PADS 2025

Improving the Efficiency of Coordinating Timed Events in Distributed Systems

ASU KIM
KNOWLEDGEABLE & INTERACTIVE MACHINES

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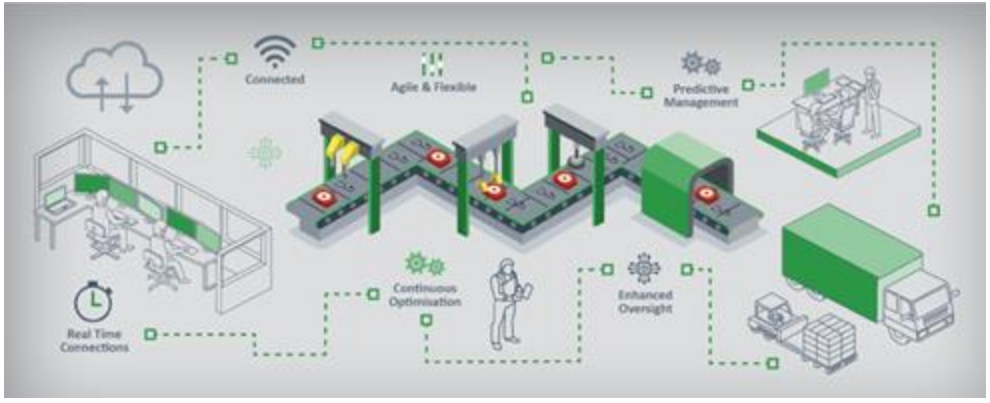
Introduction

- Distributed cyber-physical systems (CPS) requires
  - deterministic behavior
  - fine-grained timing control over network

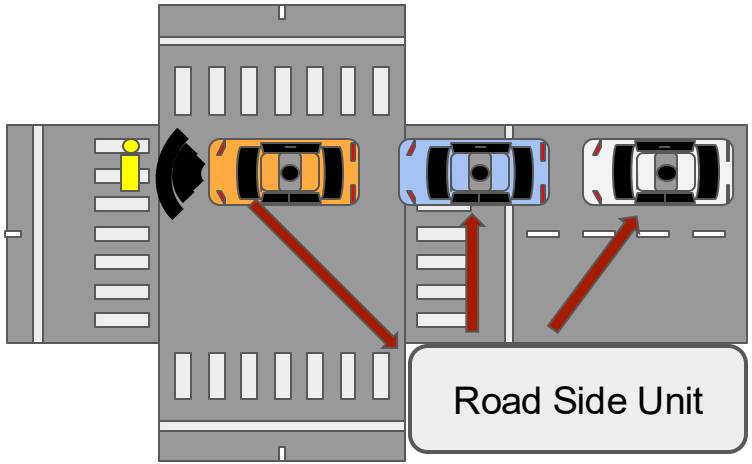
https://www.iiot-world.com/artificial-intelligence-ml/autonomous-vehicles/challenges-in-training-algorithms-for-autonomous-cars/



https://slcontrols.com/solutions/smart-factory/

Introduction

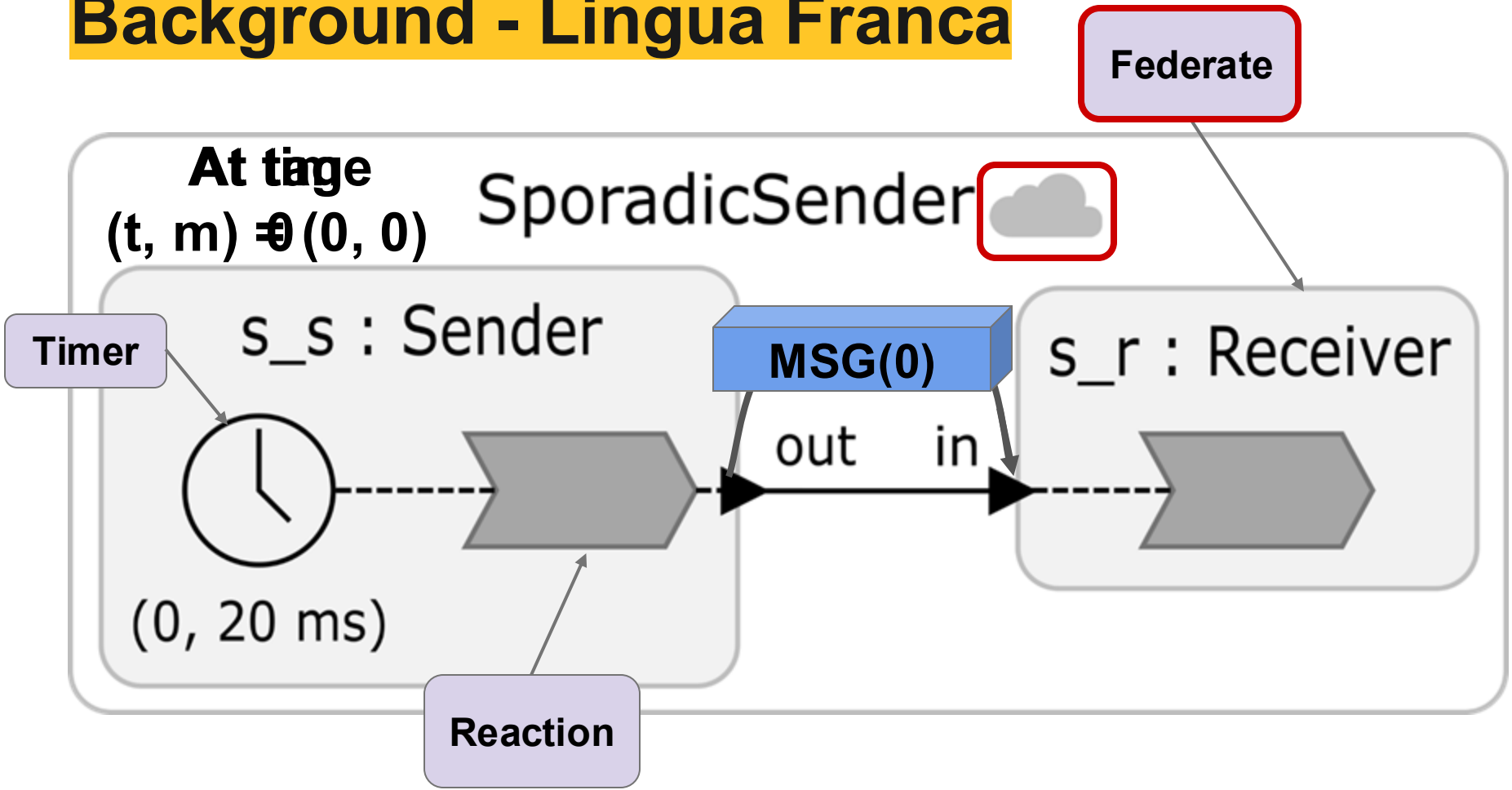
- Challenge: supporting accurate and precise timing control while ensuring deterministic behavior
  - E.g., HLA (high level architecture)’s time management mechanism ensures determinism but hinders accurate timing control



