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Modelling and simulation of distributed time critical communication and control systems in vehicles or vehicle networks

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Abstract: This paper is dedicated to the methodical analysis of distributed communication and control systems, such like systems inside modern vehicles or systems of networked vehicles. For runtime and time-behavior analyses, the basic models of a communication access and a cycle crossing between program components are discussed. For these subproblems, exemplary simulation results are shown and validated. Regarding both problems together, a mathematic approach is introduced, which describes the structure of a subsuming process, relevant for time analysis in distributed systems. The simulation of this complete process allows the derivation of realistic statements on the tolerable limits in time critical control systems.

Keywords: distributed control systems, time critical control systems, communication, modelling, simulation

1. INTRODUCTION

With the improved performance of small computers, the organization of control technology systems have become increasingly decentralized. Distributed systems have many advantages in terms of fulfilment of requirements: Unlike centralized systems, they are easier to scale and more flexible. One of the earliest examples is the replacement of discrete wiring of sensors and actuators in vehicles for communication systems. Before introducing the first fieldbus systems in vehicles in the 1990s, most difficulties were their handling and problems with weight and geometry (Zimmermann and Schmidgall (2006)). From then on, the network amount has risen sharply, so that a large amount of ECUs communicate with each other via bus systems in today's vehicles.

The vehicle manufacturers worked also on concepts of reusable software modules in order to offer a wide range of functional variants. Such an approach is the development of standards for system functions, for example the AUTOSAR-Standard (Schäuffele and Zurawka (2013)). The aim of this merger of renowned automobile companies is the development of methods that allow the reuse, exchange and scaling of cyclically operating software components. Furthermore in the near future, vehicles themselves will be components of a higher-level traffic system. The concepts that have emerged from this macroscopic view are referred to vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication.

The distribution of hardware and software components inside vehicle-systems and inside a traffic system with networking vehicles results in complex and dynamic system architectures. With the focus of time behaviour, the following challenges have to be considered:

1. The allocation of functions on the distributed hardware system will cause conflict situations when physically related communication processes are executed. Due to simultaneous requests of only one resource (the transmission channel), a non-deterministic behaviour of delays has to be expected.

2. The data transfer between functions will also suffer delays, due to necessary cycle-transitions and synchronization processes between the distributed software components.

3. Furthermore, the communication behaviour between networked vehicles has to be considered in the method of timing analysis.

Therefore, this paper deals with an (overall) methodical analysis of time behavior in time critical systems based on Petri nets. First, the behaviour of a communication bus inside a vehicle is investigated. Based on a mathematic description of the communication system, an executable Petri net model is developed. The structure of the model is presented in section 2. Furthermore, results from the simulation and the validation of the model are shown and discussed.

Section 3 studies the delays due to cycle transitions between program components. As the same procedure like the analysis of the bus behaviour, the executable Petri net model and simulation results are presented.

To consider both problems, the communication processes and the cycle-transitions, a procedure for creating a Petri net model is proposed in section 4. This model represents a complete information transmission process, taking into account the

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communication- and cycle-transition delays. For further explanation, an example will be introduced.

Using the presented simulation models of distributed control systems, dynamic properties can be detected in the early evaluation phase of a (sub)system that could help in design decisions (inside vehicle and between networked vehicles). Time critical deficiencies in system architectures and maximal response times could be revealed. Due to the mathematical description of Petri net models, comprehensive (such as V2V) systems could be automatically modelled and analysed using net based approaches.

2. BUS BEHAVIOUR

Sharing of communication resources requires transmission rights to transmit a telegram. For the communication in a vehicle (microscopic view) for example, CAN communication with the CSMA-CA method is used primarily (ISO 11898). Due to the non-deterministic communication behaviour, significant delays for sending out low priority frames could appear, especially if multiple use of the communication channel is not possible.

In the work of Ding et. al. (2009) or Cavalieri et. al.(1996) the performance of a CAN bus is already analysed based on Petri net models. But the papers do not focus on the mathematical description of relevant structures for an automatic model generation. In the work of Diekhake and Schnieder (2015) the necessary attributes for a model generation are introduced. There, structure information $\underline{\underline{C}}_K^+$ (communication functions, concluded from process functions), $\underline{\underline{D}}_B^+$ (connection between communication functions and hardware devices, also defined in the work of Kiefer (1995)) and parameter data $\underline{\underline{A}}_{K,i}$ (transmission type of communication process i) or $\boldsymbol{o}_i$ (priority of communication process i) are described and formalized.

