Chapter 3
Influence of Network Constraints on Modeling and Analysis of Cyber-Physical Systems

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ABSTRACT

A cyber-physical system (CPS) is a composition of an embedded computer, a network and a physical process. Usually, the plant, which represents the physical part, is controlled by an embedded system, which consists of computation, communication and control elements, via the global network. This contribution focuses on networked control systems (NCSs) which represents a specific class of CPS. As the problems of CPSs and NCSs are quite similar the goal is to transfer well developed techniques of NCSs to CPSs for analysis purposes. NCSs deal with the analysis of the interaction between the physical system and the cyber system. A main challenge of a control engineer is the development of stable and robust controllers for a NCS. The same goal is present in the design of CPS. To ensure this goal the analysis of such a feedback system has to be performed which is not straight forward and limited by the used modeling approach. This work compares different state-of-the-art modeling approaches for NCSs and stability analysis methods therefore.

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INTRODUCTION

Cyber-physical systems (CPS) represent a composition of an embedded computer, a network (cyber system) and a physical process (physical system) (Lee, 2006). Usually, the plant, which represents the physical part, is controlled by an embedded system via the global network (Lunze & Grüne, 2014). In the work of Baheti and Gill (2011) a more common definition of a CPS has been introduced, "The term cyber-physical systems refers to a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities" (p. 161). The physical component, which can be either a physical, biological or engineered system, is usually of large scale. Due to more efficient software, hardware and network systems, embedded systems can be found in all parts of the physical environment. As a result, a tight integration of the cyber and physical component is very important (Antsaklis, et al., 2013). A detailed analysis on the joint dynamics of the computational and physical part are the keys for a stable, robust, efficient and reliable system design (Kim & Kumar, 2013), (Antsaklis, et al., 2013), (Derler, Lee, & Vincentelli, 2012). A CPS design involves knowledge from disciplines like control, software, mechanical and network engineering. For a successful CPS design, it is important to enable a knowledge transfer between the different engineering areas (disciplines). Especially the cooperation between control and embedded systems engineers (Derler, Lee, Tripakis, & Törngren, 2013) supports the complex design process. In that context networked control systems (NCS) are getting more and more important. To optimize the hardware architecture of an embedded system and to reduce wiring as well as weight, shared buses are introduced. This means more than one control loop is closed over the communication network. Other advantages of NCS compared to point-to-point wiring are higher reliability, lower costs, less needed power and simpler installation (Walsh & Ye, 2001). To reduce communication efforts in modern vehicles, a high-speed Controller Area Network (CAN), for e.g. engine control, and a low-speed CAN, for e.g. window control are integrated (Walsh & Ye, 2001).

Apparently, a shared network represents an unreliable communication link. Hence, packet loss may occur during the system's runtime. Such data loss probably degrades the system's performance (Zhang, Branicky, & Phillips, 2001).

In addition, the scheduling of the control tasks within a shared network may influence the feedback system's behavior and performance. Different scheduling algorithms cause different values of time delays which can lead to different stability properties. Thus, the control system closed over the networked, together with a specific scheduling, need to be analyzed (Walsh & Ye, 2001).

Nowadays, cyber-physical systems become very important in the field of engineering. They include devices, vehicles, management processes, web services etc. (Geisberger & Broy, 2012).

During the last century, our society has steadily increased the dependence on engineered systems. Engineered systems are such as vehicles, health systems or smart buildings. CPS are expected to positively influence the way of interaction and operation between human beings and engineered systems. Besides technology, society is a driver for CPS (Kim & Kumar, 2013). For example, to increase the passenger's safety in vehicles driver assistance functions like adaptive cruise control are introduced (Goswami, et al., 2012). Current popular examples of CPS are: Automated traffic control (Antsaklis, et al., 2013), Drive-by-Wire systems (Howser & McMillin, 2013), power grids (Kim & Kumar, 2013) etc.

A representative automotive CPS example is the adaptive cruise control unit interacting with the vehicle itself which represents the plant. The controller is implemented on an ECU (electronic control unit, discrete part) and interacts with a real-world model (continuous part). Additionally, a CPS within

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