REVIEW

on the procedure for obtaining

educational and scientific degree "Doctor"

by

Candidate: Tsvetan Krasimirov Tsokov,

Dissertation thesis title: "IoT Platforms and Protocols",

Scientific advisor: Assoc. Prof. Hristo Kostadinov, PhD,

Scientific field: 4. Natural Sciences, Mathematics and Informatics,

Professional field: 4.6. Informatics and Computer Science,

Doctoral program: „Informatics",

Department: Mathematical Foundations of Informatics, Institute of Mathematics and Informatics at the Bulgarian Academy of Sciences (IMI-BAS).

This review report has been prepared by **Assoc. Prof. Todorka Gerasimova Alexandrova, PhD, IMI-BAS,** as an internal member of the scientific jury for the current procedure for obtaining educational and scientific degree "Doctor" according to Order № 322/19.09.2024 of the Director of IMI-BAS and decision of the Scientific council (Protocol № 11/13.09.2024).

The review report has been prepared in accordance with the requirements of the Act on Development of the Academic Staff in the Republic of Bulgaria, the Regulations for its implementation, the Rules for the conditions and regulations for acquiring scientific degrees and occupying academic positions in the Bulgarian Academy of Sciences and the relevant regulations of IMI-BAS.

1. General description of the dissertation thesis and the presented materials

The dissertation thesis is in English and consists of **76** pages, containing table of contents, lists of figures and tables, an abstract, an introduction, six chapters (containing 1, 5, 4, 2, 1 и 1 paragraphs, accordingly), acknowledgments, three appendices, author`s scientific contributions, list of publications and presentations, and bibliography with **86** entries. The dissertation meets the generally accepted requirements for obtaining the educational and scientific degree "Doctor". The bibliography shows that Tsvetan Tsokov has good knowledge of the field that he is researching.

From the required documents and papers submitted by Tsvetan Krasimirov Tsokov, it can be confirmed that he meets the requirements of the Act on Development of the Academic Staff

in the Republic of Bulgaria, the Regulations for its implementation, the Rules for the conditions and regulations for acquiring scientific degrees and occupying academic positions in the Bulgarian Academy of Sciences and IMI-BAS, as well as the specific requirements for obtaining the educational and scientific degree "Doctor", given in the Rules for the conditions and regulations for acquiring scientific degrees and occupying academic positions in IMI-BAS.

2. Short CV and personal impressions of the candidate

Tsvetan Tsokov received his Bachelor`s Degree in Computer Systems and Technologies from the Technical University in Sofia in 2015 and his Master's Degree in Informatics-Distributed Systems and Technologies form the Faculty of Mathematics and Informatics, Sofia University in 2017. In January 2020 he enrolled as a part-time doctoral student at IMI-BAN, doctoral program "Informatics", Department of Mathematical Foundations of Informatics, and in January 2024 he fulfilled the requirements for starting the procedure of his dissertation defense. During the last 12 years he has been working as a software developer at two large international software companies.

I have known Tsvetan Tsokov personally since his enrollment in the doctoral program in the Department of Mathematical Foundations of Informatics, and I believe that he is an extremely talented young researcher who has very deep theoretical and practical knowledge and skills in the field in which he works. From personal conversations with his scientific supervisor, Assoc. Prof. Hristo Kostadinov, I know that they have an excellent professional working relationships as a scientific supervisor and a doctoral student, which is also evident from the joint scientific results presented in their papers and the dissertation.

3. Analysis of the scientific and applied achievements of the candidate contained in the presented dissertation thesis and the publications for the procedure

The aim of the presented dissertation is to provide solution for optimal management of computational and network resources in Cloud/Edge/Fog distributed system platforms, which involve dynamic moveable infrastructure nodes and end-users. In such dynamic environment the state of the art of the existing platforms of this type are failing to manage the Quality of Service (QoS) and Quality of Experience (QoE) of the latency-demanding business applications, leading to big end-to-end network latencies and degraded user experience at runtime. Proposing a solution to this problem the dissertation makes possible the support of real-time IoT applications with mobile nodes such as autonomous vehicles, augmented/virtual reality (AR/VR), spacecraft computing, smart city, etc.

