UNIVERSITY OF NOVI SAD   FORM – 6
FACULTY OF TECHNICAL SCIENCES

DOCTORAL DISERTATION EVALUATION REPORT

I	COMMITTEE INFORMATION

1. Date and body that assigned the committee:
   Dean of the Faculty of Technical Sciences based on the decision of the Teaching and Scientific Council of the Faculty of Technical Sciences; Decision No. 012-199/22-2023 of 28.03.2024.

2. Committee members information in accordance with regulations for doctoral studies at the University of Novi Sad:

1.	dr Slaviša Tomić	Associate professor	Telecommunications and Signal Processing, 01.02.2022.
	Surname and name	Title	Scientific field and date of election
	Lusófona University, Lisbon, Portugal		Chair
	Institution of employment		Role of committee member
2.	dr Čedomir Stefanović	Full professor	Telecommunications and Signal Processing, 01.01.2021.
	Surname and name	Title	Scientific field and date of election
	The Technical Faculty of IT and Design, Aalburg University in Copenhagen		Member
	Institution of employment		Role of committee member
3.	dr Karolina Kasaš-Lažetić	Associate professor	Theoretical Electrical Engineering, 13.06.2021.
	Surname and name	Title	Scientific field and date of election
	Faculty of Technical Sciences, University of Novi Sad		Member
	Institution of employment		Role of committee member
4.	dr Milica Petković,	Assistant professor	Telecommunications and Signal Processing, 15.07.2022.
	Surname and name	Title	Scientific field and date of election
	Faculty of Technical Sciences, University of Novi Sad		Member
	Institution of employment		Role of committee member
5.	dr Dejan Vukobratović	Full professor	Telecommunications and Signal Processing, 26.09.2018.
	Surname and name	Title	Scientific field and date of election
	Faculty of Technical Sciences, University of Novi Sad		Supervisor
	Institution of employment		Role of committee member

6.	dr Marko Beko	Full Professor	Telecommunications and Signal Processing, 01.07.2018.
	Surname and name	Title	Scientific field and date of election
	Lusófona University, Lisbon, Portugal		Supervisor
	Institution of employment		Role of committee member

II CANDIDATE INFORMATION

1. Name, name of one parent, surname:
   Tijana, Dubravka, Devaja

2. Date, municipality and country of birth:
   09.08.1993, Novi Sad, Serbia

3. Name of the academic institution, previously completed academic program and the title acquired:
   Faculty of Technical Sciences, University of Novi Sad, master's academic studies, Master in Electrical and Computer Engineering

4. Year of enrolment into doctoral studies and name of the PhD study program:
   2017, Power, Electronic and Telecommunication Engineering

III TITTLE OF THE DOCTORAL DISSERTATION:

Дизајн и анализа масивне мреже интернета ствари у режиму преноса кратких порука
(Design and analysis of massive IoT networks in finite block-length regime)

IV OVERVIEW OF THE DOCTORAL DISSERTATION:
Concisely summarize the dissertation content with indicated number of pages, chapters, figures, images, charts etc.

The doctoral dissertation encompasses 139 numerated pages, 10 tabels, 31 figure, and 174 references.

It consists of the following chapters:
1. *Introduction*
2. *Error Probability Analysis of LP WAN Networks in Nearest Base Station*
3. *Error Probability Analysis of LP WAN Networks in Macro diversity reception Regime*
4. *Slotted Aloha with Capture for OWC-based IoT: Finite Block-Length Performance Analysis*
5. *Massive Machine-Type Communications via Hybrid OWC/RF Networks in Finite Block-Length Regime*
6. *Conclusions*

V EVALUATION OF INDIVIDUAL DISSERTATION CHAPTERS:

VI   LIST OF SCIENTIFIC AND PROFESSIONAL MANUSCRIPTS PUBLISHED OR ACCEPTED FOR PUBLICATION, WHICH ARE BASED ON THE RESULTS OF THE DOCTORAL RESEARCH:

List the manuscript titles, where and when they were published. First, list at least one paper published or accepted for publication in accordance with the *Rules of Doctoral Studies of the University of Novi Sad* that is related to the content of the doctoral dissertation. In the case of manuscripts accepted for publication, list the titles of the works, where and when they will be published and attach a confirmation from the journal editor.

