INtERCEDE: An algorithmic approach to networked control system design

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1. Introduction

The modern control systems are getting more complex and comprehensive. This trend is supported by the integration of computing, communication and control into different levels of machine/factory operations and information processes. The control applications are implemented in a distributed fashion where the components (sensors, actuators and controllers) are at different physical locations. Different from monolithic implementations where these components exist on the same physical device and can share information for free, a distributed implementation requires a communication network to transmit sensor data to controllers and control data to the actuators. To this end, a control system where the control loop is closed over a communication network is called a Networked Control System (NCS) (Yang, 2006; Hespanha et al., 2007). Examples for NCS include manufacturing systems and vehicle electronics (Thomesse, 2005; Navet et al., 2005).

In NCS the sensors, actuators and controllers constitute nodes that are sending messages to each other (Yang, 2006). The control applications that run on these nodes are often time-critical such that violating the operational requirements might lead to loss of human life and property. Hence, a family of special Industrial Communication Protocols is developed to meet these requirements (Felser, 2005; Willig et al., 2005). Industrial communication protocols are mostly of shared-medium type where the nodes get access to the network through strict priority, event-triggered arbitration or through time-triggered mechanisms. The most well-known event-triggered standard is the Controller Area Network (CAN) (GmbH., 2003; Almeida et al., 2002; Scarlett and Brennan, 2006; Echelon, 2009) while TTCAN (Leen and Heffernan, 2002), FlexRay (Consortium, 2004), TTP/C (GmbH., 2003; Wang et al., 2007) are prominent time-triggered standards. Time-triggered networks are found to be a better suited architecture for NCS as it supports the periodical operation of distributed control systems (Albert, 2004). There are also hybrid structures (CAN/ATM) as in Erturk (2005).

From the operational perspective, multiple nodes share the communication network to transmit their messages. Hence, the messages are transmitted with certain delays that affect the performance of the control system. In particular, the time that elapses from the generation of a signal until its reception by the intended node should be bounded such that the control system is stable. Furthermore the response of the NCS should be as close as possible to a monolithic implementation without any adverse effects of the network. In the system design, these performance requirements have to be specified in the form of message properties such as message generation frequency and the maximum message delay.

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