The dissertation makes a comprehensive analysis of the available related works in the field and identifies several major parameters, which should be supported by one Cloud/Edge/Fog platform in order to handle effectively moveable infrastructure nodes and application's QoS/QoE dynamically. All works, including the proposed solution in the dissertation, are compared against them and at the end the benefits of the proposal are evaluated and highlighted.

The dissertation formulates the stated issue as a mathematical optimization problem and then proposes a Mixed-Integer Linear Programming (MILP) model for finding optimal solution. Its architecture is designed and implemented in the most popular Cloud/Edge platform used in the practice, called Kubernetes (K8s). The implementation is done in the Golang programming language. A testbed cluster containing resource-constrained devices (Raspberry Pi) is built and the implemented Edge/Fog platform is deployed on it. The testbed is emulating dynamic environment composed of geo-distributed mobile Edge/Fog nodes moving in space. Its aim is to evaluate how the proposed model reduces total end-to-end network latency of a business application in this environment. The business application used for the evaluation is also implemented as part of the dissertation. It is called EcoLogic and represents a practical edge-native IoT application. Its functionality is to measure and control carbon emissions from vehicles and is suitable for execution in smart city scenarios. The obtained results show that the model is scheduling and moving resources on proximal infrastructure nodes by coping to the movements of the nodes. In this way the business application end-to-end network latency is kept at minimum on runtime and in continual manner. One of the most important outcomes of the dissertation is that the solution is suitable for real-world practical infrastructures with constrained ARM64 devices.

Chapter 1 presents an overview of Edge/Fog distributed systems, the existing problems in them, and an analysis of previous research on the subject, which shows the relevance of the problem and the need for an effective solution.

Chapter 2 proposes a solution for real-time monitoring and detection of rising levels of carbon emissions from vehicles, called EcoLogic. It is used also for evaluation of the presented framework for resource scheduling in dynamic Cloud/Edge/Fog platforms with moveable infrastructure nodes, described in next chapters. The proposed EcoLogic application includes hardware module, which collects sensor data related to vehicle's carbon emissions. The data is transferred to cloud-based applications, where it's stored and analyzed. The results from the analysis are used to control the carbon emissions through driver notifications and vehicle's power limitations. The obtained results, resources and source code of the main software com-

ponents of the solution are publicly available. The repositories contain information on how to setup the projects and deploy them on hardware device and server or in the cloud.

Chapter 3 makes a comparative analysis of some important results for resource allocation in Edge/Fog platforms related to their major features identified in Chapter 1. The features are infrastructure topology awareness, virtualization type, support for application microservice dependencies, dynamicity, mobility, network latency awareness, ARM64 CPU architecture support and evaluation type.

Chapter 4 proposes a novel MILP optimization model for network-aware microservice container provisioning in dynamic Cloud/Fog infrastructures composed of moveable and constrained nodes with ARM architecture. Its objective functions maximize the total number of deployed workloads, minimize total replica movements across nodes and minimize the workload's network latency in order to provide optimal placement solution.

Chapter 5 presents two examples that demonstrate how the described model handles the identified in Chapter 1 major features of Edge/Fog computing platforms in a realistic mobile environment. The examples are conducted in a testbed, which uses Kubernetes (version 1.24.3) Cloud/Fog platform and container-based virtualization. They are aiming to evaluate realistic workload represented by the EcoLogic sample application.

The main scientific contributions of the thesis are as follows:

1. The existing MILP model is extended with new latency matrix for inter-pod communication variable, node availability region variable and objective function for minimization of replica movements across mobile nodes.
2. Capacity and demand vectors are replaced by direct variables (Bn, Cn, En, bp, cp, ep) used into the constraints and objective functions in the mentioned MILP model.
3. The execution flow of the above MILP model is modified in order to support dynamic optimization of replica placements with moveable nodes. The flow consists of phases and iterations.
4. The MILP optimization model is implemented in real Cloud/Edge/Fog platform (Kubernetes).
5. The algorithm and platform are evaluated in a testbed.
6. Design and implementation of a real-world edge-native IoT application, called EcoLogic, for monitoring and control of carbon emissions from vehicles, suitable to run in smart city environments.
7. Validation of the EcoLogic's algorithm for clustering analysis, which detects outlier vehicles that pollute the air excessively.

