

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

Roman Lim, Balz Maag and Lothar Thiele

Computer Engineering and Networks Laboratory, ETH Zurich

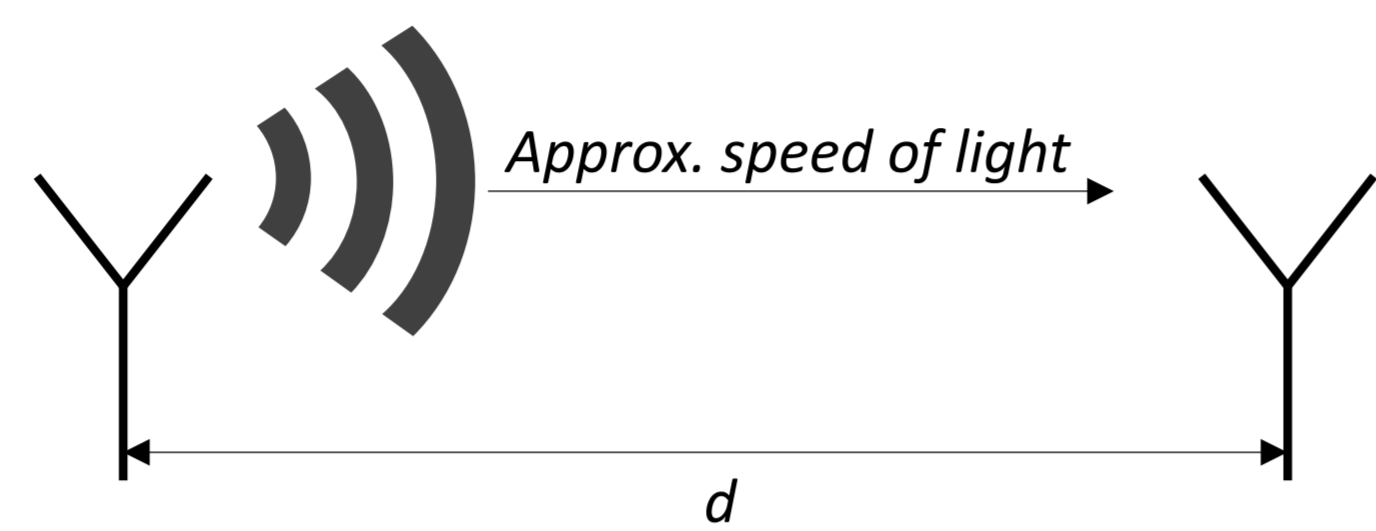
Motivation

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 ($> 2 \mu\text{s}$) time synchronization using a low-power wireless multi-hop network.

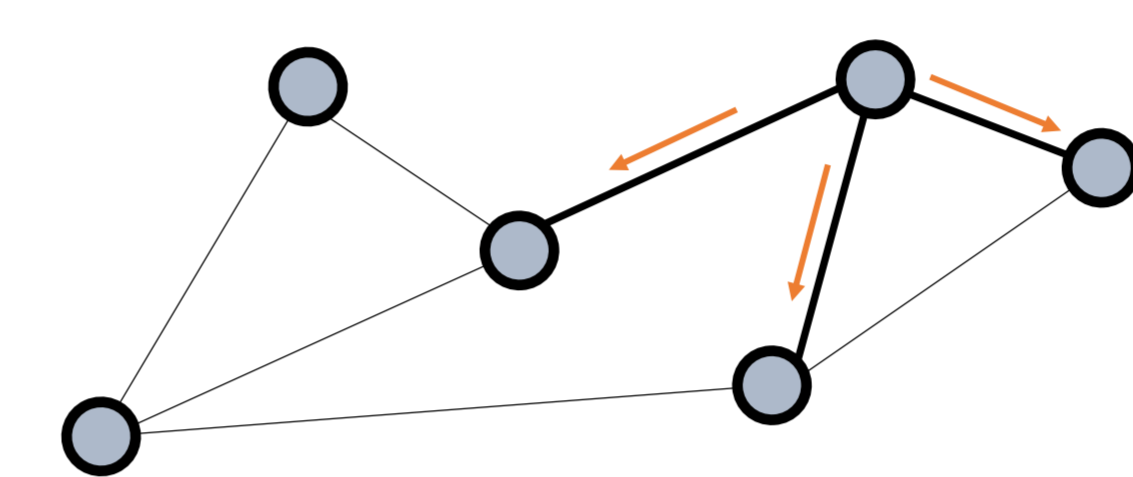


Sub-microsecond accuracy requires compensation of propagation delays.



