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

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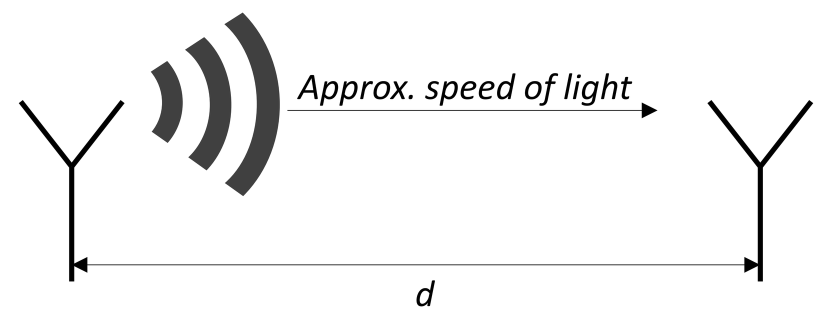
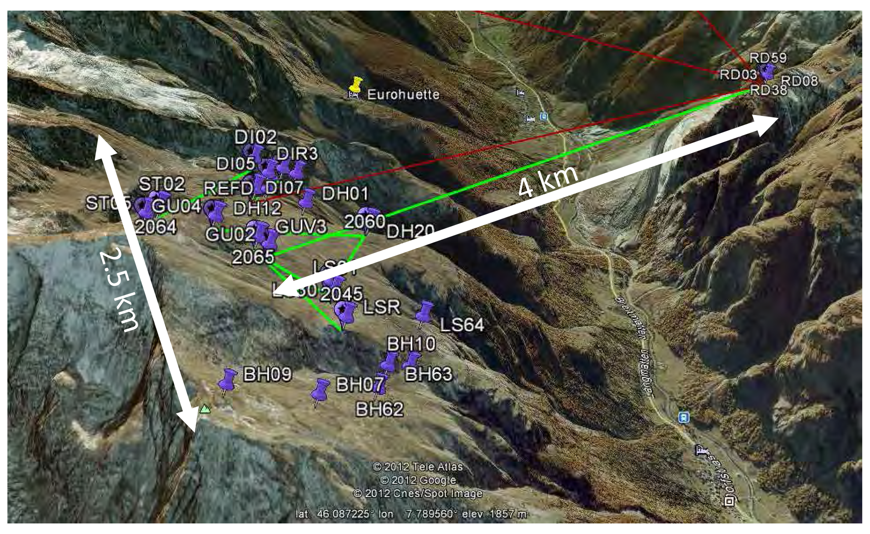
Motivation

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



Sub-microsecond accuracy requires compensation of propagation delays.



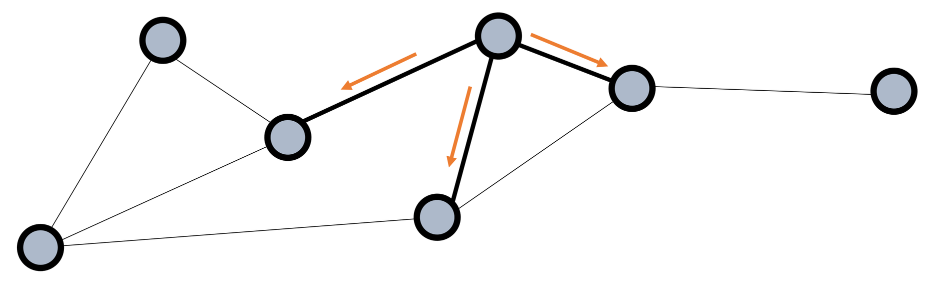
Sub-microsecond time synchronization for a distributed system can be achieved using GPS receivers. For many applications, this is not a feasible approach because

- GPS receivers are costly, both economically and power-wise, and
- they do not work in places without satellite reception, e.g. indoors.