List of results M22 - Paper in a top international journal

1.   T. Devaja, M. Petković, F. J. Escribano, Č. Stefanović and D. Vukobratović, "Slotted Aloha With Capture for OWC-Based IoT: Finite Block-Length Performance Analysis," in IEEE Access, vol. 11, pp. 76804-76815, 2023, doi: 10.1109/ACCESS.2023.3287931.

2.   T. Devaja, M. Petkovic, C. Wang, M.Beko and D. Vukobratovic, "On Error Probability Analysis of Short-Packet Communications in Massive Internet of Things," IEEE Access, (accepted).

Presentation from the international meeting printed it its entirety.
1.   T. Devaja, Đ. Novakovic and Ž. Bojovic "Monitoring of HRV parametar in order to detect physical stress", Telfor Journal, Telecommunications, Society and Academic Mind, Belgrade, 2017, DOI: 10.1109/TELFOR.2017.8249294.
2.   T. Devaja, Ž. Bojović, A. Žunić , "SDN Cloud Platform for Smart Vehicles", 10th international conference on Internet of Things, Venice, Italy, 2018.
3.   T. Devaja, D. Vukobratovic, D. Bajovic, G. Gardasevic: "Scheduling in 6TiSCH Networks via Max-Product Message Passing," IEEE EUROCON 2019, Novi Sad, Serbia, July 2019, doi: 10.1109/EUROCON.2019.8861979.
4.   M. Cosovic, T. Devaja, D. Bajovic, J. Machaj, G. McCutcheon, L. Stankovic, V. Stankovic, D. Vukobratovic: "Distributed Intelligent Illumination Control in the Context of Probabilistic Graphical Models," 4th Conference on Smart and Sustainable Technologies SpliTech 2019, Bol (Brac), Croatia, June 2019, doi: 10.23919/SpliTech.2019.8783018.
5.   T. Devaja, M. Petkovic, A. Munari, F. Clazzer, M. Beko and D. Vukobratovic, "Massive Machine-Type Communications via Hybrid OWC/RF Networks,", 13th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), 2022, doi: 10.1109/CSNDSP54353.2022.9907922.
6.   M. Petkovic, T. Devaja, D. Vukobratovic, F. J. Escribano, and C.Stefanovic, "Reliability Analysis of Slotted Aloha with Capture for an OWC-based IoT system", in Proc. 2021 17th International Symposium On Wireless Communication Systems (ISWCS), pp. 1-6, 2021, doi: 10.1109/ISWCS49558.2021.9562172.
7.   T. Devaja, M. Petkovic, A. Munari, F. Clazzer, M. Beko and D. Vukobratovic, "Massive Machine-Type Communications via Hybrid OWC/RF Networks in Finite Block-Length Regime", IEEE Wireless Communications and Networking Conference (WCNC), 2023, doi: 10.1109/WCNC55385.2023.10118842.

VII   CONCLUSIONS AND RESEARCH RESULTS:

The research is based on a problem that occurs in networks, because the transmission between the device and the base station is limited by various types of interference such as interference from other users. Extension of the previous research on the error probability that a randomly selected active device will be decoded by the nearest base station in the scenario where we have a low power broadband network is presented. Recent works are elaborated by deriving a final expression for the error probability in the asymptotic regime and extending it to the regime where FBLs are used. The system model under consideration is based on the Slotted Aloha (SA) protocol, where a set of randomly selected devices arranged according to the Poisson Point Process (PPP) is active in each slot. In the thesis is proposed a way to calculate the probability that an active device is decoded at the nearest base station. The focus of the research is the scenario where the PDF-Probability Density Function of the interference power can be derived in a closed form.

The first part of this dissertation investigates the design of LP WAN that assumes balancing and trade-offs between: 1) interference, modeled using stochastic geometry, 2) short packet transmission reliability, quantified by finite block length information theory, and 3) random access mechanism. In this thesis, it is derived an exact closed-form expression for the probability that a device data packet is not decoded at the nearest or macro station, in the case of the Nakagami-m channel. Extension of the analysis is conducted in order to provide an approximation of the error probability in the finite block regime. With the help of numerical results, evaluation of the accuracy of the obtained expressions and their applicability to system design and examination of the performance within a number of relevant system parameters is conducted.

