Prof. dr hab. inż. Jordi Mongay Batalla
Politechnika Warszawska
Jordi.mongay.batalla@pw.edu.pl, Tlf. +48 609 709 150

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Reviewer's opinion

on Ph.D. dissertation authored by

Salim Janji

entitled:

Dynamic Resource Allocation for UAV-Aided Networks

1. Problem and its impact

The thesis introduces a holistic framework for designing and optimising DBS-assisted (Drone Base Station) wireless networks, with particular emphasis on the unique considerations of DBS deployment.

The PhD candidate claims five important contributions in the Thesis that collectively advance the design and optimisation of drone base station (DBS)-assisted wireless networks, addressing both fronthaul and backhaul dimensions in depth. On the fronthaul side, the work introduces innovative placement strategies tailored to different levels of knowledge about ground node (GN) locations. When the positions of GNs are known, a clustering approach based on the signal-to-interference-plus-noise ratio (SINR) is employed to determine efficient DBS deployment patterns that maximise coverage and minimise interference. In contrast, when GN locations are uncertain, the thesis leverages multi-agent reinforcement learning to enable DBSs to autonomously adapt their placement decisions, thereby ensuring robust connectivity in dynamic environments. To complement these placement strategies, a Monte Carlo Tree Search algorithm is developed for adaptive transmission power control. This algorithm enhances link reliability by dynamically adjusting power levels, improves energy efficiency by reducing unnecessary consumption, and introduces the capability of cell deactivation, which further optimises network performance under varying traffic demands.

Turning to the backhaul dimension, the thesis proposes a visibility-graph-based placement framework that deliberately sets aside fronthaul optimisation in order to focus on inter-cell connectivity. This framework integrates solar energy harvesting to extend the operational lifetime of DBSs and incorporates reconfigurable intelligent surfaces to strengthen line-of-sight (LOS) connections between cells. By leveraging directive channel technologies, the framework ensures reliable backhaul links even in challenging deployment scenarios, thereby addressing one of the most critical bottlenecks in DBS-assisted networks. Building upon these separate fronthaul and backhaul contributions, the thesis then moves toward a joint optimisation strategy. Here, hierarchical clustering is employed to simultaneously satisfy fronthaul coverage requirements and backhaul mesh connectivity constraints. This integrated approach ensures that the network can achieve balanced performance across both dimensions, avoiding trade-offs that would otherwise compromise overall efficiency.

Finally, the thesis introduces a genetic algorithm (GA) to tackle the Drone Network Problem, which is formulated as a graph optimisation challenge under flow and degree constraints. By applying evolutionary search techniques, the GA is able to optimise the wireless mesh topology, producing configurations that are both efficient and resilient to changes in network conditions. Taken together, these contributions form a comprehensive deployment framework that not only addresses the distinct challenges of fronthaul and backhaul optimisation but also provides adaptive mechanisms capable of responding to evolving network dynamics. The result is a robust and flexible system design that advances the practical feasibility of DBS-assisted wireless networks and lays the groundwork for future research in this rapidly developing field.

I fully agree with the author that these 5 points are the main contributions of the Thesis.

The Thesis addresses a practical problem: how to locate drones to optimise connectivity while maintaining reduced energy consumption and dynamic resource relocation. Such a network may be deployed where a terrestrial mobile network cannot be established or where coverage is insufficient to meet demand. The candidate has a clear practical vision of the problem, but is well fixed in the theory of radiocommunications.

The problem is of real applicability, especially in cases of a lack of terrestrial network coverage (e.g., a natural disaster) or insufficient radio resources (e.g., during populated events).

2. Contribution

The thesis delivers a comprehensive investigation into the design, optimisation, and integration of drone-based base stations (DBSs) within next-generation wireless networks. It addresses the full spectrum of challenges associated with DBS deployment—from fronthaul and backhaul connectivity to energy constraints, placement strategies, and multi-hop networking—while proposing a suite of novel algorithms and frameworks that significantly advance the state of the art.

The work begins by characterising the operational landscape of DBSs, including UAV (Unmanned Aerial Vehicles) classifications, regulatory considerations, and architectural constraints. It then establishes (Chapter 2) a unified simulation environment incorporating diverse Ground Node (GN) mobility patterns, urban topologies, channel models, and energy harvesting mechanisms, forming the analytical foundation for all subsequent contributions.

A series of innovative placement and optimisation strategies is introduced in Chapter 3. These include fronthaul-aware DBS positioning using clustering based on expectation-maximisation for known GN locations and a model-free multi-agent Q-learning approach for unknown GN distributions. A new access-probability model for vehicular users under beamforming is also developed and integrated into a mixed-integer linear program formulation that minimises the number of active DBSs.

The thesis further (Chapter 4) proposes a Monte-Carlo-Tree-Search-based power optimisation algorithm, demonstrating that transmission-power control can outperform altitude tuning in both energy efficiency and link reliability. Backhaul-aware placement is addressed in Chapter 5 through visibility-graph modelling, with extensions incorporating solar energy harvesting and reconfigurable intelligent surfaces to enhance connectivity in obstructed environments.