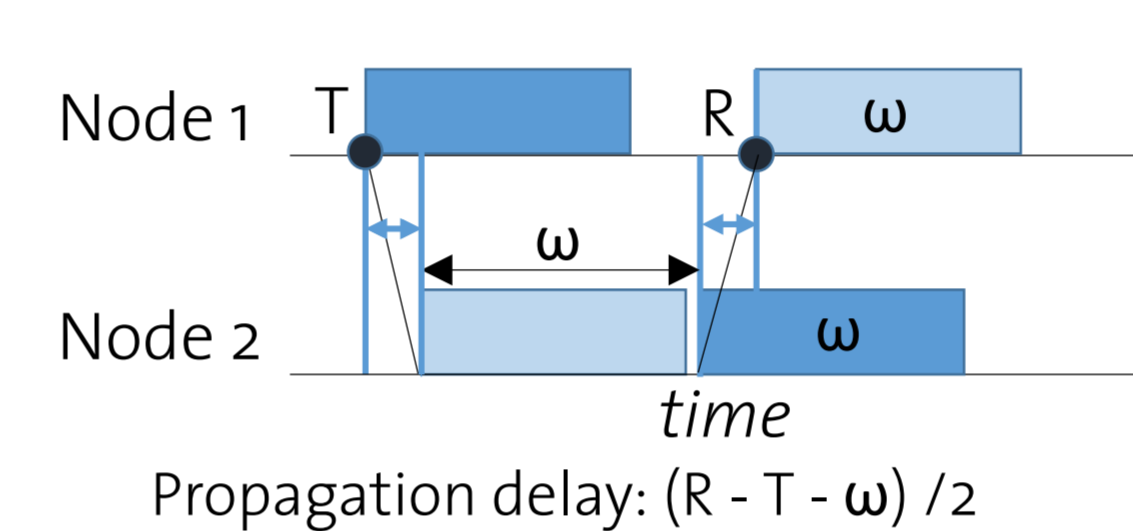
Time Synchronization

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:



