SYNCHRONIZATION ERROR ACCUMULATION WHEN USING BROADCAST DISTRIBUTION OF A REFERENCE TIMESTAMP

Karaman D. G., Dzevochko O. M.
National Technical University «Kharkiv Polytechnic Institute», Kharkiv

In cyber-physical systems (CPS), time synchronization is a fundamental component of the stable and secure operation of distributed devices. In particular, accurate clock alignment between nodes ensures the correct execution of real-time algorithms, precise event processing, protection against attacks, and reliable decision-making in automated systems [1].

One of the promising and practical synchronization concepts for networks with limited resources is the use of broadcast distribution of a reference timestamp [2]. The core idea is not to synchronize subordinate nodes directly with the master node but to establish synchronization among all subordinate nodes through the reception of a shared broadcast message transmitted via a common communication environment (wire or radio channel).

This approach significantly reduces the number of error sources associated with asymmetric delays inherent in traditional synchronization mechanisms. Specifically, in classical schemes, transmission and medium access delays affect each node's synchronization time individually. In contrast, when using a broadcast message, these components are identical for all receivers and, therefore, can be excluded from the critical path in error calculation.

However, the accuracy of synchronization is still limited by random, non-deterministic delays that accumulate at different stages of message transmission.

The broadcast-based synchronization mechanism, particularly the Reference Broadcast Synchronization (RBS) protocol, allows for the exclusion of time delays at the sending and medium access stages from the error calculation, since these values are identical for all nodes within a single transmission. Thus, the remaining influencing factors are only the delays associated with signal propagation and processing on the receiving side.

Despite the reduction of error sources, the delays remain non-deterministic and accumulate over time, which can significantly affect synchronization accuracy. Studying these processes is an important scientific and practical task, especially for constructing error estimation models, developing corrective filters, and improving the resilience of systems operating in real-world networks with random delays.

References:

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