Prof. Jaap van de Beek
Luleå University of Technology
Jaap.vandebeek@ltu.se

January 25, 2026

Reviewer's opinion
on the Ph.D. dissertation authored by

Marcin Hoffman

entitled:

Radio Environment Maps, and Machine Learning Techniques for Spectral and Energy Efficiency Improvement of Wireless Communications, with Emphasis on Massive MIMO Systems.

1. Problem and its impact

What is, in your opinion, the most important problem discussed in the dissertation? Is it a scientific one? Does it have a practical meaning?

The subject addressed in the reviewed thesis focuses on the general problem of how to systematically improve spectral efficiency (SE) or energy efficiency (EE) in 5G and beyond (6G) wireless networks by exploiting Radio Environment Maps (REM) in combination with machine learning (ML). As wireless networks evolve to support diverse service classes (eMBB, URLLC, mMTC), they face increasing challenges related to interference management, energy consumption, network densification, and dynamic user behaviour. Traditional rule-based or static optimization methods are insufficient to cope with these challenges in real time.

The thesis formulates the core problem as a lack of context-aware, data-driven network intelligence that can leverage historical and real-time radio information to make optimal decisions across multiple layers of the radio access network. REMs provide a structured way to store spatial, temporal, and contextual radio data (e.g., interference levels, beam patterns, user distribution), but on their own they do not yield performance gains unless coupled with intelligent decision-making mechanisms. A key scientific question is thus how to design ML and reinforcement learning algorithms that can effectively use the REM data to optimize network operation without excessive complexity or signalling overhead.

This problem is investigated across three main 5G/6G use case classes: V2X (also known as Ultra-Reliable Low-Latency Communications URLLC), M-MIMO (known as enhanced Mobile Broadband, eMBB), and IoT (known as massive Machine Type Communications, mMTC). In V2X communications, the challenge lies in ensuring reliable, low-latency links under mobility and interference uncertainty, where REM- and ML-based interference modelling, channel assignment, and beam management can directly translate SE gains into EE benefits (e.g., fuel savings in platooning). In massive MIMO eMBB systems, the core issue is balancing throughput, interference, and power consumption through intelligent control and assessment of cells, antennas, power amplifiers, and user-centric architectures. Finally, for IoT/mMTC, the problem extends to

protecting vulnerable, low-power devices from signalling storms and DoS attacks, where maintaining SE also preserves battery life.

The unifying scientific problem is thus how to transform rich radio-environment knowledge into actionable, ML-driven network control strategies that jointly enhance SE and EE across diverse 5G/6G scenarios, while remaining compatible with realistic channel models and, for instance, Open-RAN architectures. This problem has a clear and strong practical meaning. Improving spectral and energy efficiency directly translates into higher network capacity, lower operational costs, and reduced energy consumption for mobile operators. In practice, REM- and ML-based control enables networks to adapt in real time to user mobility, traffic demand, and interference, which is essential for reliable V2X safety services, cost-efficient massive MIMO deployments, and long battery life for IoT devices.

2. Contribution

What is the main, original contribution of the dissertation? If appropriate, you can make a distinction between what the Ph.D. candidate claims to be the main contribution and what you consider as the main contribution. If this is the case, indicate the reason for which you do not agree (e.g. it could be that somebody else has already proposed a given idea or it can be original but not correct due to some flaws described in Sec. 3 of the reviewer's opinion). You can also comment on practicality of the proposed solutions (it could be that the problem is highly practical, but the proposed solution is not). If applicable, you can refer to other quality indicators you know about (e.g. quality of publications by the candidate, patents authored by the candidate, citations, existing applications of the proposed solutions etc.).

The thesis' contributions are broad. The thesis delivers multiple concrete, REM-aware algorithms for interference modelling, beam management, power control, cell/antenna activation, and security, all validated under realistic conditions.