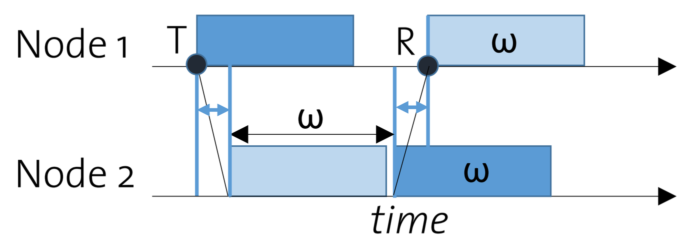
To provide an economic solution, we aim to push the limits of state-of-the-art (> 2 μs) time synchronization using a low-power wireless multi-hop network.

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: (R - T - ω) /2

Propagation delay measurement
A two-way packet exchange allows to obtain an estimate of the propagation delay.

- ***Flooding requires 1 broadcast per node***
- ***Delay measurements need 2 packets per link***

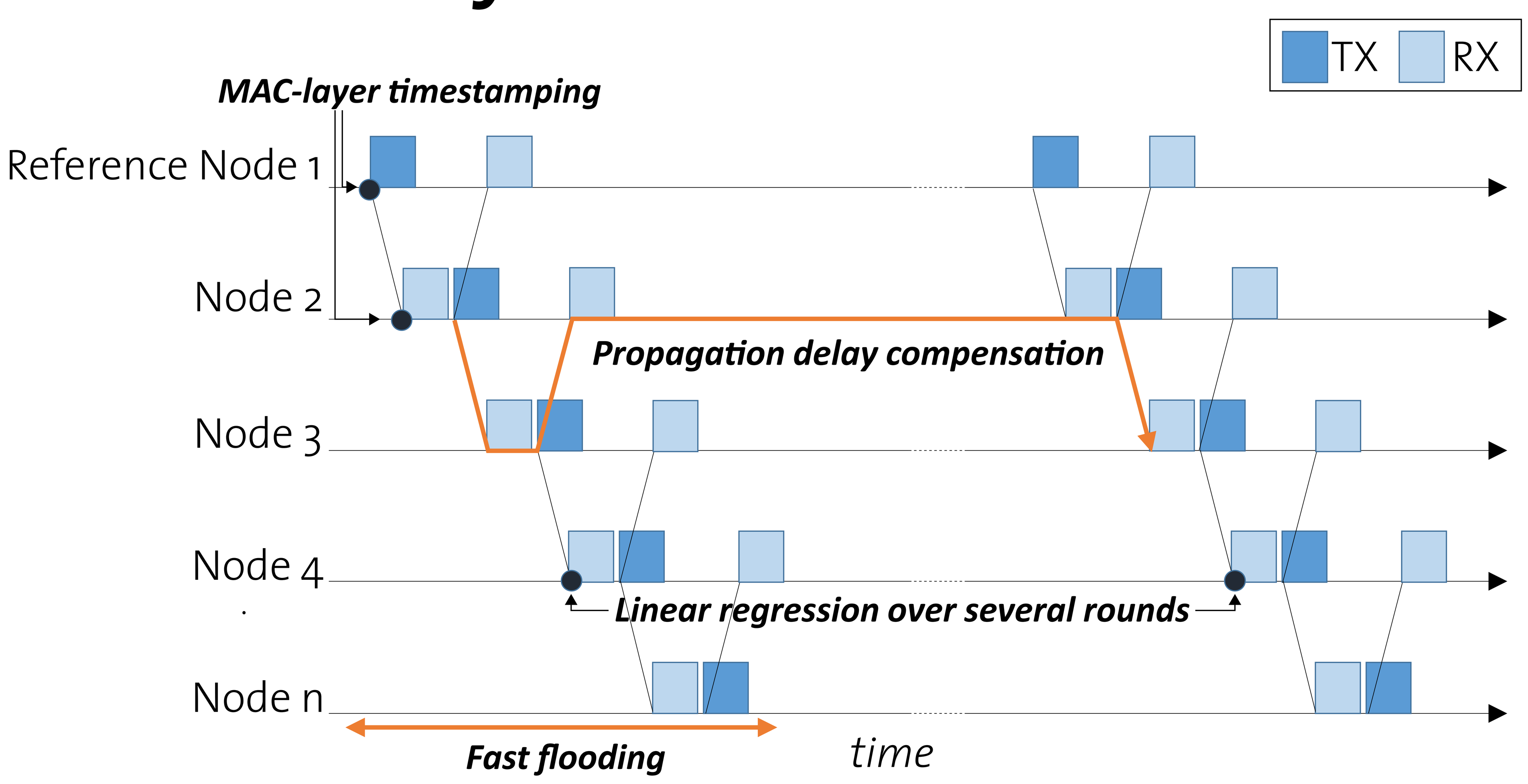
Can we combine this efficiently?

