Protocol-Aware Dynamic Synchronization for Multi-Rate Maritime Co-Simulation

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***Abstract*— Maritime cyber–physical systems increasingly integrate navigation, control, sensing, and heterogeneous communication technologies, requiring simulation frameworks that accurately capture interactions across widely different time scales. However, conventional co-simulation approaches with a uniform communication step fail to represent the millisecond-level timing of transport-protocol events while simultaneously accommodating the second-level evolution of vessel motion and control processes. This paper proposes a protocol-aware dynamic synchronization method for multi-rate maritime co-simulation. The method leverages internal protocol-state information to switch between fast and slow execution modes, selectively activates only the FMUs relevant to each mode, and emulates event-driven actuator activation without requiring advanced clock semantics. Numerical experiments demonstrate that the proposed method restores realistic TCP handshake latency under varying network delay and packet-loss conditions while significantly reducing the computational load associated with slow-scale physical models, achieving the fidelity of fine-step simulations at a fraction of the cost.**

***Keyword*—Co-simulation, Dynamic Synchronization, FMI**

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