Towards CityMoS: A Coupled City-Scale Mobility Simulation Framework

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***Abstract*—Simulation has become one of the primary tools for the evaluation of transportation systems. To investigate novel concepts such as autonomous vehicles or car-2-car communication, new simulation and modelling techniques are required to increase the meaningfulness and impact of simulation studies. To this end, we develop CityMoS, an easy-to-use, city-scale, microscopic, agent-based mobility simulation framework. The main intended use of this framework is the assessment of autonomous vehicles (AV) with a particular focus on the interaction with conventional vehicles (CV). In order to achieve this, we aim at revising conventional car-following models as well as introducing novel hierarchical models for AVs. A focus will lie on providing a validated city-scale scenario that researchers can parametrise and use to evaluate novel applications. Lastly, we put an emphasis on making our simulation environment interoperable with existing tools either by coupling them or by providing open interfaces to interact with CityMoS.**

I. Introduction

The future of mobility will most likely be autonomous. This does not only add challenges to private road traffic, but also to public transportation on and off the road. In order to evaluate the impact of such fundamental changes on current and future infrastructure, simulation tools are required that allow researchers and policy makers to evaluate possible scenarios to support long-term decision making. Ideally, these tools are able to simulate entire cities or regions with a large number of agents (>100k) while at the same time maintaining a manageable level of complexity.

The number of agents is by far not the only requirement: The performance of the simulation environments has to be magnitudes better than wall-clock time in order to explore the large parameter spaces associated with autonomous vehicles. Also, most existing microscopic mobility models are not sufficient to simulate autonomous vehicles (AV) as they only focus on the low-level control of the vehicle without considering trajectory planning or higher level decision making. Lastly, in the context of intelligent transportation systems and smart cities, the high level of connectivity will have a significant impact on the traffic. This includes other participants, e.g., pedestrians, as well as infrastructure such as car parks, signage or traffic lights. Disregarding this aspect will therefore not allow researchers to investigate the full scope of future traffic.

A new approach towards city-scale mobility simulation is required, where many different concepts of models have to be integrated. The simulation has to provide the possibility to explore large city areas, while at the same time offering a high level of detail. In this paper, we are presenting the current plans for city-scale mobility simulation platform *CityMoS*, which aims at solving the aforementioned challenges. An integral part of this simulation platform is the support for high performance computing environments and cloud-based solutions. This is necessary due to the computationally intensive nature of high-detail city-scale simulations that might be infeasible to run on a workstation computer.

To achieve this high level of detail and to arrive at meaningful results, a focus of CityMoS will be the modelling of conventional vehicles and autonomous vehicles. Microscopic mobility models for human drivers are optimistic in the way that they do not allow for human errors or unexpected behaviour. This is, however, necessary to learn how, in a mixed traffic scenario, autonomous vehicles will react to such behaviour. Secondly, limiting autonomous mobility to only car-following and lane-change models is insufficient as it disregards higher level control of the vehicle that will have a decisive impact on the decisions and routing of the vehicle. Lastly, the interconnectivity of intelligent transportation systems has to be taken into account. To this end, we implemented the TraCI protocol into CityMoS to allow coupling with network simulations such as ns-3 [1] and OMNeT++ [2].

II. State of the Art

There exists quite a number of traffic simulation platforms.

Among the most widely used commercial traffic simulators, VISUM and VISSIM [3] play an important role. VISUM is a macroscopic traffic simulator that focuses on the modelling of traffic demand and traffic flows. VISSIM on the other hand simulates on a microscopic level, that is, each vehicle is an agent with specific behavioural models such as car-following and lane-change models. Due to the closed-source nature of VISSIM, it is not possible to extend it in a way so that studies of mixed CV and AV traffic can be conducted. VISSIM is therefore more suitable for traffic planning in general than for the development of models to study of novel applications.

The *Multi-Agent Transport Simulation* (MATSIM) [4] offers a microscopic traffic simulation platform for the simulation of large scenarios. It works on activities that are fixed at the beginning of the simulation, which makes it impossible to change routes or behaviour of vehicles during run-time. This is a major drawback when it comes to investigation of autonomous mobility in an interconnected intelligent transportation system.