The main original contribution of the V2X part of the thesis consists of four parts: (1) a new model for the RTK localization error is derived and analyzed, (2) a channel frequency selection algorithm based on a GMM model of the interefernce is derived and evaluated, (3) a federated-learning approach to the updating of the radio environment map for multiple platoons is proposed and further explored, and (4) a REM-based beamforming scheme in Open RAN is proposed. The thesis contributes to the end-to-end use of Radio Environment Maps combined with machine learning to enable interference-aware, mobility-driven resource management for vehicular communications. and shows how these maps can be exploited—using ML, federated learning, and policy iteration—to improve channel assignment and beam management in highly dynamic V2X scenarios.

The main original contribution of the MMIMO part of the thesis is the systematic application of REM-driven machine learning and reinforcement learning to control the energy–throughput trade-offs of massive MIMO networks in a realistic, system-level setting. The work introduces novel algorithms for cell and antenna on/off switching, power-amplifier input back-off optimization, dynamic point blanking, and user-centric cell-free MMIMO, all guided by REMs capturing user spatial distribution and channel conditions. Crucially, these solutions are validated using accurate 3D ray-tracing channels, nonlinear hardware models, and Open RAN implementations, demonstrating large, practical SE and EE gains beyond state of the art.

The main original contribution of the IoT part of the thesis is the development of REM- and ML-based algorithms to protect low-power IoT devices from signaling storms and DoS attacks while

preserving network performance. Specifically, it introduces a KPI-profile–based Signaling Storm Detection algorithm compatible with Open RAN, which maintains spectral efficiency and extends device battery life. This contribution is validated both in simulation and on a real-world 5G testbed, and demonstrates a practical, data-driven approach to securing massive IoT deployments without compromising energy or network efficiency.

The general approach to these solutions is through modelling, measuring, simulating and methodological innovations. This results in conceptually new engineering algorithms and methods that can be taken up by the research community and industry for further refinement and/or implementation. It is not always clear how the performance of the provided solutions quantitatively relates to real-world system requirements, and whether the solutions actually solve an existing problem for today's or tomorrow's wireless network operators. However, I recognize that the real-world complexity of the networks Marcin Hoffmann assesses in his thesis, oftentimes prevents more generalized, quantitative conclusions, than those stated in the papers. These are no simple problems – generally applicable quantitative statements are often very difficult to conclude upon.

3. Correctness

Can we trust what is claimed in the dissertation? Are the arguments correct? Indicate the flaws you have noticed, if any. Also point out those aspects concerning correctness that you value most (elegance of proofs, design of experiments, analysis of empirical data, quality of prototype software/hardware etc.).

The thesis is written in English in a good style. It is a broad substantial body of research covering many aspects of modern wireless networks. It is an interesting scientific reading. The conclusions drawn based on the collected research material are by and large correct and clear. The thesis is based on the work in 16 separate scientific contributions, nine (9) journal papers (all published in well-known journals) and seven (7) conference contributions. Marcin Hoffmann is the first author on all of the papers, but one. Twelve (12) of the papers are authored by three authors or less. It is evident that Marcin Hoffmann has contributed significantly to the collective works in this thesis. The fact that the works have been peer-reviewed and published, along with the evident quality of the publishing journals also largely guarantee the correctness, timeliness, novelty and value of the thesis' contributions.

The introductory part of the thesis, preceding the included paper, is written in the style of a summary and overview of the contributions and solutions in the thesis. It could have been written to make the thesis more accessible. In particular I would have appreciated a more in-depth introduction to the notion of Radio Environment Map (REM), the main topic of the thesis. What is a REM? What does it contain? How does it work? How do its embodiments look like? An introduction Section would provide a nice basis for the reader to then read and absorb the subsequent papers. In fact, many of the papers do not either give a stringent definition of a REM and the characteristics of the REM notion only slowly appear throughout reading the thesis.

As a second aspect of accessibility, I would also have appreciated if the introduction would have taken a deeper dive in the quantitative aspects of the requirements of the key KPIs: energy efficiency, spectral efficiency, latency, positioning accuracy, etc. How much latency do we require? I cm-level position accuracy good enough? How much reduction of the consumed energy

do we target? Indication to answers to these questions would then put the results of the subsequent papers in a nice quantitative context.

