Closing summary of the project „Design of Distributed and Self-organizing IT Systems” (PD 121201)

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The workplan of the project

At the beginning I planned to select the distributed services or applications to be focused on. At the time

- services and applications of the domain of Internet of Things (IoT);
- value-added services in a federative setting of Internet Service Providers (ISPs);
- Big Data computing systems and data center networks

were those distributed systems that received the highest attention in the computer science research. Focusing on these application domains, my goal was to lay down the fundamentals of a generic modeling framework.

I modeled the selected distributed systems with the toolset of game theory and with uni-, bi-, or multilateral matching theory. By the end of the first year my publication goal was to publish at least one research conference paper and then to submit its extended version to an academic journal. The expected outcome included abstract incentive scheme models that ensured the outcomes expected by the system designer, plans of robust systems and favorable game theoretical results.

In the second year I meant to investigate the more practical, but analytically more complex questions. I studied the system dynamics that the designed incentive schemes caused within the system while ensuring the advantageous user behavior. These dynamics touch upon the question of convergence that is essential for robust systems, scalability, analysis of the dynamics of system growth. The goal of the second year was to publish at least two conference papers on the implementation of distributed algorithms and on system(s) simulations to validate the analytical results.

Based on simulation results of the second year, in the third year my goal was to implement the "Proof of Concept" prototypes of the selected system(s). The implementation of distributed algorithms in this phase was to be carried out based on the underlying theoretical model and simulation results. The work consisted of the implementation of commercially valuable and quickly deployable service prototype system(s). The results of the third year were to be published at system-focused conferences and journals.

Overall, the publication goal amounted to 4 conference papers and 2 journal articles.

The results of the project

In Year 1, focusing on the 3 listed application domains, my goal was to lay down the fundamentals of a generic economic modeling framework. The results of Year 1 were in line with the workplan:

- I gathered thorough knowledge of novel distributed self-organizing networks, systems and services: I analyzed a time-critical Internet of Things system and the federation of telecommunications service providers in the envisioned setting of 5G;
- I lead intensive research on economic aspects related to the chosen applications, I dove into the state-of-the-art: I studied the pricing aspects, market mechanisms, actor-role models and business incentives in these systems.
- I examined the economic questions of the selected distributed systems.
- I created a generic stochastic game theoretic model for the pricing of Network Function Virtualization (NFV) models.
- I formulated the required specifications for the time-critical Internet of Things systems, and I integrated the special requirements into the model.
- I analyzed the models: the existence of equilibrium, social welfare, participant strategies, price of anarchy.

As results, I created abstract incentive scheme models that assure the outcomes expected by the system designer for two systems.

In Year 2 my plan was that I would analyze the distributed services and applications selected in Year 1. These application domains and my contributions in Year 2 are the following:

- distributed resource allocation algorithms for services and applications of the domain of IoT;
- convergence and stability analysis of value-added services in a federative setting of ISPs, where NFV is the enabling technology;
- simulation of performance analysis of big data computing systems and data center networks.

My results of Year 2 were in line with the workplan:

- I continued the analytic examinations of Year 1, and I studied convergence issues, e.g., in 5G federations;
- I developed and evaluated distributed algorithms for resource allocation and orchestration in NFV and IoT frameworks;
- I supported analysis results with simulations in all the application domains;
- I studied the feasibility of analytic results, particularly in the domain of 5G services.

By Year 3 the plan was to implement the first 2 years' results and publish the proof of concept prototypes at system-oriented academic venues. Furthermore, it was expected by the end of the project when journal submissions potentially arrive in a published phase. My results of Year 3 were in line with the workplan:

- in addition to IoT and federated providers for 5G, I also tackled big data distributed systems, as those are considered to be a hot topic nowadays;
- an extension for OpenStack and for Kubernetes, which enable those cloud resource manager frameworks to efficiently orchestrate distributed IoT applications, were implemented and published in demo sessions of top-tier conferences;
- journal articles were submitted containing the extended versions of the published conference papers on 5G federations and on IoT systems.

Altogether, the publication record acknowledging this project consists of 8 conference papers, 1 demo paper, and 2 journal papers (currently in submission, after minor revision). Moreover, 3 conference papers and 1 demo paper are related to this research, but acknowledgment were given to other supporting actions of NKFI, direct outcomes of this project: the research started in this project continues within an industrial Lendület program with Ericsson (research group leader: Balazs Sonkoly), and in a Hungarian-Korean innovation project (2018- 2.1.17-TÉT-KR-2018-00012). Furthermore, a practical exploitation of this project is an accepted US patent, submitted with co-authors at Ericsson Research.

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