fast flooding
time

Can we combine this efficiently?
Other important techniques:
- Linear Regression
- MAC-Layer timestamps

Head-to-head Comparison
Metric: Largest time offset between reference node and any of the other 7 nodes with GPS.
Other protocols: PulseSync and Glossy

Numbers:
- From literature
- Measured on FlockLab

Time-of-flight aware time synchronization is less topology dependent and achieves up to 7x better performance than the state of the art.