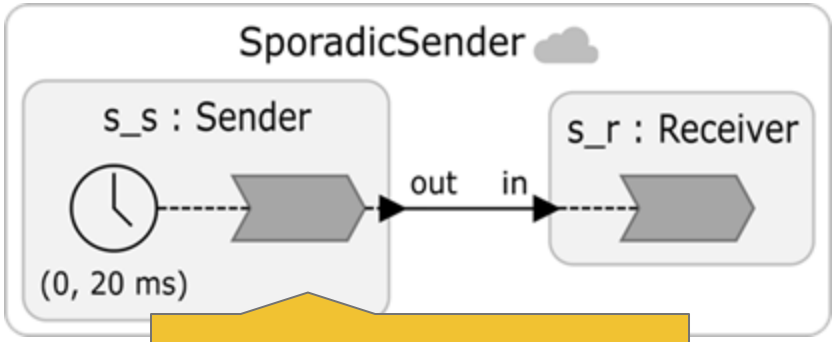
Contributions

- Identify challenges in **deploying** HLA-based time management techniques in distributed CPS
  - Infeasible fine-grained timing control
  - Huge network overhead
- **Enable accurate timing control** and improve network communication efficiency in such distributed CPS

Background - Lingua Franca

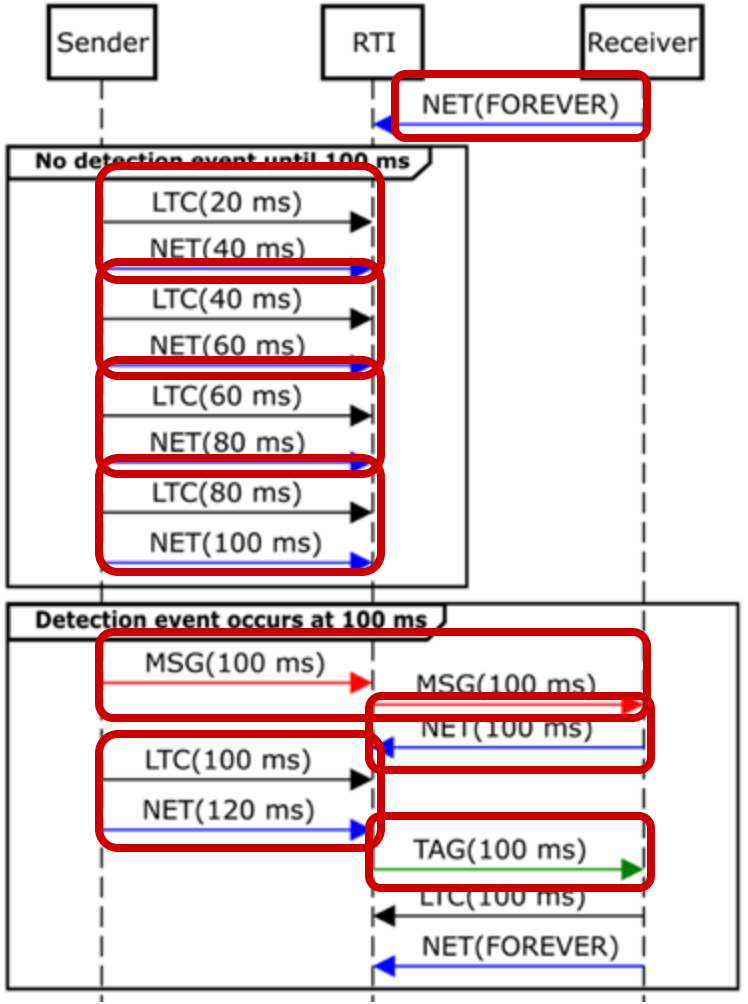


Background - Time Management Mechanism

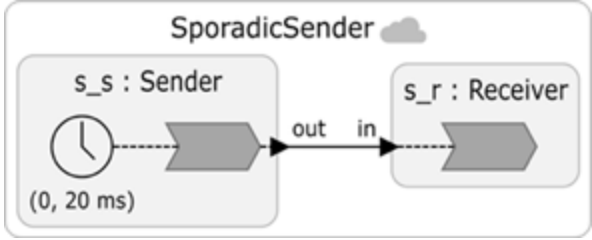


Send a message at 100 ms

Acronym	Definition	Acronym	Definition
NET	Next Event Tag	TAG	Tag Advance Grant
LTC	Latest Tag Complete	MSG	Tagged Message

