NTNU
Norwegian University of
Science and Technology

PhD DEGREE
Examination result form

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1. Name of candidate: Nemanja Zdravković

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2. Evaluation committee members (name, title, place of work)

Ioannis Chatzigeorgiou, lecturer, Lancaster University

Stig Petersen, senior scientist, SINTEF Digital

Daniela Milović, professor, University of Niš

Zoran Čiča, assistant professor, University of Belgrade

Stefan Werner, professor, NTNU

Administrator: Torbjørn Svendsen, professor, NTNU

Observer(s):

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3. PhD thesis

Norwegian title:

English title: Performance Analysis for Industrial Wireless Networks

Supervisors: Professor Kimmo Kansanen, NTNU
                 Professor Goran Đorđević, University of Niš

☒ Approved   ☒ Decision was unanimous

☐ Rejected   ☐ Decision was not unanimous

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4. Public trial lecture

Norwegian title:

English title: Internet of Things (IoT) in Industry

Date: 26. June 2017   Result: ☒ Approved   ☐ Rejected

5. Assessment of the trial lecture

The lecture was well prepared, well organized and well presented. The content and presentation of the lecture slides were of good academic quality. An overview of IoT history and technologies was given before shifting the attention to industrial applications. The candidate gave an excellent presentation, and handled comments and questions after the lecture in a competent and confident manner. Overall, the public trial lecture was of high quality and is unanimously approved.

6. Explanation of the content and assessment of the quality and originality in the thesis

The thesis provides an exhaustive analysis of wireless network performance in different slow fading environments and contributes to new knowledge to the discipline. The contributions extend known observations to a more general scenario, and introduce novel ideas.

The thesis consists of an introductory section (Chapter 1), four chapters on topics related to the performance analysis of wireless networks in industrial settings (Chapters 2-5) and a chapter that summarizes key findings (Chapter 6). More specifically, Chapter 1 provides a thorough literature review, which presents the challenges encountered in industrial wireless networks and various solutions based on cooperative relaying. The motivation, research directions and objectives of the thesis are elaborated in this chapter. Chapter 2 considers a known cooperative protocol that has been analysed for Rayleigh fading channels and makes a simple but useful extension of the analysis to the Generalised-K fading channel. Chapter 3 investigates the impact of temporal fading correlation and dynamic shadowing, considers different and more involved distribution probabilities, and re-derives the outage probability for a practical setting. Tractable expressions for high values of internode and uplink signal-to-noise ratios (SNRs) are also obtained. Chapter 4 introduces the capability of cooperating nodes to exchange feedback on the received packets, and explores the effect of automatic-repeat request on performance. A method, which determines the value of an SNR threshold and uses it as input to the outage probability in order to approximate the packet error rate, has been utilised. Chapter 5 focuses on link re-use and studies simultaneous outage probability, thus adding another layer of difficulty to the system model. The chapter presents a framework for the accurate calculation of the outage probability for two source nodes, utilising moment generating functions and inverse Laplace transforms. The proposed framework is then used as the basis for the formulation of outage probability expressions for multiple source nodes. Theoretical models and derived expressions in Chapters 2-5 have been validated through simulations in MATLAB. Chapter 6 reflects on practical implications of the research findings, briefly touches on directions for future work, and concludes the thesis.

Overall, the thesis is well structured and written in a scholarly manner. The motivation for the research is clearly explained and properly elaborated. A thorough literature review has been carried out to identify issues that remain unaddressed and establish the originality of the presented work. Throughout the thesis, appropriate methodological approaches have been used to develop, evaluate and validate well-founded theoretical models and mathematical expressions. The main contribution of the thesis is the derivation of formulas, either exact or asymptotically accurate, for a variety of settings and channel models that unveil: (i) the interplay between system parameters and channel conditions, and (ii) their impact on the successful delivery of data. The findings of this research can provide guidance and insights into the design of cooperative protocols and topologies for industrial wireless networks. The research can be easily extended to other types of wireless networks in slow fading environments. Given that the type of work is mainly theoretical, the candidate could have expanded the rather short section on future work in Chapter 6 and included the development of a sensor test-bed, its deployment in an industrial setting and the comparison of performance predictions obtained from the theoretical models with real-world measurements. Additional evidence for the quality of the presented work is the fact that it has already been disseminated in the form of seven papers that appeared in reputable peer-reviewed journals and international conference proceedings.

The oral presentation of the thesis was clear and concise. The candidate provided detailed and precise answers to the questions from the opponents, demonstrating a mature and thorough knowledge of the field.

7. Assessment of the academic standard of the thesis in relation to the international standard of equivalent doctoral work at evaluator(s) home institution.

The structure, clarity and thoroughness of the thesis, the quality of the writing, the novelty and originality of the presented ideas, and the publishability of the proposed solutions fully comply with the requirements for the award of the PhD degree at Lancaster University in the United Kingdom.

The topic of the thesis is relevant and fully complies with the academic requirements of the University of Nis in Serbia. The structure of the thesis is somewhat different than the required form, but all relevant parts (introductory, technical chapters and conclusions) are present. The presented material has been published in international peer-reviewed journals with impact factor, and therefore the thesis fulfils the requirements of the University of Nis. Additionally, the University of Nis does not require an opponent from another country, but several opponents are selected from other eminent institutions and universities in Serbia.

The thesis complies with the PhD thesis requirements (structure of the thesis, clarity and quality of writing, originality of the research, at least one paper published in a journal with impact factor) requested at the School of Electrical Engineering University of Belgrade.

8. Publication of this work (international journals, conferences etc.)

N. Zdravković, "Packet error rate of decode-and-forward cooperative wireless networks over composite fading channels," in Proceedings of th 12th International Conference on Applied Electromagnetics (PES), Niš, Serbia, Aug. 2015.

N. Zdravković, "Outage analysis in clustered cooperative networks over K fading channels," in Proceedings of the 23rd Telecommunications Forum (TELFOR), Belgrade, Serbia, Nov. 2015, pp. 95–98.

N. Zdravković, "Outage analysis of clustered cooperative networks in generalized fading and shadowing," TELFOR Journal, vol. 8, no. 2, pp. 81–86, 2016.

N. Zdravković, A. Cvetković, G. T. Đorđević, and K. Kansanen, "Outage probability of decode-and-forward network with threshold based protocol over Rayleigh fading," in Proceedings of the 21st Telecommunications Forum (TELFOR), Bel-grade, Serbia, Nov. 2013, pp. 315–318.

N. Zdravković, A. Cvetković, K. Kansanen, and G. T. Đorđević, "Outage performance of low-latency decode-and-forward cooperative wireless networks," EURASIP Journal on Wireless Communications and Networking, vol. 2016, no. 1, pp. 1–10, 2016.

N. Zdravković and A. Cvetković, "Packet error rate analysis of decode-and-forward wireless networks with internode SR-ARQ protocols," in Proceedings of 12th International Conference on Telecommunication in Modern Satellite, Cable and Broadcasting Services (TELSIKS), Niš, Serbia, Oct. 2015, pp. 39–42.

N. Zdravković, K. Kansanen, and G. T. Đorđević, "On the outage correlation analysis of decode-and-forward cooperative wireless networks," IEEE Transactions on Wireless Communications (under review), 2016.

9. Signatures

Place, date: Trondheim, 26.06.2017.

Ioannis Chatzigeorgiou

Stig Petersen

Daniela Milović

Zoran Čiča

Stefan Werner

Torbjorn Svendsen