

**Reviewer's opinion**  
**on Ph.D. dissertation authored by**  
*Cezary Adamczyk*  
**entitled:**

*Conflict mitigation in open radio access networks*

**1. Problem and its impact**

The main thesis of the reviewed dissertation is that conflict mitigation mechanisms can significantly improve the performance, stability, and reliability of O-RAN networks operating with conflicting applications. The author assumed that without effective conflict detection and resolution measures, the benefits of an open ecosystem cannot be fully realized. Therefore, the main goal of the presented research is to propose, implement, and evaluate a comprehensive framework for conflict detection and resolution that is universal, robust, and fully compatible with the O-RAN architecture. The author addresses the necessary assumptions described in the latest standards, while enabling the resolution of all types of conflicts. The conducted research allows for the definition of a framework for conflict detection and resolution that can be used in both near-RT and non-RT RIC networks, ensuring effective conflict neutralization in many possible network scenarios.

The problem is scientific. As part of the research, a proprietary O-RAN network simulation environment was designed and implemented. This software models the network environment and allows for the execution of conflict scenarios under consistent conditions, enabling the reliable measurement of performance metrics (Key Performance Metrics, KPIs). As part of the proposed solution, multiple conflict detection and resolution algorithms were implemented to assess their effectiveness. The research included the development of a solution based on artificial intelligence. Actor-critic artificial neural networks trained using reinforcement learning were used, enabling adaptive management of detected conflicts. The performance of these algorithms was analyzed using a novel evaluation metric designed specifically for comparing conflict resolution solutions.

The results obtained by the author definitely confirm that the proposed framework for conflict detection and resolution can be implemented in real networks and used with success. The author proposed a solution called the Conflict Mitigation Framework (CMF), which is an architectural extension of the Near-RT RIC. The solution introduces dedicated agents for conflict detection and resolution and provides a transparent conflict handling mechanism compatible with third-party xApps, facilitating the coordination of various peer-to-peer applications. Experimental evaluation, conducted on a physical O-RAN-compliant testbed, provided empirical evidence supporting the solution's effectiveness in real-world conditions. This demonstrates that the proposed solution has practical relevance and can be implemented in real-world networks.

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## 2. Contribution

As a main part of the research, the doctoral student designed and implemented a proprietary simulation environment for the O-RAN network. This activity constitutes the primary contribution to the dissertation. The developed software enables modeling of the network environment and allows for the execution of conflict scenarios under consistent conditions, enabling the reliable measurement of performance metrics (KPIs). The simulator was designed to model RAN behavior at an appropriate level of abstraction to capture essential network characteristics while maintaining low computational and implementation complexity. This approach enables efficient experimentation during the research process, and the simulator acts as a practical and extensible platform for implementing and evaluating ConMit solutions.

The doctoral student developed and implemented numerous conflict detection and resolution algorithms in the simulator and testbed of the O-RAN network. The initial stages focused on implementing conventional conflict resolution methods, which served as benchmarks. Subsequent research involved the design and development of an artificial intelligence-based solution. For this purpose, the doctoral student used actor-critic artificial neural networks trained using reinforcement learning. This enabled adaptive, data-driven management of detected conflicts. Resolving complex control conflicts between applications proved possible. The performance of the developed algorithms was analyzed using a novel evaluation metric designed specifically for comparing conflict resolution solutions.

The problem solved by the PhD student is practical and can be implemented in existing networks. The proposed Conflict Mitigation Framework, a standardized, logic-agnostic architectural extension for Near-RT RIC with dedicated agents for conflict detection and resolution, allows for conflict handling compatible with third-party xApps, avoiding the pitfalls of non-standard peer-to-peer application coordination. Although partially similar solutions exist, this is one of the most advanced proposals in this category.

## 3. Correctness

The analysis conducted by the PhD student was gradual, starting with simple solutions and ending with a more advanced solution. Applications attempting to modify the same control parameter were analyzed first. Experimental evaluation, conducted on a physical O-RAN-compliant testbed, confirmed that the network can exhibit instability when unresponsive. Implementing CMF with rule-based prioritization effectively neutralized the emerging conflicts, reducing throughput variability by approximately 78%. This result confirms that in the case of direct conflicts, even a relatively simple solution is sufficient to restore network stability and ensures predictable quality of service (QoS).