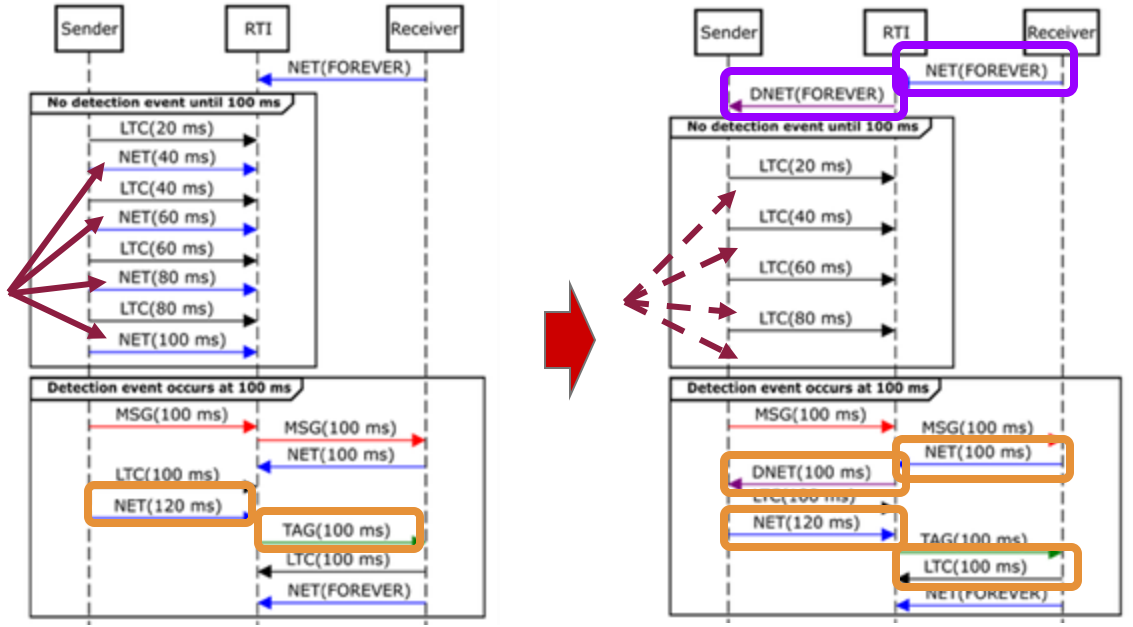


Our Previous Work[1]



- **Downstream Next Event Tag (DNET)[1]**
  - Remove some unnecessary NET signals

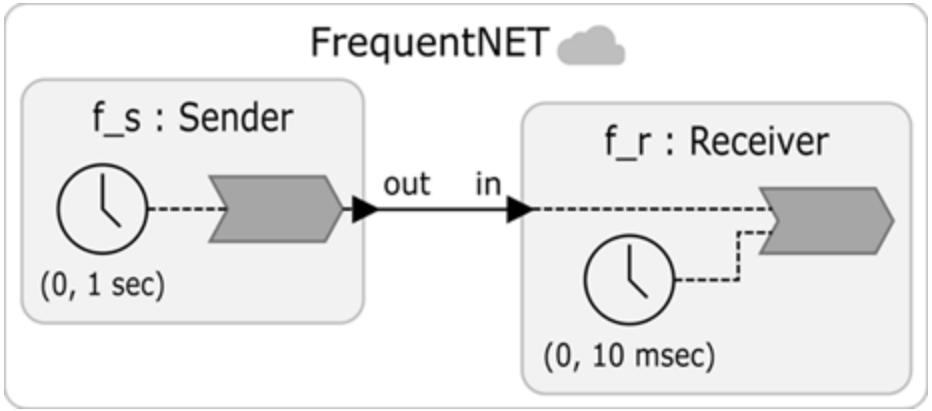
Unnecessary!!