Fig. 1 depicts a minimal example of an executable model of a CAN bus, which is based on the mentioned attributes. Six communication processes are shown on the left side (functional view), which are mapped to five transceivers on the right side (resource view). The transceivers are connected via one communication channel called *bus*.

Selected simulation results for this model are shown in Fig. 2. The general increasing of the delay times due to a rising busload is depicted on the left side. The measurement results are derived from a test board with five transceivers, whereby the sending rate frequency was varied to represent busloads from 0%, 50%, 75%, 90% and 100%. In the figure it can be seen that the maximum delay time for a low-priority telegram is 3,5 ms, if the busload is 100 %. The course of the delay time of a low-priority telegram for maximum bus load is depicted on the right side. Both, the measurement and simulation results shows a lognormal-distribution for the time-delay. It can be seen, that the expected value of the time delay is about 500 µs.

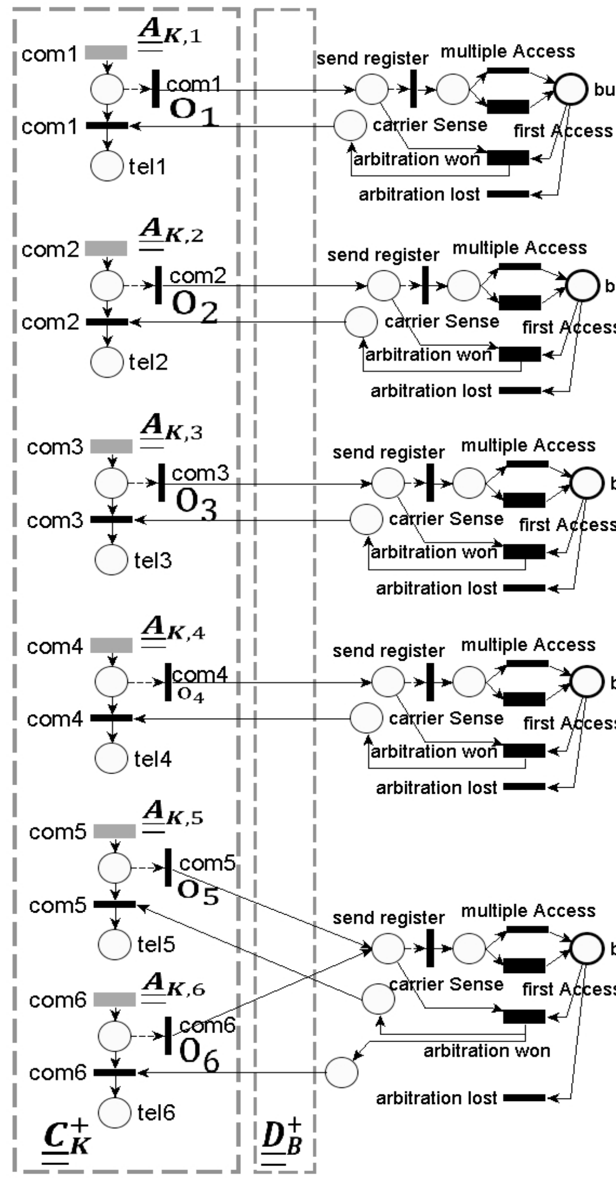

Fig. 1. Example of an executable Petri net model for the investigation of the bus behaviour of a distributed control system

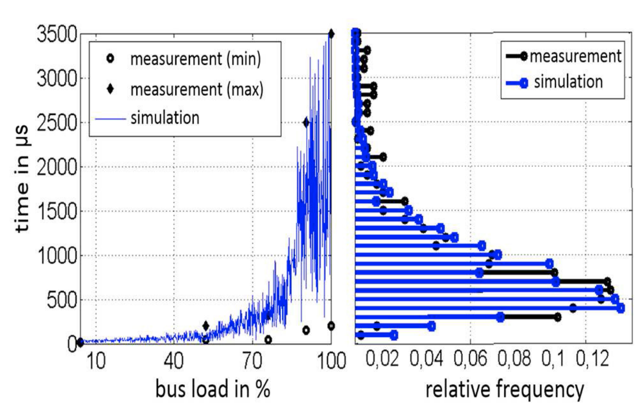

Fig. 2. Delay time vs. bus load (left) and delay time course for maximum bus load (right)