Thirdly, the thesis has a clear engineering approach in that the focus is on contributions in terms of 'solutions'. While the thesis Introduction chapter does state a clear research hypothesis, it is not clear right away to which specific quantitative engineering research problems the presented results are solutions. Again, for the sake of accessibility, it would have been nice if this were the already assessed in the Introduction. Particularly the relation of the novel IoT solutions to the main central research hypothesis on REMs (and thus the role and purpose of papers P1, P2, and P3 towards the hypothesis) could have been more deeply assessed.

Finally, I noticed as an editorial error that Section 2.3 consistently refers to paper [P4] while clearly paper [P5] is meant.

My comments above in no way offset the great value and quality of the work and conclusions in the thesis and there is no doubt that Marcin Hoffman is able to conduct high-quality scientific work. My above comments do not affect the positive final assessment of the work as a whole.

4. Knowledge of the candidate

What are the chapters of the dissertation (or sections in chapters) that resemble a tutorial and thus confirm a general knowledge of the candidate in the discipline of ***Information and Communication Technology****. What areas of that discipline are covered by those chapters/sections? What do you think about quality of those chapters/sections? What is your opinion on the list of references? What is the degree of its completeness? Provide any other arguments in favour or against the claim that the candidate has general knowledge and understanding of the* ***Information and Communication Technology*** *discipline.*

The 268-page consists of an Introductory Part (with an introductory section, three sections on service use case groups, a summary section, and a reference list), along with 16 published scientific papers, In my judgement, this is well beyond the volume and width needed to demonstrate the capabilities to conduct research. The introductory Part of the thesis contains background and explanations of a broad variety of relevant and timely use cases and provide the part of the thesis where Marcin Hoffmann shows his knowledge in the area of Information and Communication Technology. In particular, many aspects the areas of 5G, beyond 5G, notably the broadly understood use-case families of eMBB, URLLC, and mMTC. The quality of these chapters is in general good. My remarks to the accessibility and the extent to which these chapters introduce the papers are mentioned in the previous section of this report. Much of the knowledge in the topic area is further demonstrated in the many high-quality papers in the Second Part of the thesis. Details about many contemporary standards, about the regulatory state-of-the-art, and about the behaviour of radio networks illustrates this throughout the remainder of the thesis.

5. Other remarks

With this thesis Marcin Hoffmann demonstrates not only a broad mastering of many general topics of Information and Communication Technology and the area of Radio Communication Networks, their context and relevance, but his thesis also shows a strong engineering and scientific ability to develop and analyze new solutions that target their important weaknesses – solutions with a clear potential to improve and impact the performance and development of future radio systems.

6. Conclusion

Taking into account what I have presented above and the requirements imposed by Article 187 of *the Act on Higher Education and Science of the Polish Parliament* (Dz. U. 2018 poz. 1668 with amendments)[1], my evaluation of the dissertation according to the three basic criteria is the following:

A. Does the dissertation present an original solution to a scientific problem? (the selected option is marked with **X**)

[X]	[ ]	[ ]	[ ]	[ ]
Definitely YES	*Rather yes*	*Hard to say*	*Rather no*	*Definitely NO*

B. After reading the dissertation, would you agree that the candidate has general theoretical knowledge and understanding of the discipline of **Information and Communication Technology**, and particularly the area of ....?

[X]	[ ]	[ ]	[ ]	[ ]
Definitely YES	*Rather yes*	*Hard to say*	*Rather no*	*Definitely NO*

C. Does the dissertation support the claim that the candidate is able to conduct scientific work?

[X]	[ ]	[ ]	[ ]	[ ]
Definitely YES	*Rather yes*	*Hard to say*	*Rather no*	*Definitely NO*

Prof. Jaap van de Beek

[1] http://www.nauka.gov.pl/g2/oryginal/2013_05/b26ba540a5785d48bee41aec63403b2c.pdf