Optimistic Synchronization in a distributed V2X-Communication simulation infrastructure

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I. Introduction

With the growing significance of V2X-Communication, i.e. communication of vehicles with other vehicles on the road as well as road-side units, an increased demand for simple and affordable testing and validation of embedded software came up. V2X simulation systems facilitate this by allowing the developer to embed software into realistic traffic scenarios without the effort and costs of real test-drives.

The development of such a simulation system includes many challenging tasks in order to provide a reliable and realistic simulation environment. An infrastructure that integrates heterogeneous simulators like traffic-, network-, environment-, and application-simulators is required in order to cover all aspects of a complex V2X communication scenarios.

Previous work on this topic has included the development of such an infrastructure, called Vehicle Simulation Runtime Infrastructure (VSimRTI). This infrastructure is based on the IEEE standard for modeling and simulation (M&S) high level architecture (HLA) and allows the simulation modeler to integrate an arbitrary number of simulation systems and support their interaction in order to create a realistic simulation.

Besides the facilitation of a transparent communication among all participants, such an infrastructure also allows to distribute simulations onto several physical processes, thus creating a distributed parallel simulation system. This again requires implementation of a so-called global time management, i.e. synchronizing the local time and event processing of each individual simulator in order to guarantee correctness and repeatability of the simulation.

Generally there are three concepts for such a synchronization, each having its individual drawbacks. In VSimRTI, the central time management which controls the simulator synchronization implements two of them: sequential event processing and conservative synchronization. Sequential event processing forces all simulators to execute sequential, one after another. That way, a situation when two or more simulators compute their results faster and can advance far ahead of time, is impossible to occur. Obviously, any parallelism that could speed up the simulation is impossible in this scenario. Conservative synchronization tries to allow parallel execution when it is safe, i.e. when the synchronization mechanism can guarantee that no simulator will ever send a message to another simulator that occurs in that simulators past. In cases where that cannot be guaranteed at all, conservative synchronization performs equally to sequential execution. While sequential simulation does not allow any parallel execution at all, conservative synchronization allows at least some parallelism, depending on the simulation model. That way, the real time (wall-clock time) that is required to simulate a certain amount of simulation time, can be influenced by the amount of physical processors that are used. Anyhow, using conservative synchronization, the potential benefit from scaling the underlying hardware or distributing the simulation onto a larger cluster of processors, is generally bounded.

Besides these two concepts that are already implemented in VSimRTI, another approach exists that tries to bypass the boundaries of sequential execution and conservative synchronization. Instead of circumventing inconsistent situations to the costs of parallelism, optimistic synchronization allows these situations to occur and provides mechanisms to recover from such errors. If a simulator recognizes an illegal event, rollback mechanisms are used to shift the simulation back in time to a valid state and unsent messages that were sent before. This allows each simulation to proceed with its calculation although some information from other simulations might not be available yet thus avoiding unnecessary delays while waiting for these simulators.

II. Objectives and Scope

- *This thesis aims to discuss different approaches to realize an optimistic simulation synchronization suitable for vehicle simulation scenarios*

Various algorithms have been proposed in the past, addressing different problems of the implementation of optimistic synchronization mechanisms. The objective of this thesis is to discuss these algorithms and evaluate their suitability for distributed vehicle simulation systems with special regard to VSimRTI.

- *This thesis aims to define a concept to enable rollback in an HLA based distributed simulation infrastructure with no or minimal modifications of the participating simulators.*

VSimRTI is designed to allow the integration of arbitrary simulators without modifying the simulators themselves by using an ambassador pattern. Since the integration of optimistic synchronization involves the tracing of local state changes and eventually rolling back calculations that were made by each simulation, it is essential to study the steps that are necessary in order to integrate sequential simulation systems into the infrastructure. It is a goal of this thesis to define a concept that allows an integration of simulators with only minimal modifications of the simulators themselves.

- *This thesis aims to develop a global time management architecture for VSimRTI that allows optimistic synchronization within a distributed vehicle simulation.*

The existing system VSimRTI will be modified and a global time management and rollback controller has to be introduced in order to enable optimistic synchronization within the existing infrastructure. Mechanisms that control the proceedings of simulation within each participating simulator need to be integrated into the central simulation management instance rather than into specific simulators, thus requiring the modification of the existing VSimRTI infrastructure.

- *This thesis aims to provide a proof of concept simulation setup that shows the benefits of optimistic synchronization in distributed vehicle simulations compared to conservative synchronization.*

In order to illustrate the performance benefits of optimistic synchronization in distributed vehicle simulation, it is a goal of this thesis to provide a proof-of-concept simulation setup that illustrates the results of the modified architecture. It will be shown how optimistic synchronization influences the time required for a simulation by analyzing and comparing the elapsed wall-clock time necessary in a certain simulation scenario - using sequential, conservation and optimistic synchronization. Further it will be analyzed up to which degree applications scale that are distributed among several physical processors while using optimistic synchronization.

III. Thesis Statement

I propose the following statement:

- *A distributed simulation architecture that facilitates optimistic synchronization among the participating simulators improves the performance and scalability of the simulation system.*