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Report on PhD Thesis: "Resource Reservation and Analysis in Heterogeneous and Distributed Real-Time Systems"

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Thesis Reviewer: RNDr. Tomáš Bureš, Ph.D., Charles University, Prague

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Content and contribution of the thesis

The submitted PhD thesis focuses on design, implementation and evaluation of a software framework for facilitating development of real-time distributed applications. More specifically, the thesis builds on the work, which was done by the candidate in the frame of the project FRESCOR (FP6 STREP). The FRESCOR project itself aims at developing technology and infrastructure for efficient use of advanced techniques for real-time applications with flexible scheduling requirements.

The thesis provides implementation (called FRSH/FORB) of the API (called FRSH) defined within the FRESCOR project. In elaborating on realization of the FRSH/FORB framework, the candidate deals with related issues that comprise integration of different resources (CPU, disk wireless networks, FPGA) to the framework, performance evaluation of the framework on a real-life case study and formulation of the holistic scheduling analysis as an integer linear programming problem. Thus, the thesis succeeds in binding together a bit loosely coupled topics in quite a cohesive manner.

The description of actual contribution of the thesis starts in Chapter 3, where the proposed FRSH/FORB framework is described. The need for a new framework is quite well motivated, especially with stressing high modularity, resources with varying capacity and task migration between resources (e.g. in the presence of FPGA node). The chapter further describes the architecture of the framework, which consists of CORBA-like communication middleware (FORB) and FSRH contract broker agent (entity responsible for implementing the FRSH API) and various concepts for contracts and resources. The chapter also proposes its own version of transaction API as the replacement of unnecessarily complicated transaction extension in original FRSH API. The chapter concludes with a mathematical model of the framework that formally defines transactions in the framework and uses it to define the problem of optimal distribution of the spare capacity across multiple resources.

Another major contribution of the thesis comes in Chapter 4, where integration of various resources into the framework is described. In addition to CPU resource, which is achieved by combining the FRSH/FORB implementation with AQuoSA real-time scheduler for Linux, the thesis introduces support for disk, wireless LAN, wireless sensor networks, and FPGA. The support for disk is achieved by implementing a BFQ scheduler and integrating it with FRSH/FORB, similarly there have been implemented resource managers for two types of wireless sensor networks (ITEM and Cluster-Tree Network).

The resource reservation on wireless LAN represents a significant contribution of the thesis. The candidate has proposed a simple admission test on IEEE 802.11e wireless networks, which aims at preventing saturation under the dynamically changing conditions experienced

in wireless networks. In addition to the test itself, the thesis presents the experiments used to fine-tune parameters of the admission test and the experimental evaluation of the admission test with respect to actual utilization of the wireless network.

The presented work on FPGA support is also interesting, since it requires the framework to support allocation of task in a heterogeneous environment.

Chapter 5 of the thesis deals with evaluation of the proposed FRSH/FORB framework on a real-life case study of surveillance system. The results show improvements in throughput and end-to-end response time when FRSH/FORB framework is employed. However, most of the improvement can be attributed to real-time CPU scheduling. The network scheduling does not show any significant benefit, which however is probably due to incomplete measurements – TCP stream was used to simulate interference, however, TCP adapts its bandwidth according to detected channel capacity, thus it itself tries to avoid saturation.

The thesis supplements the elaboration on the resource reservation framework by mathematical formulation of the holistic scheduling problem, which is inherent to real-time distributed systems, as an integer linear programming problem. This part of the thesis provides interesting insights too. The experiments performed by the author however show that the technique cannot be used as is since the size of the generated ILP program corresponds to number of steps of the classical exponential algorithm for response time analysis, thus this part of the thesis has more theoretical value than any direct practical implications.

The last interesting contribution of the thesis is the change proposal of the FRSH API (in Appendix A) based on practical experience with implementing the reservation framework that provides FRSH API and implementing a real-life case study that employs multiple resources. This chapter provides a good overview of the problems of FRSH API along with categorization of the problems.

Presentation and writing style

The thesis is well written and structured, and the flow of information is appropriate. There are several typos and grammar errors in the text, but these do not hinder understandability of the thesis. The way of presentation is also appropriate, only in Appendix A, the language veers to more informal style.

Issues and questions for the defense of the thesis

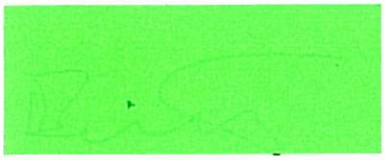
1. Section 2.3.2 lists FRSH as the related work or even as an alternative approach, however the rest of the thesis suggests that FRSH/FORB is rather an implementation and enhancement of FRSH. It would be helpful if more clarification on the mutual relationship of FRSH and FRSH/FORB together with details of their differences are given. I think this is important, because FRSH/FORB framework is the main contribution of the thesis. Similar objection could be raised with respect to Section 3.1, where FRSH implementation is mentioned, but no comparison with FRSH is provided and not deeper description of FRSH is give as well.
2. The author claims in Section 3.3.5 that the original distributed transaction manager of FRSH was unnecessarily complicated, however, no details are given, only a new set of functions is proposed with basically no motivation or justification.
3. The author states that 96% is the empirically determined value for the utilization bound. However, no explanation is given how this value has been determined and under which conditions it holds. The author further claims that the utilization based test with the tuned empirical constants is sufficient for most real-world soft real-time

applications. In my opinion this should be justified either by discussion why this is true or by more extensive set of experiments.

4. The thesis mentions in Section 4.5.1 that static reconfiguration for FPGA is used. However, there is no mention of how state transition, real-time loading and co-existence of multiple cores are achieved.
5. It would be very beneficial for the results presented in Chapter 5, if the measurements were done in some controlled environment. For example measurements done in Figure 5.2 and 5.3 are biased by external interference, which is even different between the two cases as the measurements were done under different conditions.
6. Section 5.3.3 mentions that each experiment lasted 500 frames. Why 500 frames? Did the author try to use some statistical methods to know how many samples to collect to get statistically sound results?
7. In Section 5.3.3, the author simulates interference by running TCP flow together with data being transmitted. However, the TCP congestion control causes that the TCP flow is limited with respect to the saturation of the channel. The UDP could not have been used due to problems with network adapter driver. How does this influence the results presented in Figure 5.7 b) and g)? How well does this experiment emulate interference by other WiFi networks?
8. The discussion in Appendix A seems quite important to me. I think it is a bit unfortunate that the author stopped at informal overview of problems instead of elaborating on the problems in greater depth and coming with more comprehensive proposal for improved API.

Judgment

The candidate has without doubts proved that he is able to work creatively and come with innovative solutions to research problems. The thesis deals with relevant goals and succeeds in fulfilling them. The method of achieving the goals is also sound and the solution has been experimentally evaluated. Thus, the thesis represents a significant and novel contribution to current state-of-the-art in the area of distributed soft real-time systems. This includes especially the FRSH/FORB framework itself, methods of wireless LAN reservation as well as integration of other resources, change proposal for FRSH API and integer linear programming formulation of the holistic scheduling problem. Therefore, I recommend the thesis for a defense and judge the candidate worthy of the degree of PhD.



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