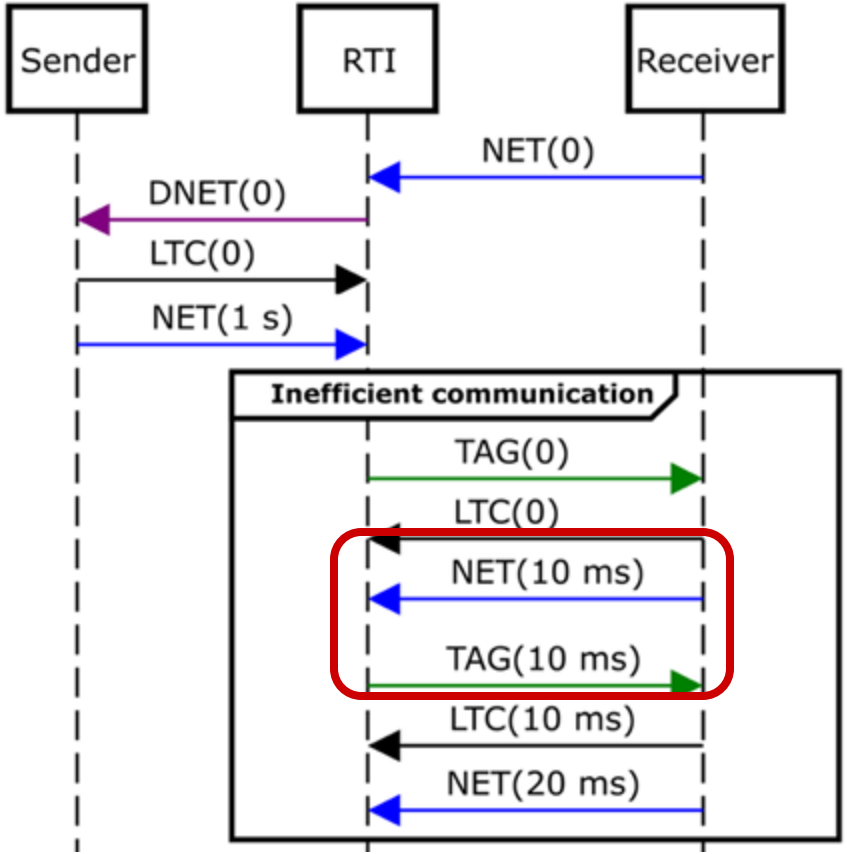


[1] B. Jun, E. A. Lee, M. Lohstroh and H. Kim, MEMOCODE at ESWEEK'24

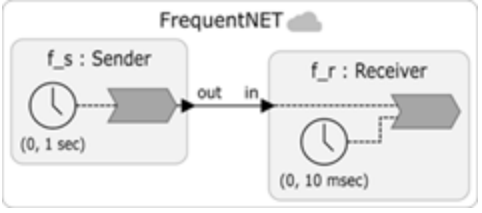
Research Goal 1 - Accurate Timing Control

- Inefficient signal exchanging delay the execution of events
- How can a federate proceeds its next events without inefficient signal exchanging?