The second part of the thesis includes the first hybrid optical wireless/radio frequency (OWC/RF) system

consisting of an indoor optical wireless OWC system and an outdoor low-power broadband IoT system. More specifically, it is analyzed a two-layer system based on OWC/RF SA focusing on one large indoor OWC-based IoT system with a number of indoor OWC access points (APs) acting as relays to perform RF transmission to an outdoor LP WAN base station (BS). The system is later extended to the case of a solution inspired by the SA ALOHA protocol for indoor optical systems of the Internet of Things based on optical wireless communication containing IoT devices exchanging data with an access point. Here, it is derived the error probability of decoding a short data length packet originating from a randomly selected OWC IoT device in the presence of interfering users.

The committee considers that conclusions are logically derived from the obtained results and clearly reflect the significance and scientific contribution of the conducted research.

VIII ASSESSMENT OF THE METHOD OF PRESENTATION AND INTERPRETATION OF RESEARCH RESULTS:
Explicitly state a positive or negative assessment of the way research results are presented and interpreted.

The research results in this dissertation are well described and presented. The design and analysis of a massive IoT network in short messaging mode is clearly explained, and the results are presented through figures, tables and diagrams that are easy to understand and aid in interpretation. The analysis of the results is consistent, logical and well moderated in drawing conclusions. Also, the results are compared with earlier research, and suggestions for future research and practical application are given. In short, the way of presentation and interpretation of research results in this dissertation is well structured, clear and supported by appropriate visual means.

The work was checked in the software for plagiarism detection iThenticate, in the Library of the Faculty of Technical Sciences, about which the committee was informed via e-mail. The similarity check is 52% since PhD thesis consists of three scientific papers where candidate is the first author.

IX FINAL ASSESSMENT OF DOCTORAL DISSERTATION:
Explicitly state if the dissertation is or is not written in accordance with submitted dissertation proposal, as well as does it contain all the important elements. Provide clear, precise and concise answers to questions 3 and 4

1. Was the dissertation written in accordance with the previously submitted dissertation proposal?

Yes, the dissertation is written entirely in accordance with previously submitted dissertation proposal.

2. Does the dissertation contain all the important elements?

Yes, the dissertation contains all the essential elements, including the title, content, results, and their interpretation, which is required from this type of work.

3. Why does this dissertation provide original contributions to science?

The original scientific contributions of the part of the doctoral dissertation related to the design and analysis of massive IoT networks in FBL regime are as follows:
1) A new approximate but accurate probability of failure for massive IoT networks in FBL mode is given.
2) Derivation of a series approximation of the error probability expression in the FBL regime that improves upon the existing literature which is often strictly based on an analysis using Rayleigh fading is provided.
3) Asymptotic probability of error based on threshold detection improves accuracy and facilitates the use of complex mathematical formulas used in previous research.
4) Scheme and architecture analysis for future IoT systems based on short-range OWC technology are proposed and access scheme design proposal for OWC-based IoT indoor network is given.
5) Error and coding rate characterizations are based on FBL performance analysis for IoT systems using communications in the visible part of the spectrum.
6) Analysis of the entire system, bandwidth and reliability with respect to the probability of failure in optical wireless communications are given.
7) Numerical results are shown in order to provide guidelines for optimal system design, investigating the

effects of major OWC parameters on system performance. These contributions are particularly important, because the implementation of an IoT network in the real world requires not only that its physical parameters are properly set, but also that the access protocol is properly configured to achieve optimal performance.

8) Performance analysis of hybrid OWC/RF systems and calculation of error probability in FBL mode was performed. More specifically, based on the results of the proposed FBL information theory and the SINR statistics, it is calculated the overall error probability of a hybrid IoT system based on optical wireless communications at the first level and radio frequency communications at the second level.

4. What are the shortcomings of the dissertation and what is their impact on the research results?   **In the dissertation, no shortcomings were observed that would affect the results of the research.**

X   PROPOSAL:
Based on the indicated information, the committee is proposes:
a) To accept the doctoral dissertation and approve the candidate's defense;   б) To return the doctoral dissertation to the candidate for revisions (to supplement or modify);   в) To reject the doctoral dissertation.

Place and date: Novi Sad, 24.04.2024.

1. dr Slaviša Tomić,
associate professor
_____, chair

2. dr Čedomir Stefanović,
full professor
_____, member

3. dr Karolina Kasaš Lažetić,
associate professor
_____, member

4. dr Milica Petković,
assistant professor
_____, member

5. dr Dejan Vukobratović,
full professor
_____, supervisor

6. dr Marko Beko,
full professor
_____, supervisor

NOTE: A committee member who does not want to sign the report because they disagree with the majority opinion of the committee is obliged to provide an explanation or reasons why they do not want to sign the report and to sign it accordingly.