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Optimized task allocation on private cloud for hybrid simulation of large-scale critical systems

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HIGHLIGHTS

- Hybrid simulation of complex critical systems in private cloud is presented.
- Simulation and emulation interoperability has been managed by federation.
- Allocation of simulation tasks is implemented by multi-objective approach.

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ABSTRACT

Simulation represents a powerful technique for the analysis of dependability and performance aspects of distributed systems. For large-scale critical systems, simulation demands complex experimentation environments and the integration of different tools, in turn requiring sophisticated modeling skills. Moreover, the criticality of the involved systems implies the set-up of expensive testbeds on private infrastructures. This paper presents a middleware for performing hybrid simulation of large-scale critical systems. The services offered by the middleware allow the integration and interoperability of simulated and emulated subsystems, compliant with the reference interoperability standards, which can provide greater realism of the scenario under test. The hybrid simulation of complex critical systems is a research challenge due to the interoperability issues of emulated and simulated subsystems and to the cost associated with the scenarios to set up, which involve a large number of entities and expensive long running simulations. Therefore, a multi-objective optimization approach is proposed to optimize the simulation task allocation on a private cloud.

1. Introduction

Modern critical infrastructures play a key role in improving and preserving the quality of life. Few examples include power grids, smart cities, transportation (e.g., aerial, railway, maritime) systems, and financial IT infrastructures. Designing and managing complex critical infrastructures is increasingly challenging, as more and more systems are required to interoperate in order to provide new functionalities while assuring dependable and cost-effective implementations. Future generation of such systems in domains like air, naval, and railway traffic management, is expected to have a stronger focus on a System of Systems (SoS) concept as driving design criterion, as new needs for interoperability among (often independent) actors are rapidly rising.[1] As a result, the design, development and analysis of such systems is extremely complicated, due to the integration of heterogeneous and widely distributed systems, of new and legacy entities, of proprietary and off-the-shelf components into a unique design. Besides functionality, performance and dependability requirements can become hard to satisfy in such complex scenarios, because of subtle defects difficult to reproduce [1,2].

A powerful tool to support the lifecycle of these systems is simulation. Being able to simulate their behavior accurately would allow engineers to evaluate alternative design decisions, to

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1 Examples are initiative like the SESAR program: "As the technological pillar of Europes ambitious Single European Sky (SES) initiative, SESAR (Single European Sky ATM Research) is the mechanism which seeks to coordinate and concentrate all EU research and development activities in ATM, pooling together a wealth experts to develop the new generation of ATM"—http://www.sesarju.eu.

assess the expected performance and dependability under several different scenarios, to pinpoint possible architectural bottlenecks, so as to drastically reduce the cost for testing and maintenance by setting up onsite simulated testbeds instead of expensive (often unfeasible) real test scenarios. All this favors a suitable design and an early detection of possible problems before the actual deployment, after which the occurrence of failures could be extremely harmful for both producers (indeed, cost of operational failures is much higher than cost of pre-deployment failures) and for end-users (operational failures of such infrastructures could cause serious damages to people and/or the environment). On the other hand, simulation of these complex and distributed systems present serious challenges. Different simulation tools, simulation environments, real sub-systems (usually Commercial Off-The-Shelf) and experimental platforms need to interact in a coordinated way. Such an integration requires sophisticated modeling practices and complex experimentation environments. In addition, despite the advantages of simulation, the complexity of the systems to simulate and the large number of involved entities can lead to very high cost and simulation time.

This work proposes a middleware to implement locally controlled testbed for large-scale mission-critical systems by means of cost-effective distributed and hybrid simulation techniques. The middleware allows setting up simulation platforms integrating emulated and simulated subsystems on distributed testbeds in order to closely mimic the real behavior of the scenarios under test. It offers services for the seamless integration and interoperation among simulated and emulated subsystems and for supporting decisions of the simulation manager about the optimal simulation planning.