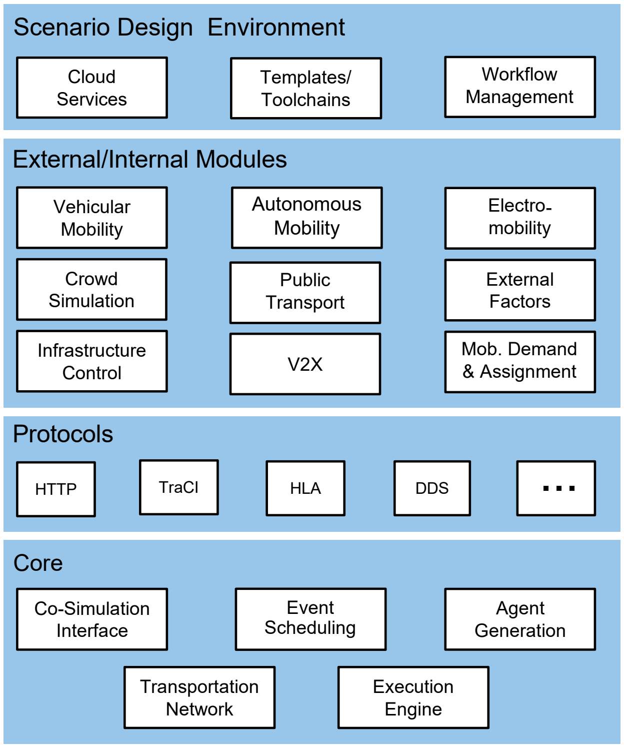

Fig. 1. Components of CityMoS.

Furthermore, creating scenarios in MATSIM is a complex task due to the lack of a general user interface.

SUMO, short for *Simulation of Urban Mobility* [5], is a microscopic agent-based traffic simulator that allows to simulate a large number of vehicles in a predefined network. It features well-known car-following models such as the intelligent driver model (IDM) [6], but lacks the possibility to easily extend or introduce new models, which is something we believe is necessary to study autonomous vehicles. The road network can be generated from open street map data or it can be synthetically generated. SUMO comes with a graphical user-interface but only for controlling the simulation and inspecting the current simulation progress, the configuration has to be created externally and loaded into the GUI at start. SUMO comes with TraCI, an interface to retrieve information about the simulation and also to control it during simulation time. This interface is based on TCP socket and a binary protocol. It has been used to bidirectionally couple network simulators such as ns-2 (Trans [7]), ns-3 (iTetris [8]) or OMNeT++ (veins [9]) with SUMO. This is important to learn how network communication can influence traffic and also how the network topology affects communication metrics.

A simulation environment that combines various simulations from different domains is VSimRTI [10]. It couples various simulators such as OMNeT++, VISSIM, or SUMO following concepts similar to IEEE HLA [11]. The simulator itself takes the role of the controller, dealing with synchronization, interaction and all other management tasks. Other simulators can be coupled using generic VSimRTI interfaces. The concepts and methods of VSimRTI are interesting and will serve as valuable input for the development of CityMoS.

In earlier work, we presented SEMSim (*Scalable Electro-mobility Simulation* traffic [12]), a (sub-)microscopic traffic simulation platform initially developed to study the effect of electric vehicles on the transport system. In this context, sub-microscopic means that, in addition to lane-change and car-following models, agents also incorporate different vehicle components such as the battery. SEMSim is designed to be a city-scale simulation platform that can be used in a single or multi-node execution environment. It is the basis for the development of CityMoS.

III. CityMoS

The *City Mobility Simulator* (CityMoS) aims at being an extendible simulation platform that allows the evaluation of various mobility aspects holistically on a city scale. An overview of all planned and already functional components is given in Figure 1. The core is a discrete event simulation (DES) platform that deals with the dispatching and scheduling of events as well as the necessary steps to realize parallel execution. A particular focus will be set on the development of new modules to incorporate more modes of transport as well as the support for various co-simulation protocols to couple other simulation environments with CityMoS. This includes the TraCI protocol which is widely used in the context of vehicular network simulation [9]. Furthermore, we aim at supporting HLA as well as being Functional Mockup Interface (FMI) [13] conformable.