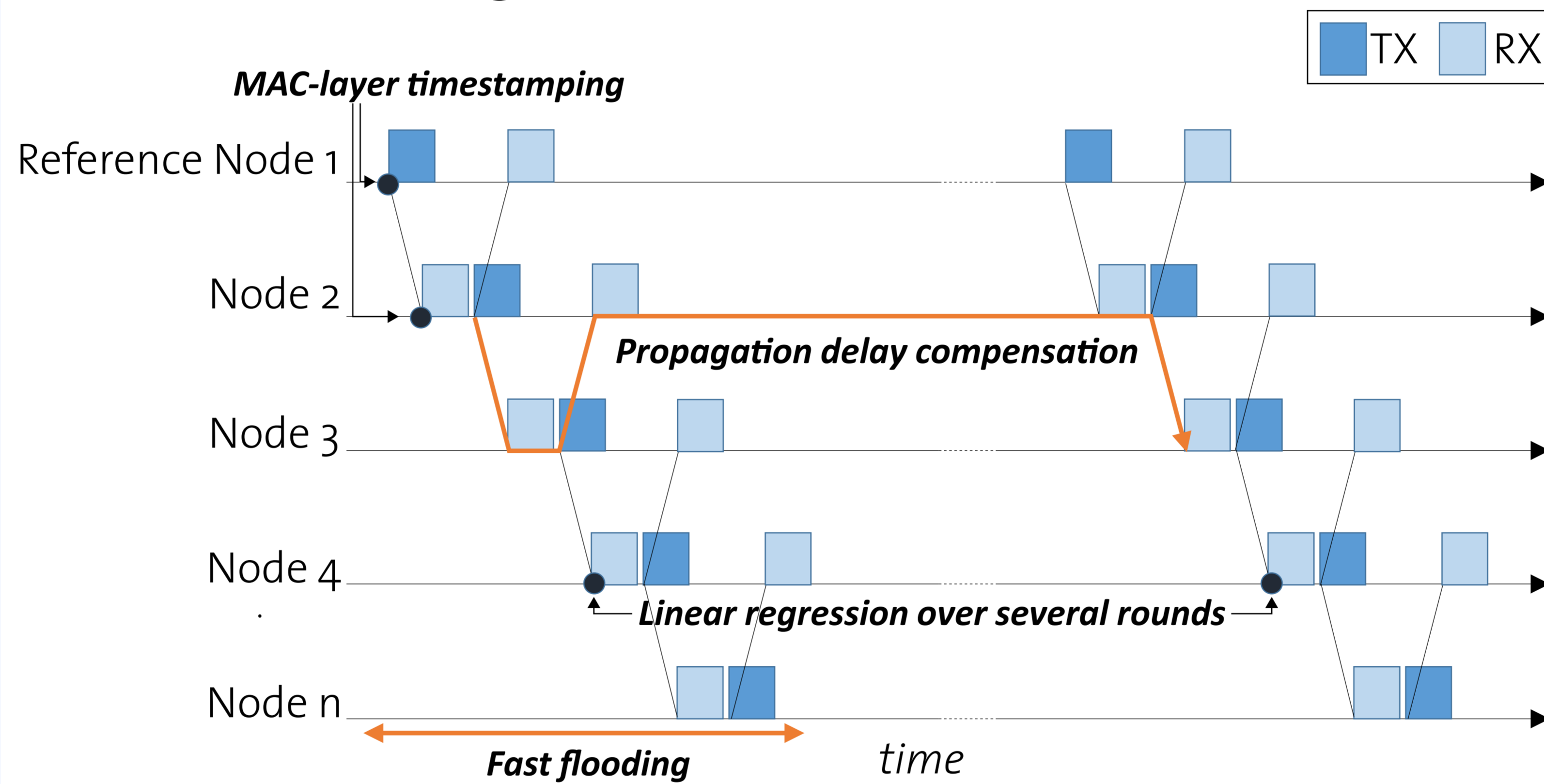
Fast Network Flooding

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.

Time Synchronization Protocol



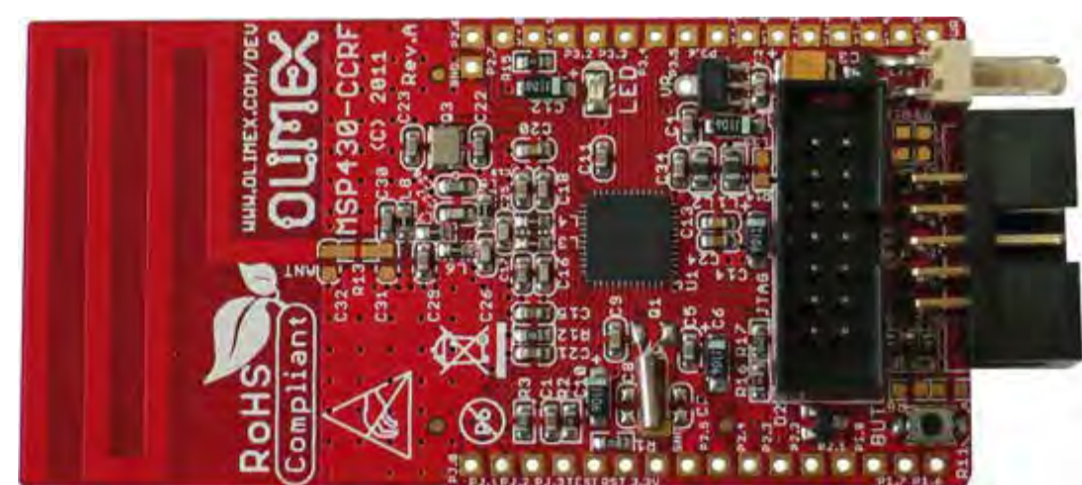
- Flooding requires 1 broadcast per node
- Delay measurements need 2 packets per link

Can we combine this efficiently?