The middleware is based on the High Level Architecture (HLA) paradigm [3], a standard for distributed computer simulation that allows the integration of multiple independent simulation environments within a more complex federated simulation system. An HLA-based implementation enabled us to address the critical challenge, exacerbated in large-scale and mission-critical scenarios, of highly heterogeneous environments that need to communicate to each other (e.g., ensuring the accuracy of the experiment threatened by the different time domains on which the simulated and the real platform operate and by communication overhead between the simulation and the emulation environment). On top of this platform, a cost-effective management of simulation resources is implemented. Indeed, very high costs are entailed by the complex scenarios of the simulated systems of systems and by the high number of entities involved. On the other hand, the criticality of the involved systems imply the set-up of testbeds on private infrastructure. Therefore, the careful planning of such scenarios over the available resources is crucial. In the proposed solution, resources are managed via virtualization – a solution that allows overcoming the HLA shortcomings in managing and scheduling capabilities of resources – enabling the on-demand elastic deployment of simulation environments on modern cloud platforms [4]. Based on this, an optimization approach is implemented to support the simulation manager decisions about how to allocate simulation tasks, based on their features, to the available cloud resources, while controlling the total cost of the simulation and its running time. A multi-objective model is proposed, solved by three well-known evolutionary algorithms, which provides the best scheduling of simulation tasks on resources according to a user-desired objective to optimize.

The middleware is designed to support development of complex and critical infrastructures. It is being developed within the frame of a public–private research project named *DISPLAY (Distributed hybrId Simulation PLAtform for ATM and VTS sYstems)*, which is realizing a distributed and hybrid simulation platform for engineering systems of Air Traffic Control (ATC) and maritime Vessel Traffic Systems (VTS). The platform will support the system engineers, enabling the relatively fast deployment of complex scenarios on local testbeds, favoring alternative system design evaluations, pre-deployment testing activities and maintenance operations—the latter two being usually very expensive tasks, due to the wide geographically distributed nature of the considered systems. The platform is expected to remarkably reduce ATC and VTS production and maintenance cost.

The rest of this paper is organized as follows: related work is presented in Section 2. Section 3 shows the logical view of the hybrid simulation middleware named 'DISPLAY'. A detailed description of the DISPLAY implementation is presented in Section 4. A typical simulation scenario of a Vessel Traffic System is described in Section 5. The optimization model of simulation tasks on virtual resources and its experimental evaluation are presented in Sections 6 and 7. Section 8 concludes the work.

2. Related work

Several works proposed unified stand-alone frameworks for simulating complex systems, usually based on a single specialized specification language used to represent the whole system. For example, MATLAB/Simulink packages and tools are available for implementing discrete event simulations, as well as providing interfaces among different discrete event/continuous time blocks [5]. A discrete event-based hybrid simulation solution based on the DEVS formalism and dealing with atomic or coupled models can be found in [6]. Similarly, a hybrid approach for system modeling based on visual syntax is presented in [7]. However, such approaches can provide a limited re-usability of the implemented system models.

Other approaches support the integration of separated simulation models by means of ad-hoc interfaces. For example, some interesting tools for integrating simulation models in hybrid control environments are provided by the BCVTB [8] and by CODIS [9] MATLAB/Simulink interfaces. The former works within the Ptolemy II framework integrated within a MATLAB/Simulink scenario. The latter supports discrete and continuous simulations, providing a co-simulation bus for integrating both a MATLAB/Simulink and a SystemC model. The different models interoperate by using specific Inter-Process Communication (IPC) primitives or interface libraries.

A more recent approach uses agent-based simulations to model and study complex multi-actor systems, complementing the long-established system dynamics and discrete-event simulation approaches [10,11]. Krozel [12] uses the Future ATM Concepts Evaluation simulation Tool (FACET) to model air-traffic in inclement weather. Agogino [13] exploits agent-based simulation for incremental enhancements of the air-traffic management (ATM). Gorodetsky [14] proposes an agent-based simulation for ATM within the air-space of large airports. The *AgentFly* [15] system, built by using the *AglobeX Simulation* platform, also aims to provide a model of the air traffic.

An alternative approach provides HLA/RTI-based interoperability among discrete event-based models and continuous ones, through an explicit spatial separation between them. For example, the framework proposed in [16] implements an HLA/RTI-based interface enabling the complete interoperability between DEVS and the MATLAB/Simulink models. Such a framework leverages the HLA/RTI time management facilities to synchronize the above models, by also relying on the analog/event interface mechanisms for data exchange among them. Furthermore, the mechanism proposed in both [17] and standard MATLAB implements an HLA/RTI interface provided as a specific package or library. There are some