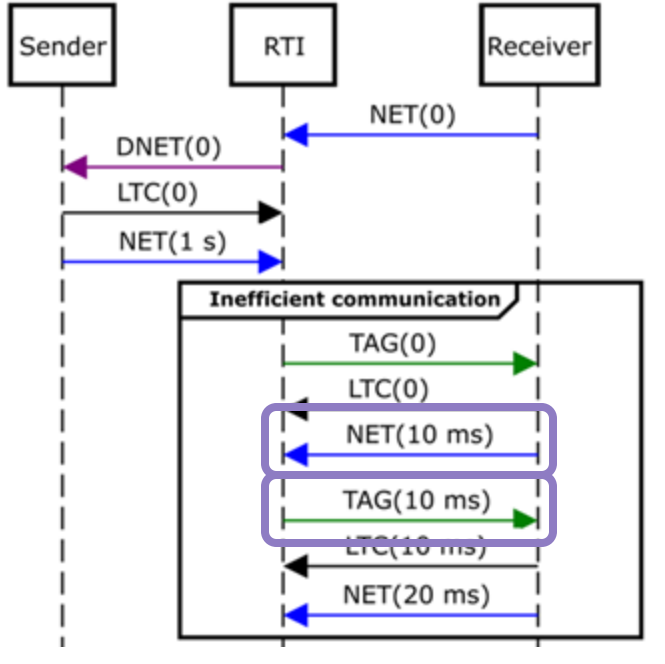


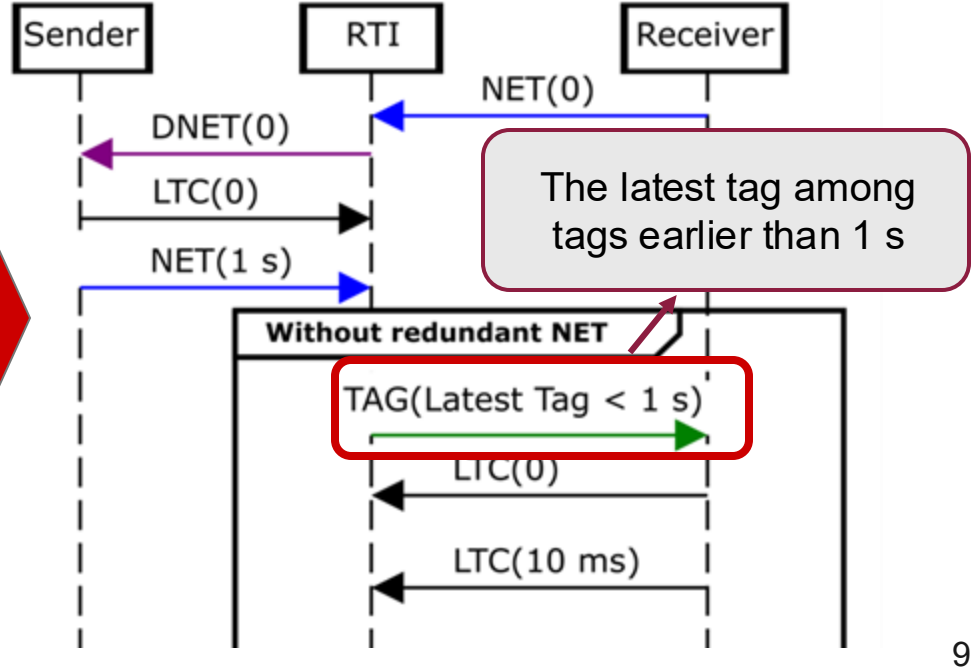


Approach 1: More Efficient TAG



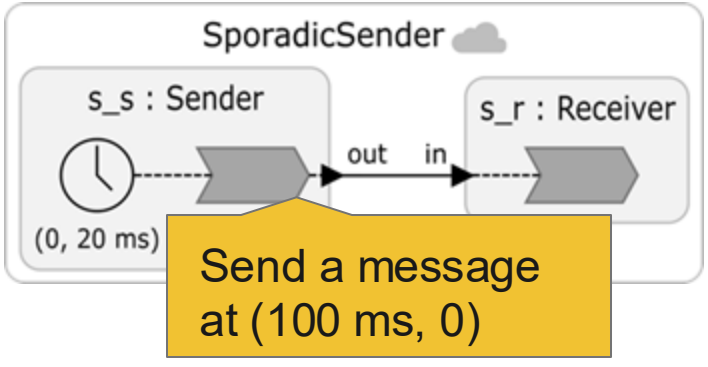
- The RTI send TAG with **the latest tag that Receiver can advance**
- Receiver mostly can advance its time without requesting a new TAG



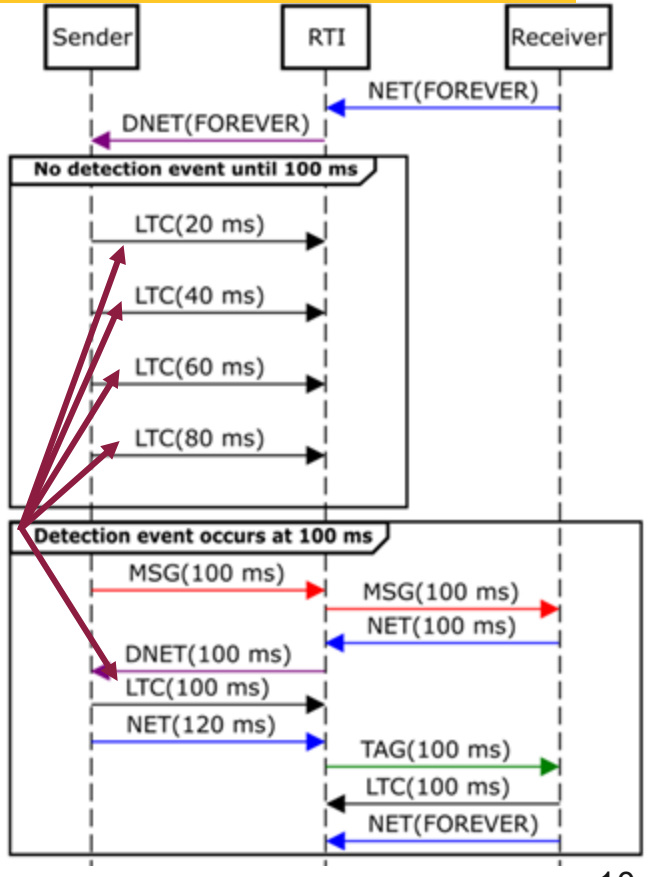


Research Goal 2 - Efficient Communication

- How can a federate avoid sending LTC signals every time it finishes a tag?

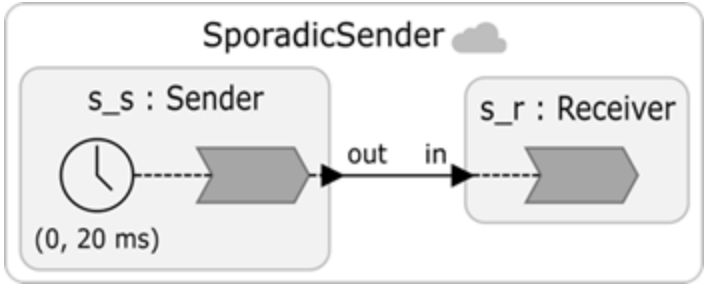


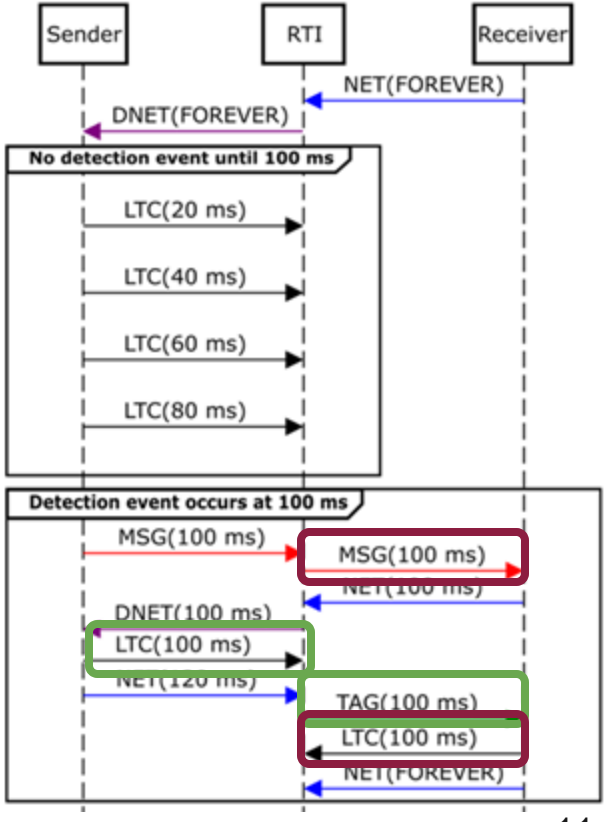
Unnecessary!!



