

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

*Cezary Adamczyk*

**entitled:**

*CONFLICT MITIGATION  
IN OPEN RADIO ACCESS NETWORKS*

## **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?

*This dissertation deals with the problem of conflict management (detection and resolution) in Open Radio Access Networks (O-RAN). In modern and future O-RANs, several network operations are regulated by the use of intelligent applications, targeting for instance to allocate network resources, minimize the energy footprint of the network, improve the end-user quality of service (QoS), etc. However, two or more intelligent applications that are deployed at the same time may provide conflicting suggestions (e.g., trying to adjust the same parameters in a different manner), based on their optimization objectives. In this context, this thesis addresses the problem of managing the conflicts between the intelligent applications. It is an extremely recent and relevant topic in the scientific and business community.*

- *From the technical perspective, the author provides a concrete Conflict Management Framework suitable for the O-RAN architecture, as well as introduces multiple concepts that will drive the future intelligent applications lifecycle and management.*
- *From the scientific perspective, these kinds of problems are in most cases non-convex, i.e., it is extremely challenging to solve them for the optimal solution. Therefore, the framework proposed by the author based on Deep Reinforcement Learning targets to solve this problem using Machine Learning methods that approach optimality.*
- *Finally, this topic is also practical, since the absence of a conflict management mechanism may lead to performance degradation in O-RAN, for instance related to QoS to the mobile users, increased power consumption that needs to be avoided by the network providers, etc. The author provides both simulation and experimental results that clearly demonstrate how the developed mechanisms in this thesis can assist in effectively mitigating the impact of conflicts in the O-RANs.*

## **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

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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 multiple contributions of this dissertation (as correctly claimed by the author) include:*

- *Architectural design of a Conflict Mitigation Framework (CMF) that can be integrated in the O-RAN architecture, identifying the required data and information flow between existing network components.*
- *This framework is evaluated in conflict detection and resolution tasks of various conflict types (direct, indirect, implicit), providing the relevant metrics and an excellent understanding of how the mitigation mechanisms work.*
- *The author describes and implements rule-based algorithms that can be used for CMF operation, as well as an ML-assisted algorithm based on Reinforcement Learning that is trained in the complex environment and can be dynamically adapted to provide near-optimal conflict management decisions.*
- *The results of the conflict management framework are showcased in an O-RAN network simulation environment implemented by the author, specifically suitable for the comparative evaluation of the developed algorithms.*
- *The CMF is additionally demonstrated in an experimental scenario using real-world equipment compatible with O-RAN, illustrating its effectiveness in detecting and resolving conflicts emerging in network operation.*

### **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 contributions of the dissertation are certainly clear and what is claimed herein can be also validated by external researchers. The main hypothesis of the dissertation is validated by simulation and experimental results and has been also published in flagship journals of the communications society, receiving positive comments for its innovative aspects. Moreover, the conflict mitigation mechanism and the involved algorithms are presented in detail, permitting interested researchers to follow-up on the problem and base their contributions on the fundamental work that has been conducted in this dissertation. Although the developed software tool that supports the simulations is proprietary, its description and structure is valuable for the scientific community, as well as the described listings that illustrate the conflict mitigation approach for the various types. In addition, the learning mechanism of the RL-assisted scheme can be used to replicate the results, consisting one of the critical contributions of this work. Finally, the experimental results that have been obtained by the configured hardware implementation, the system setup and the deployment of the intelligent applications along with the pilot scenario provide a significant added value to the dissertation, enabling the real-word understanding of the conflict detection and resolution mechanism in real-word implementations, as well as the roadmap to leverage the included ideas by interested stakeholders.*

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#### 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.

*From the dissertation structure and the content, it is evident that the candidate has a thorough understanding of the O-RAN networks and the conflict management mechanisms. In specific:*

- *Chapter 2 offers an extensive description of the general network concepts and architectures, including the O-RAN network components and how ML algorithms can be deployed and operated in the different control loops. This chapter is tutorial in nature and provides a wide perspective of modern network architectures, including multiple recent research works that can be found in the literature.*
- *Chapter 3 provides an overview of the existing conflict mitigation state-of-the-art mechanisms that are proposed/currently being discussed by the relevant standardization organizations (e.g., O-RAN alliance, 3GPP), also including a great overview of recent research work in the literature.*
- *These two high-quality chapters offer a concrete tutorial in networking concepts and architectures, illustrating the state-of-the-art research and the current challenges that need to be addressed. Furthermore, the reference list included is up to date and complete, summarizing concisely relevant work from multiple perspectives and describing relevant conflict management frameworks that have been proposed and developed by other research groups.*

#### 5. Other remarks<sup>1</sup>

*The author of this dissertation has published multiple research papers in highly esteemed peer-reviewed journals and conferences that are considered flagships for the topic of communications and networking in the duration of his PhD studies. To this end, it is evident that the author's research work is highly appreciated in the scientific community, which I can also verify from my own experience.*

#### 6. Conclusion

Taking into account what I have presented above, and the requirements imposed by Article 187 of the Act of 20 July 2018 – Law on Higher Education and Science (Journal of Laws of 2018, item 1668, as amended), 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)

Definitely YES      Rather yes      Hard to say      Rather no      Definitely NO

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<sup>1</sup> Optional



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 **communications and networking**?

*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?

*Definitely YES*    *Rather yes*    *Hard to say*    *Rather no*    *Definitely NO*

*Moreover, taking into account the impact of the research work to the scientific community presented by the candidate, I **recommend to distinguish** the dissertation for its quality<sup>2</sup>.*

Sotirios Spantideas

*Signature*

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<sup>2</sup> Obviously, this sentence is optional.

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