Examination of indirect conflicts, where applications manipulate various parameters affecting common KPIs, highlighted the need for more advanced strategies. Through advanced simulations comparing rule-based methods with the proposed ACCoRD solution, clear performance trends regarding the scalability of conflict mitigation were identified. In scenarios characterized by low traffic volume and low conflict frequency, static rule-based methods proved computationally efficient and effective.

However, as the network environment evolved towards high-traffic scenarios with frequent and complex conflicts, the limitations of static rules became apparent. In these challenging conditions, the proposed ACCoRD solution demonstrated superior performance. Unlike static policies, which can rigidly enforce suboptimal decisions, the RL-based agent dynamically learned to stabilize critical parameters,

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preventing negative network events that impact the end-user experience (such as blocked and dropped connections). As a result, ACCoRD consistently minimized network instability in complex deployment scenarios, confirming that intelligent, data-driven conflict resolution is essential for maintaining reliability in dense, busy O-RAN environments.

The conducted research and analyses are fully credible and confirm the effectiveness of the proposed solution. In my opinion, Chapter 6 deserves particular attention. The PhD student presented a detailed description of the ACCoRD system's assumptions, the learning and parameterization processes, and the evaluation method and results. The PhD student confirmed that he possesses very advanced research skills.

#### **4. Knowledge of the candidate**

The dissertation consists of eight chapters and appendices. The current state of the art is presented in Chapters 2 and 3.

Chapter 2 discusses existing generations of RAN networks, dating back to 1979. The development of 2G, 3G, and 4G networks is briefly outlined. More attention is paid to the contemporary solution, 5G. Self-Organizing Networks, as part of LTE networks, is then discussed. Consequently, the next chapter highlights the development towards Flexible RAN deployment architectures: C-RAN, vRAN, Cloud RAN, and O-RAN. A significant part of this chapter discusses the important issue of intelligent control of O-RAN network operation. The possibilities of introducing additional functionalities through dedicated applications are discussed in detail. O-RAN specifications describe rApps running in the Non-RT RIC and xApps running in the Near-RT RIC. dApps, in turn, can run in the RT control loop in O-CUs and O-DUs. The final section of the chapter presents the potential applications of machine learning solutions in O-RAN networks and highlights development opportunities in this area. The doctoral student provided an in-depth literature review in this area, presenting numerous examples of AI applications to improve O-RAN network performance.

Chapter three discusses issues related to conflict management in O-RAN networks. The doctoral student rightly noted that conflicts can occur at many levels in the O-RAN architecture, leading to various undesired effects, such as network instability and wasteful resource allocation. Chapter three discusses types of conflicts and their impact on network operation. The doctoral student provides a detailed discussion of the challenges associated with minimizing the occurrence and impact of conflicts. Conflict detection mechanisms and procedures for handling them are also discussed. The doctoral student discussed existing solutions supporting conflict management and noted that the limited observability of network control agents is another significant challenge in O-RAN ConMit. He then outlined the basic aspects of the conflict mitigation process. The chapter concludes with a discussion of existing solutions for O-RAN networks and a comparison of their effectiveness and efficiency. The analysis is thorough and based on carefully selected literature.

The presented analysis of existing solutions and current state of the art confirm the doctoral student's extensive knowledge of O-RAN networks and methods for analyzing traffic in these networks. The candidate confirmed his general knowledge and understanding of the Information and Communication Technology discipline.

The bibliography contains 163 items, including seven articles by the doctoral student. These are relevant to the topic and purpose of the dissertation. In my opinion, the bibliography is presented completely correctly. The doctoral student's publications deserve special attention. All represent high scientific

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value. Four of them were published in prestigious venues (IEEE Communications Magazine, IEEE Journal on Selected Areas in Communications, and twice at the IEEE INFOCOM conference).

## 5. Other remarks

In my opinion, the thesis is fully correct and complete. The only minor remark is related to quality and advance level of presented analysis. There is a lack of analysis of latency. More advanced scenarios related to different conflicts should be presented to additionally prove the effectiveness of the proposed solution. Moreover, scenarios with more conflicting applications should be considered. The PhD students indicates this in the conclusion. It would be great to see at least preliminary research results for above mentioned issues during the PhD defence.

## 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*

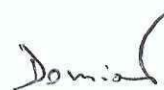
B. After reading the dissertation, would you agree that the candidate has general theoretical knowledge and understanding of the discipline of **Information and Communication Technology**, and particularly the area of **computer science**?

*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 high level of research work and valuable results, I **recommend to distinguish** the dissertation for its quality.



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