Approach 2: Removing Unnecessary LTC

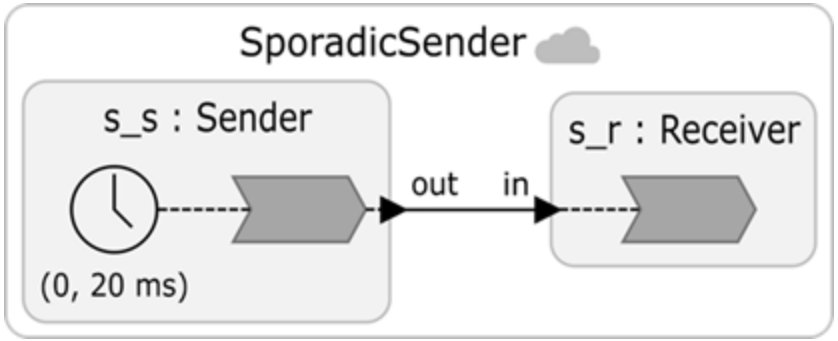
- Two purposes of LTC signals
  - Compute TAG signals
  - Track a federate's states
- Computing TAG signals can be done only with NET signals (will be proven)

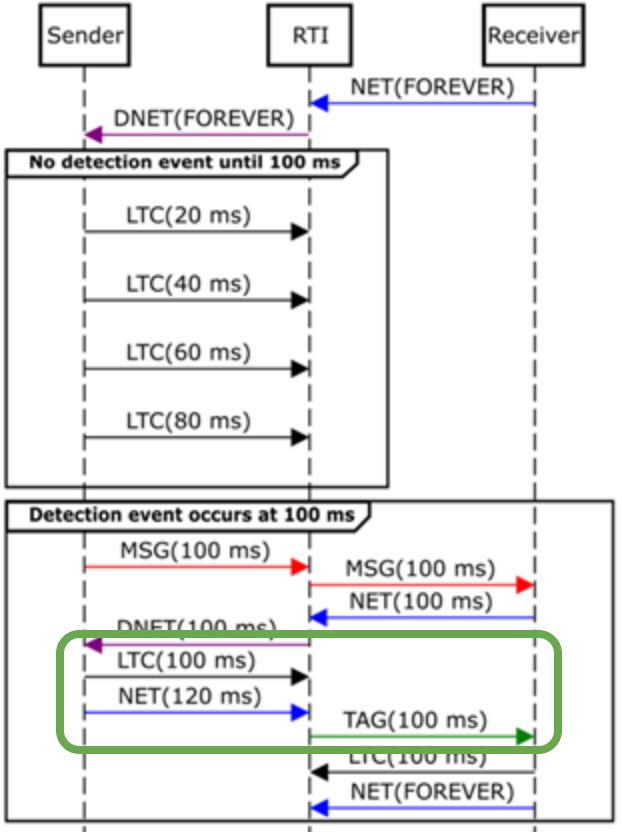




Approach 2: Removing Unnecessary LTC

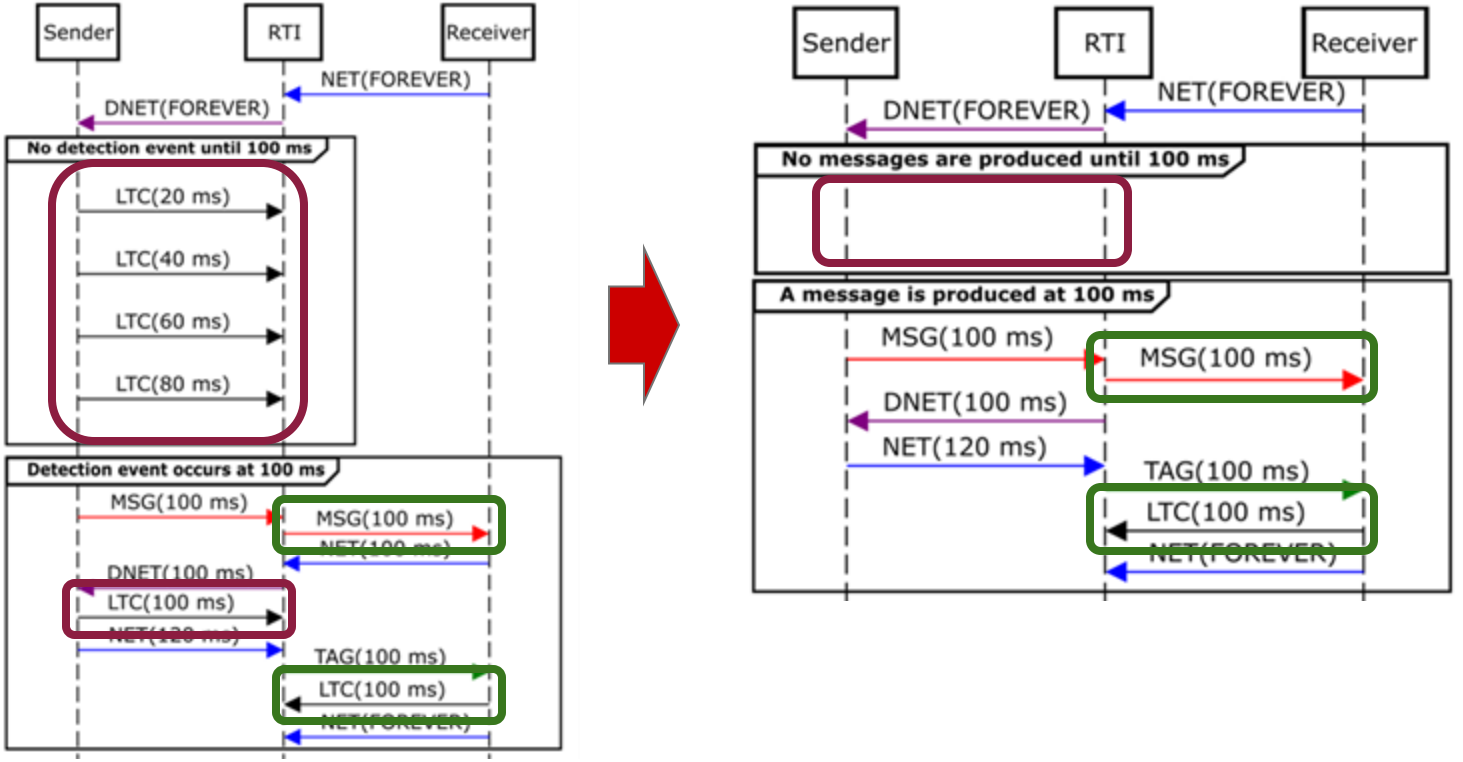
- TAG can be computed **without LTC signals**
- Possible time to grant
  - With LTC(100 ms): any time <= 100 ms
  - With NET(120 ms): any time < 120 ms