Other important techniques:
Linear Regression
MAC-Layer timestamps

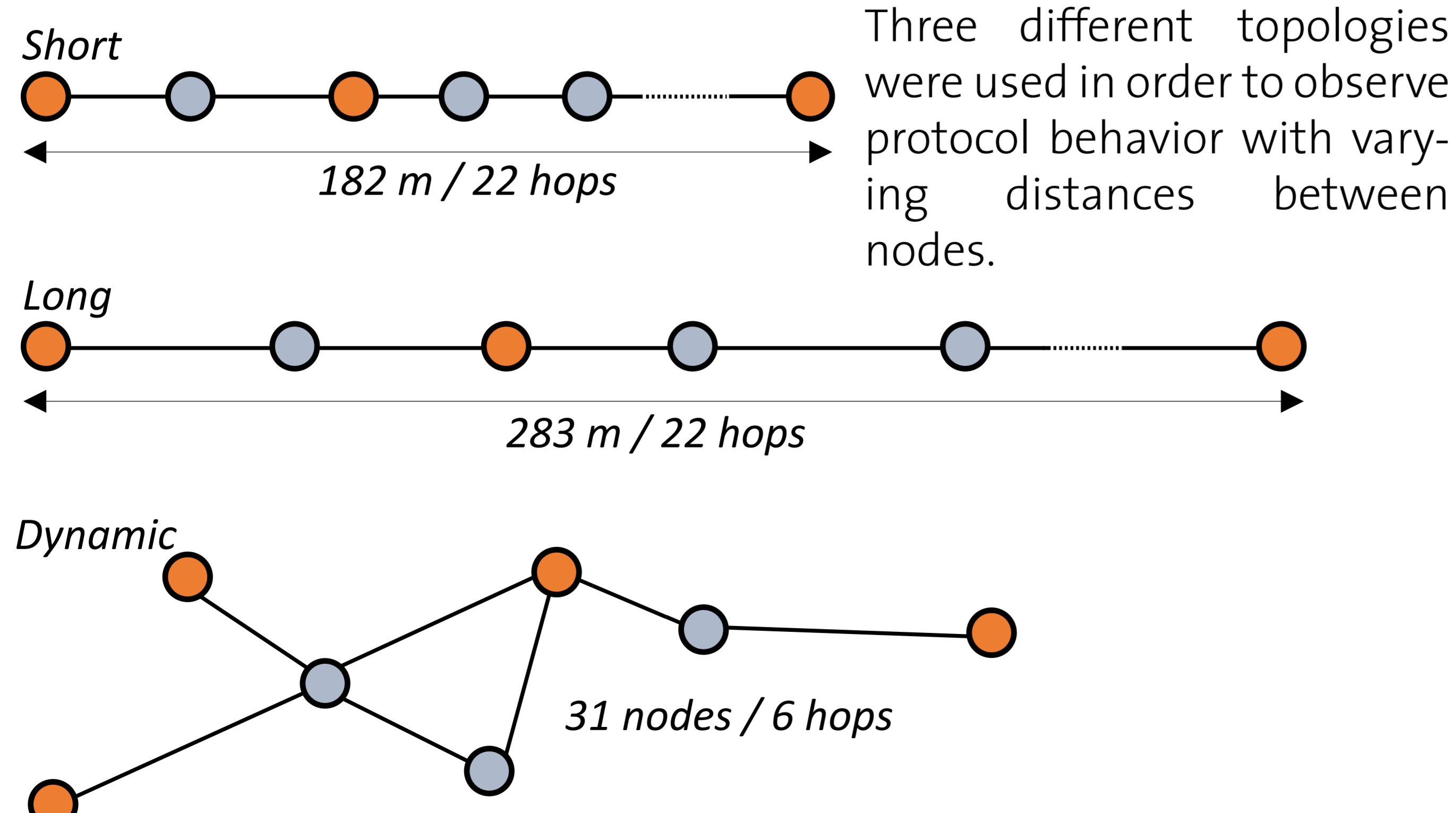
Evaluation Setup

Hardware