Other important techniques:

Linear Regression

MAC-Layer timestamps

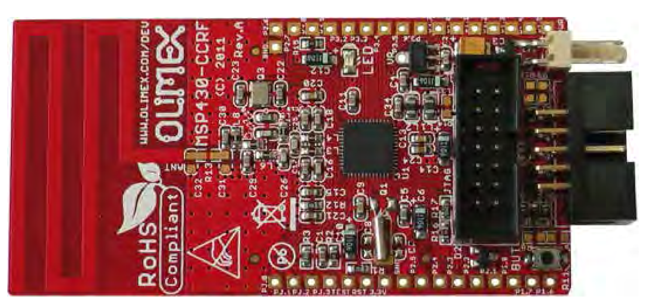
Time Synchronization Protocol



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.

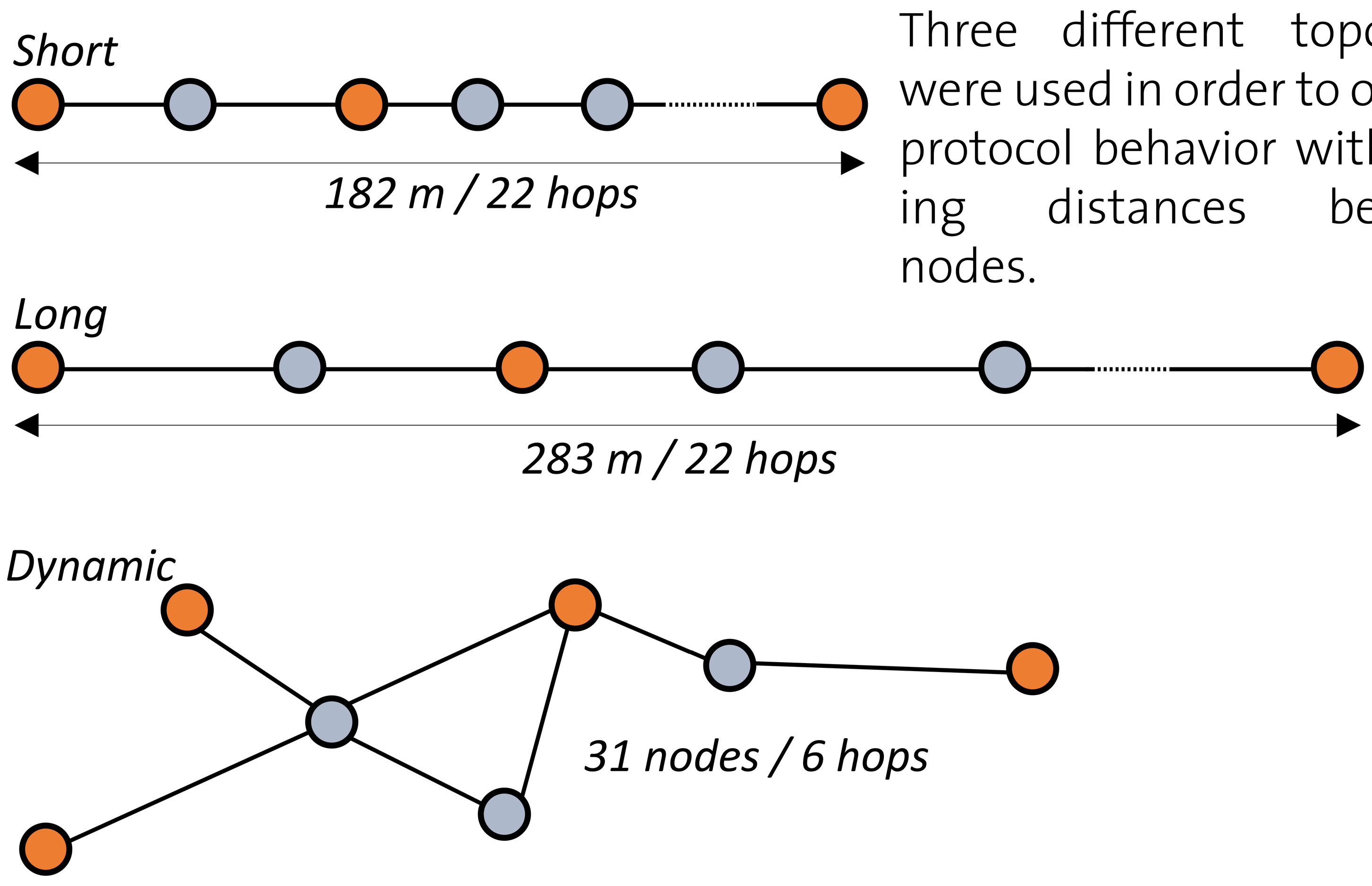
Evaluation Setup