8. Creating publicly available open-source repositories with information and source code of the important EcoLogic microservices.
9. Performing evaluations based on the EcoLogic application. They are making emulation of node movements in the testbed cluster.
10. The obtained results from the performed evaluations with the EcoLogic sample application show reduction in the workload's end-to-end latency by up to 48% compared to the latest state of the art.

11. Approbation of the results

The presented dissertation thesis is written based on the contents of the following two scientific publications:

1. **T. Tsokov** and H. Kostadinov, "System for monitoring and control of vehicle's carbon emissions using embedded hardwares and cloud applications", in Service-Oriented Computing - ICSOC 2020 Workshops, H. Hacid, F. Outay, H.-y. Paik, et al., Eds., Cham: Springer International Publishing, 2021, pp. 564-577, ISBN: 978-3-030-76352-7. doi: https://doi.org/10.1007/978-3-030-76352-7_50. [Online]. **SJR (Q2)**.

2. **T. Tsokov** and H. Kostadinov, "Dynamic network-aware container allocation in Cloud/Fog computing with mobile nodes", Internet of Things, p. 101 211, 2024, ISSN: 2542-6605. doi: https://doi.org/10.1016/j.iot.2024.101211. [Online]. **IF (Q1).**

All publications are co-authored with the supervisor of the doctoral student. I assume that the candidate's contribution to the joint publications is equivalent. The obtained results have been presented at three international and national conferences and seminars. In the presented materials on the current procedure no information has been provided on citations of the candidate`s publications. There is no plagiarism proven in the legally established order in the presented dissertation work and the scientific papers used in this procedure.

As a result, the candidate Tsvetan Tsokov covers and exceeds the minimum national requirements under Art. 2b, Para. 2 and 3 of the ADAS in the Republic of Bulgaria required for the acquisition of the educational and scientific degree "Doctor" in Professional field 4.6. Informatics and Computer Science.

12. Qualities of the abstract

The abstract of the dissertation thesis consists of 34 pages in Bulgarian language and 31 pages in English. It reflects correctly the contents, results and contributions of the dissertation.

The main scientific contributions of the dissertation are correctly and accurately presented in the summary.

13. Critical comments and recommendations

I have no critical comments and recommendations. I hope the candidate will continue actively do research in the area in the future as well.

14. Conclusion

Having become acquainted with the dissertation thesis presented in the procedure and the accompanying scientific papers, and on the basis of the analysis of their importance and the scientific and applied contributions contained therein, **I give my positive evaluation and do confirm** that the dissertation presented and the scientific publications to it, as well as the quality and originality of the results and achievements presented in them, meet the requirements of the Act on Development of the Academic Staff in the Republic of Bulgaria (ADASRB), the Regulations for its Implementation, the Rules for the conditions and regulations for acquiring scientific degrees and occupying academic positions in the Bulgarian Academy of Sciences and the relevant regulations of IMI-BAS for acquisition by the candidate of the educational and scientific degree "Doctor" in the Scientific field 4. Natural Sciences, Mathematics and Informatics, Professional field 4.6 Informatics and Computer Science. In particular, the candidate **meets the minimal national requirements** in the professional field and **no plagiarism** has been detected in the scientific papers submitted for the current procedure.

Based on the above said, I **strongly recommend** to the scientific jury to award Tsvetan Krasimirov Tsokov, the educational and scientific degree „Doctor" in the Scientific field 4. Natural Sciences, Mathematics and Informatics, Professional field 4.6 Informatics and Computer Science.

22. 10. 2024 Signature: .....

Sofia (Assoc. Prof. Todorka Alexandrova, PhD)