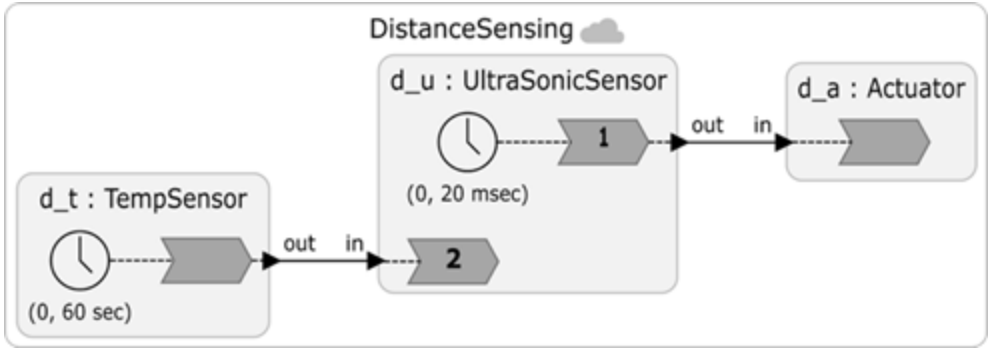


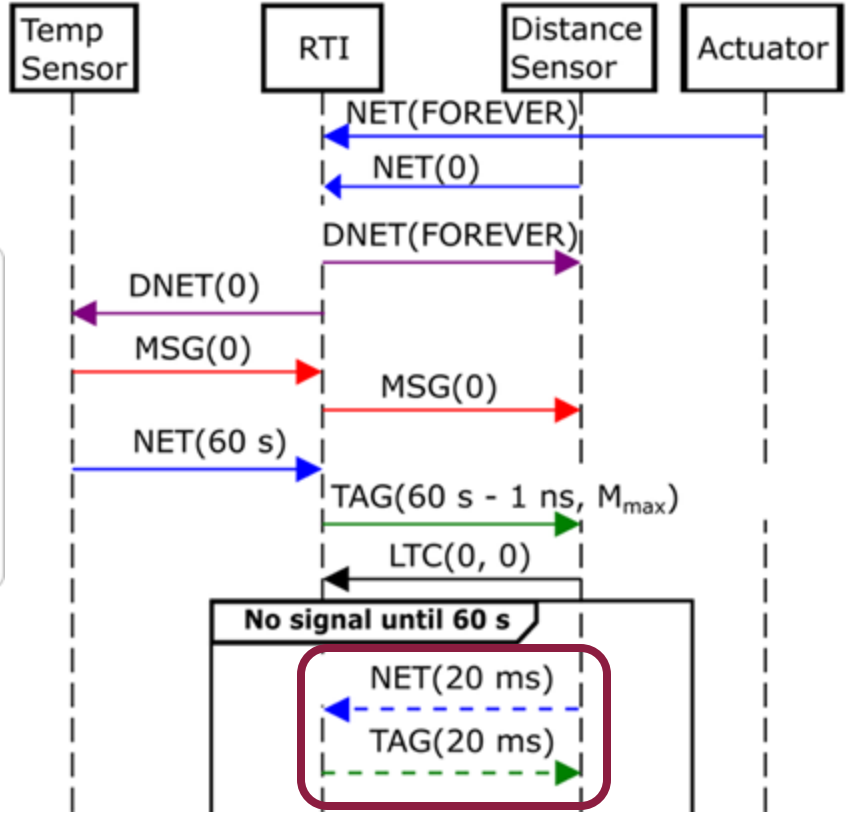
Approach 2: Removing Unnecessary LTC

- Send LTC if a tagged message has been processed at current time



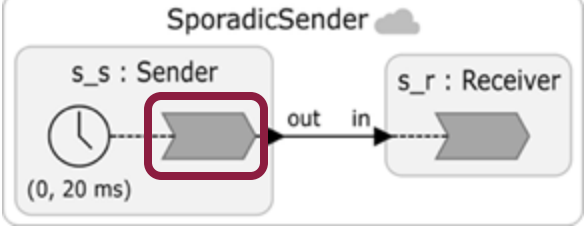
Case Study

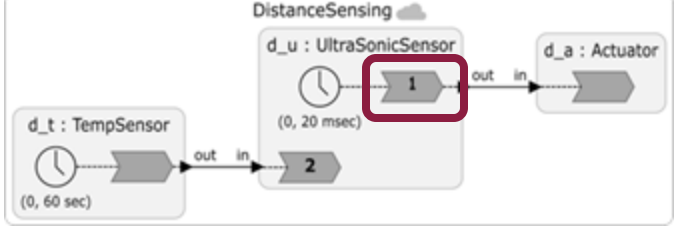


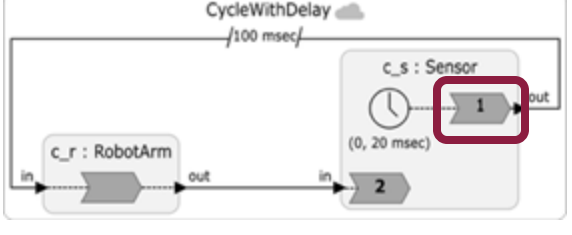


Evaluation

- We evaluated our approach using three micro-benchmarks[1]
- We measured
  - the lag, the time difference between the physical time and the logical time of sensing event
  - the number of signals during 500 seconds
- Round-trip delay between the RTI and federates
  - 10 ms ± 1 ms of jitter







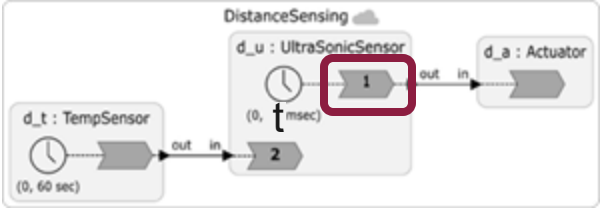
[1] https://github.com/asu-kim/efficient-DDE-experiments

Evaluation

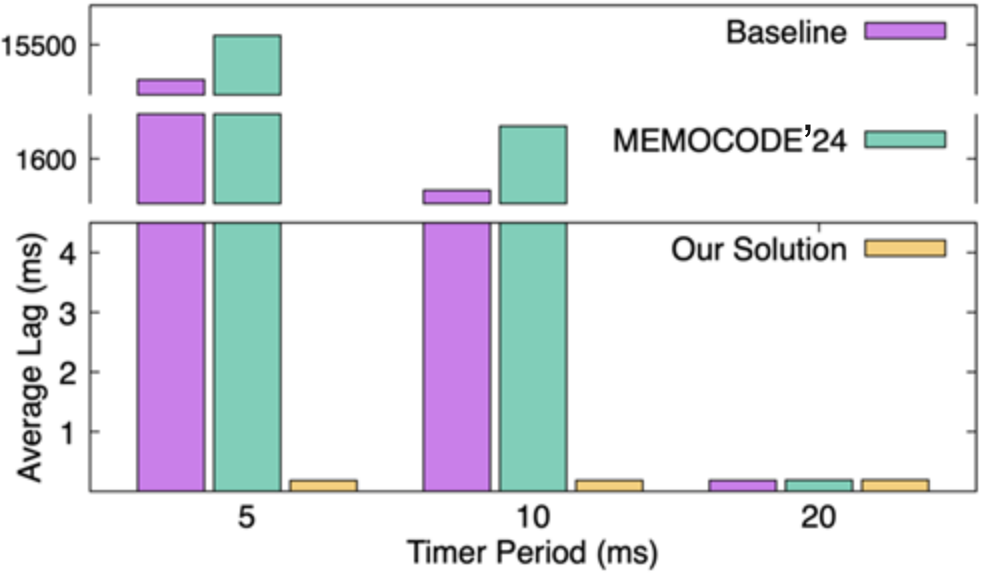
- We compare our solution with two approaches, Baseline and MEMOCODE'24[1]
- Baseline
  - Similar to HLA, a federate sends NET and LTC signals every time it wants to advance its tag
- MEMOCODE'24
  - Baseline with DNET signals eliminating some unnecessary NET signals
- Our solution
  - Based on MEMOCODE'24 with more efficient TAG and LTC

[1] B. Jun, E. A. Lee, M. Lohstroh and H. Kim, MEMOCODE at ESWEEK'24

Evaluation



- **Only our solution allows frequent sensing** (with period <= 10 ms)
- The systems with other approaches **cannot** provide fine-grained timing control (sensing with period <= 10 ms)



Average lag of the reaction of federate s_s

23x - 73x Reduction

	Baseline	MEMOCODE'24	Our Solution
5 ms	247,499	246,810	3,364
10 ms	149,258	150,044	3,345
20 ms	76,847	77,844	3,345

Total number of network signals, e.g., TAG and NET, during the 500 sec of runtime with various timer periods

Conclusion

- Allow applying HLA-based time management mechanism to **deployment of distributed CPS** by
  - **Enabling fine-grained timing control**
  - Improving efficiency of synchronization process

- Contact Information
  - Personal Website: https://byeonggiljun.github.io/
  - Email: byeonggil@asu.edu

Thank you!

- Evaluation artifact of this work: https://github.com/asu-kim/efficient-DDE-experiments

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