Hardware



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

Testbed Experiments on FlockLab



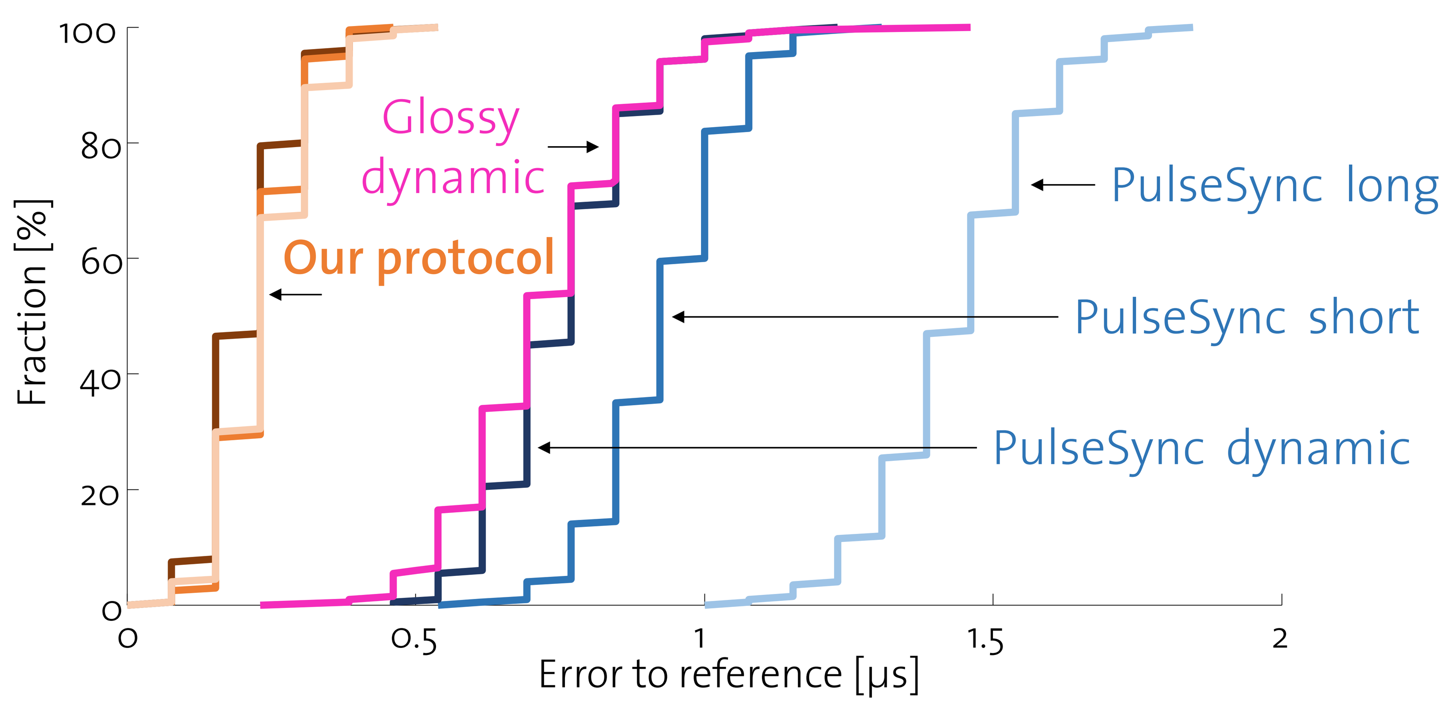
Three different topologies were used in order to observe protocol behavior with varying distances between nodes.