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

Testbed Experiments on FlockLab



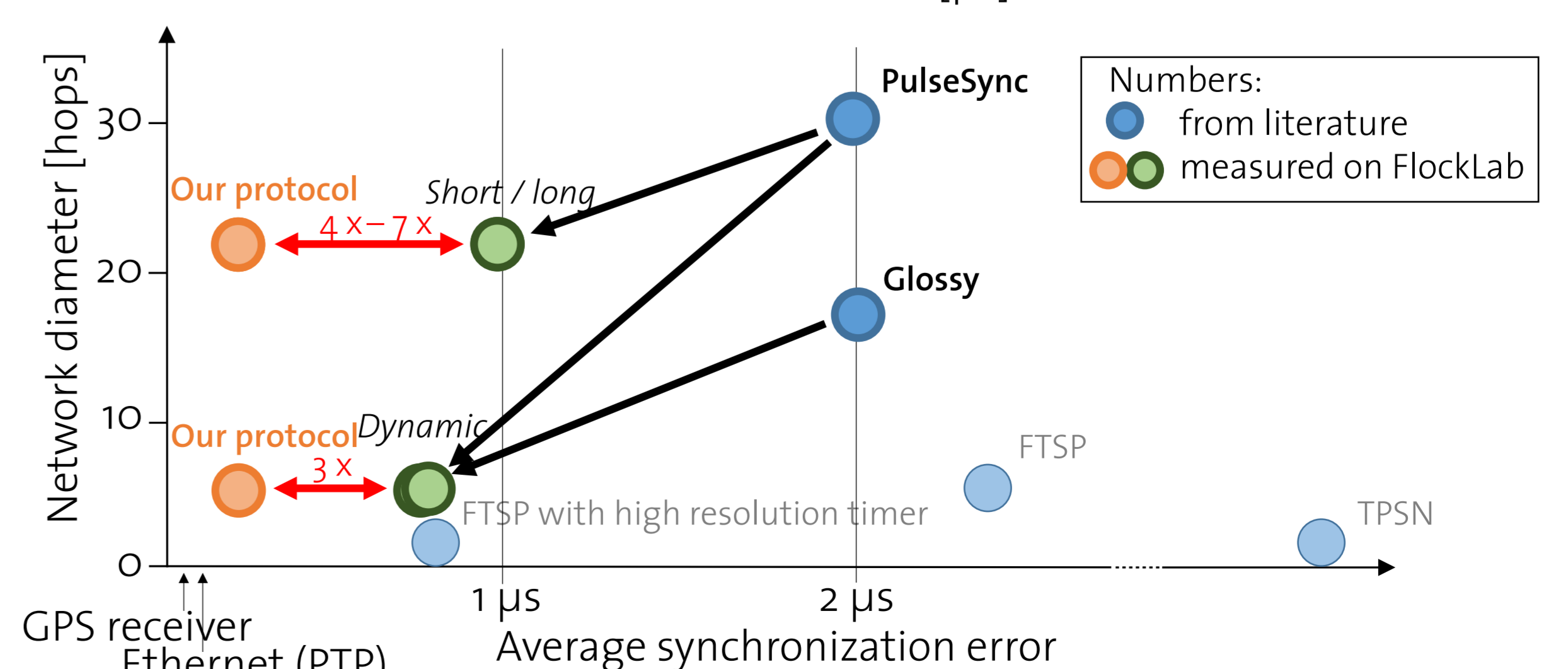
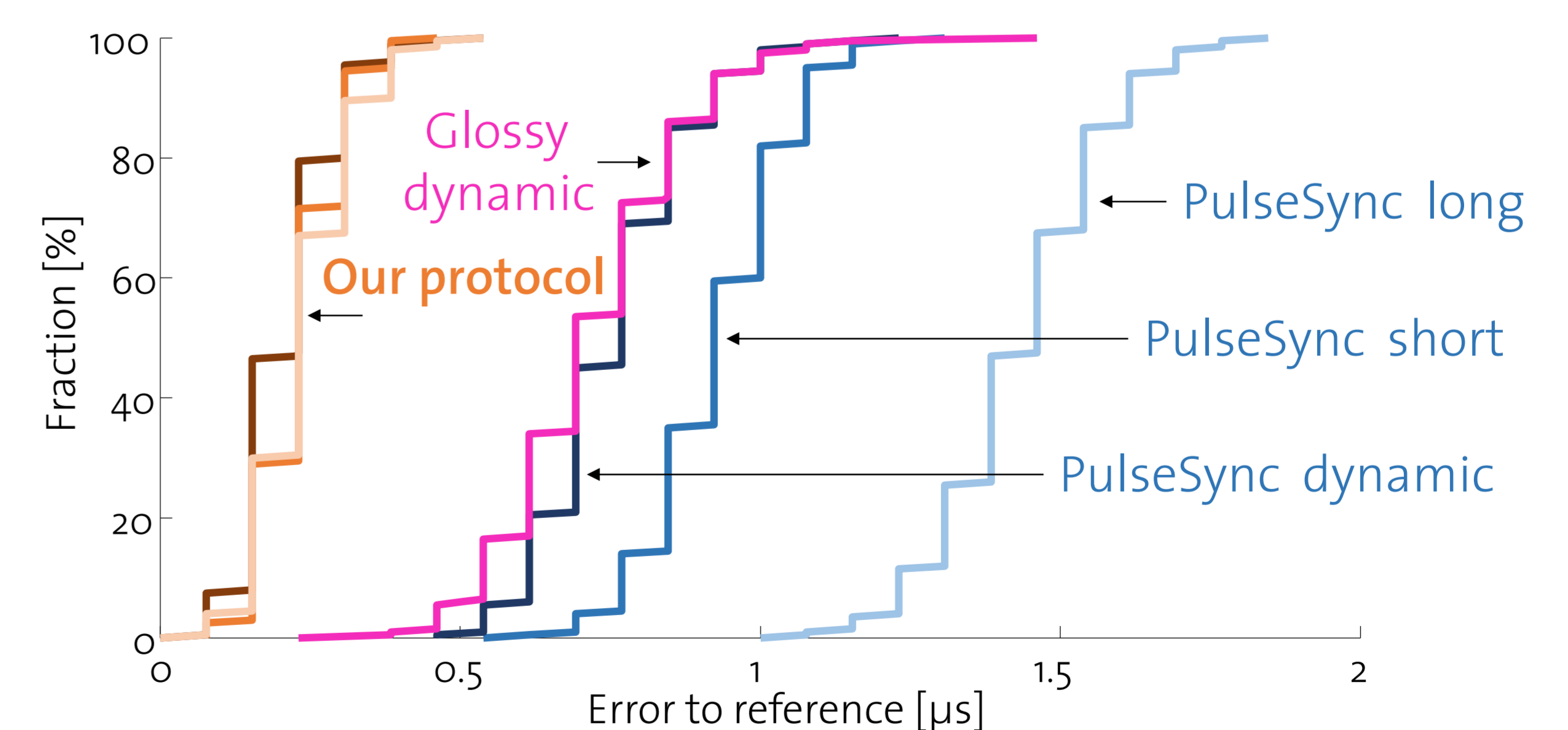
Three different topologies were used in order to observe protocol behavior with varying distances between nodes.

- 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.