Microscopic mobility models: Apart from simulating private vehicle traffic, we aim to also integrate public transport (including non-road-based transport), as well as pedestrian movement. The main advantage of using CityMoS over other solutions is the integration of autonomous models for personal vehicles and also for road-based public transport vehicles. To this end, we develop a hierarchical model that is capable of incorporating various types of incoming information, planning routes and trajectories, instead of solely controlling low-level actions of the vehicle. In order to study the effects autonomous vehicles have on conventional human-driven vehicles, we further need to revise existing car-following and lane-changing models as the ones that are currently used in simulation tools have several drawbacks: They are deterministic and collision-free, which means that unpredictable or even irrational human behaviour will not be represented in the simulation. It is however exactly this kind of behaviour which may be of interest when studying mixed traffic of autonomous and conventional vehicles. The introduction of accidents occurrence model capability will further allow to simulate traffic flow control strategies.

Scenario modelling: We aim at extending the functionality of CityMoS by including multi-mode traffic assignment and demand models. This is required since SEMSim worked solely on tempo-spatial origin-destination pairs for private vehicular traffic. CityMoS, however, with the inclusion of public transport, pedestrian and autonomous mobility, needs demand modelling on a different level. Since this data is not trivial to obtain for all scenarios, work in CityMoS will also go into building tools and guidelines to create such information. Additionally, the goal is to provide realistic large-scale multi-modal demand input data for an easy start into using CityMoS for all kind of simulation scenarios. Ideally, CityMoS will come with calibrated and validated scenarios consisting of road networks and travel demand. This enables researchers to quickly set up their simulation without spending time going through the complex process of road network conversion, demand modelling and general data-preprocessing steps.

Bidirectionally coupling: Making CityMoS capable of coupling with existing simulation environments and allowing for the easy integration of other models is one of the key objectives. We are in the process of implementing the TraCI protocol [14] into CityMoS to allow interaction with OMNeT++ and other TraCI-compatible simulators. This opens the door for the evaluation of communication networks, or in a broader scope, smart city applications. CityMoS will then serve as the provider of mobility information, offering information about the states of the simulated agents. At the same time, this interface can be used to control agent behaviour in the simulation. Coupling always comes with overhead as information between the simulations has to be exchanged and synchronization has to be taken care of. A clear software architecture with pre-defined interfaces will help users to implement their own models into CityMoS to avoid this overhead.

User interface: Another important aspect to increase user acceptance is to provide a reliable and well-structured user interface. The visualisation of the simulation for demonstration purposes needs to be appealing and meaningful, as showing how a certain application affects the simulation is often a decisive factor for research. User interfaces go beyond only visualising the current state of the simulation and includes pre-simulation data-processing tools, configuration tools as well as model and parametrization repositories, and a post-simulation analysis. We want to make the set-up process for simulations as self-explanatory and guided as possible while still providing full control over all simulation parameters.

Performance: We are aiming to provide a cloud-based solution for large-scale experiments as well as a local execution environment for smaller studies. Apart from modelling components and entities in the simulation environment, the execution of the simulation studies conducted with CityMoS should be faster than wall-clock time for a mega-city application. This means we are working on the execution environment to be scalable from a workstation computer for small-scale experiments up to high performance distributed computing infrastructures. To further speed up the simulation, we are looking into possibilities to facilitate specialized co-processors like FPGAS or GPUs.

IV. Conclusion

In this paper, we presented the current state and the road map for the development of CityMoS. It aims to be an easy-to-use city-scale mobility simulator for both decision makers and experts from academia and industry to allow high resolution modeling of various participants in an intelligent transportation system. It allows parallel, high performance simulation of time horizons ranging from minutes up to multiple days and combines various aspects of transport systems to allow users to draw holistic conclusions. We put a strong focus on the interoperability with other simulation environments, e.g., to allow studies regarding inter-vehicle communication and autonomous mobility.

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