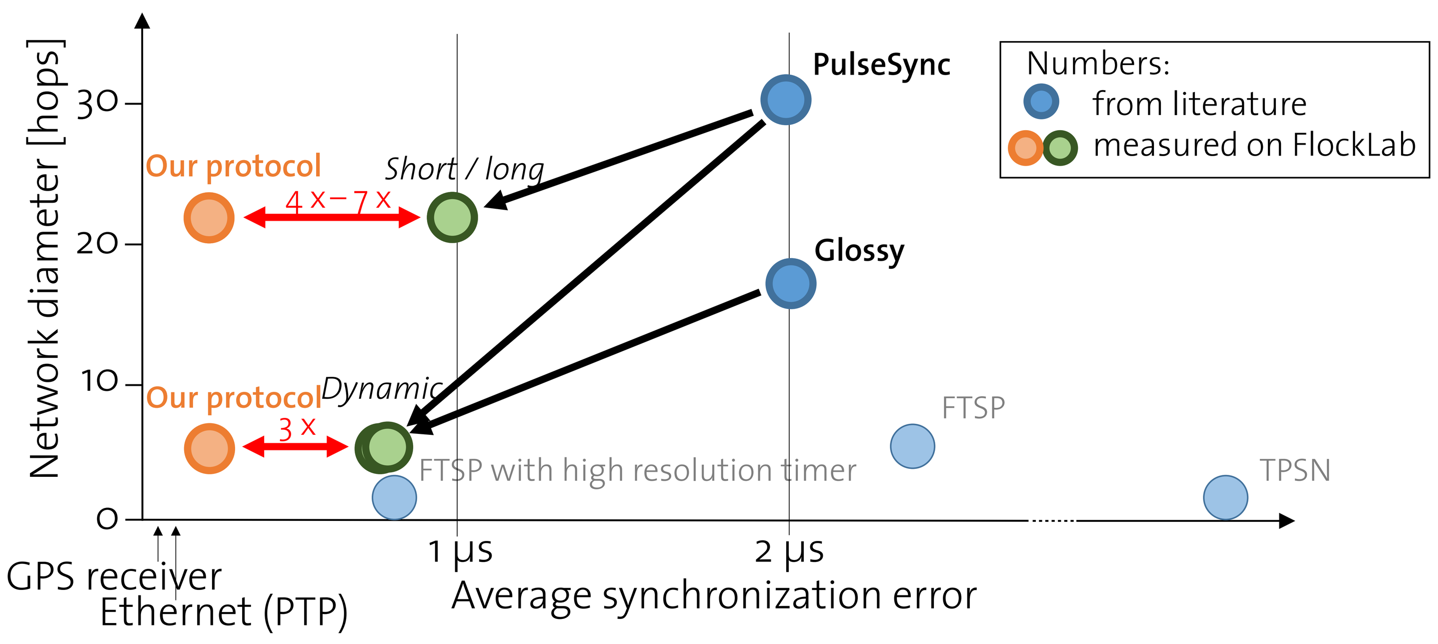
- 1 s synchronization interval
- Regression over 80 samples
- Test duration: 1 h

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

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





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