To unify fronthaul and backhaul considerations, a modified hierarchical clustering method is introduced in Chapter 6, ensuring GN coverage under SNR (Signal-to-Noise Ratio) constraints while maintaining backhaul connectivity without increasing the number of required DBSs. Finally, Chapter 7 presents a multi-hop wireless backhaul mesh design formulated as a mixed-integer linear program and solved using a tailored genetic algorithm. These components are integrated into an adaptive framework that can dynamically respond to network changes.

Collectively, the contributions of this thesis provide a robust, scalable, and energy-aware foundation for future DBS-enabled wireless networks, offering practical solutions for both fronthaul and backhaul optimisation in complex and dynamic environments.

The publications supporting the candidate's work are numerous. The candidate presents 13 publications: 3 papers published in important IEEE journals, 4 Polish journal papers, 4 international conferences (all of them well recognised) and 2 papers submitted to journals but not published. The most impressive positions are IEEE Journal on Selected Areas in Communications (Impact Factor >15), IEEE Transactions on Vehicular Networks (Impact Factor >7). Both these publications are not strictly related to the work presented in the Thesis, but the candidate is the second and third co-author of the previous publications, respectively.

The published papers containing significant contributions in the area of Dynamic Resource Allocation for UAV-Aided Networks are the following:

- Janji, S., Sroka, P. & Kliks, A. Enhancing V2X Communications with UAV-mounted Reconfigurable Intelligent Surfaces. In: Proc. 2024 IEEE PerCom Workshops, pp. 708–713, 2024.
- Janji, S. & Kliks, A. Multi-Agent Q-Learning for Drone Base Stations. In: Proc. 2023 IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 261–266, 2023.
- Janji, S. & Kliks, A. Drone Base Stations Transmission Power Control and Localization. In: Mobile and Ubiquitous Systems: Computing, Networking and Services, LNICS, vol. 492, Springer, pp. 356–377, 2023. https://link.springer.com/10.1007/978-3-031-34776-4_19
- Janji, S., Samorzewski, A., Wasilewska, M. & Kliks, A. On the Placement and Sustainability of Drone FSO Backhaul Relays. IEEE Wireless Communications Letters, vol. 11, no. 8, pp. 1723–1727, 2022.
- Janji, S. & Kliks, A. Energy-Efficient User Clustering for UAV-Enabled Wireless Networks Using EM Algorithm. In: Proc. 2021 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), pp. 1–6, 2021.

In all the previous publications, the candidate is the first author. There is one publication in IEEE Communications Letters (Impact Factor >4) and 4 publications in recognised international conferences. The list of publications is impressive, demonstrating the importance and reliability of the research provided by Mr Janji.

By examining the list of authors for the candidate's publications, it is evident that Mr Janji has collaborated closely with many colleagues from his institution, with special mention to Prof. Kliks, who is a co-author in nearly all the publications, but also with Dr Sroka. Prof. Kliks has been fairly mentioned by the candidate in the Acknowledgements of the PhD Thesis.

The candidate has more than 100 citations in Google Scholar. This is a good number of citations for an early-stage researcher and foresees a further development of his research career.

3. Correctness

The work done by the candidate is methodological and well organised. The problem is well presented and positioned in the scientific literature. The use of theoretical models is, in general, appropriate (some minor flaws can be found below), and the deployed tools (especially the simulator) have decisively helped in the development of the Thesis and the obtention of the results.

I could not find serious flaws in the Thesis. The analysis appears to be correct throughout the 150 pages of the work. Nevertheless, I have a few considerations and questions about the candidate's work, as follows.

One of the main issues is related to the methodology used. The research methodology is presented in Section 1.5.2. It is mainly based on the simulation tool developed by the candidate. By using this tool, the author adjusts the system's parameters and optimises the objective functions (energy, coverage). The primary issue I identify is that simulation-based analysis is constrained by the limitations of the simulations' assumptions, as well as by the complex interrelationships among the various parameters in mobile networks. The results must be considered only within the limits of the simulation model and, most likely, within the scope of the simulated scenarios (due to parameter correlation). The approach is sometimes the unique solution to solving complex problems; however, in my opinion, the literature shows that many models exist for clusters of DBSs (Drone Base Stations) that offer connectivity in a spatial region (see Khayat's publications). Similar models could help extend the limits of the model; these limits are generally much wider than those of simulations. It is true that the author refers to the principles of radiopropagation theory and theoretical models have been used for deploying the simulation tool; however, more advanced models or even models proposed by the candidate could generalise the validity of the results.

The candidate is aware of, or partially aware of, this point and states (at the end of Section 1.5.2) that documenting the assumptions, together with a systematic variation of the simulation parameters, provides a valid methodology for the research. In my opinion, this is only true within the limits of the proposed scenarios. Moreover, the author recognises that numerous mechanisms influence the simulation results and are not accounted for in the tool. For example, the candidate mentions scheduling, channel reuse and interference management. I fully agree that these mechanisms provide other parameters that could be considered in the research (left to further work by the author) and have an impact on the results. In conclusion, I believe that the results cannot be generalised to broader scenarios of DBS serving connectivity in a given area.

In Chapter 4, the candidate provides a comparison analysis between the proposed TP-MCTS (Transmission Power Monte Carlo Tree Search) and the legacy PSO (Particle Swarm Optimisation) algorithms. Both algorithms aim to optimise different parameters of the network, so there is no point in comparing those algorithms. The author has concluded that the proposed TP-MCTS outperforms PSO in terms of link reliability and energy performance. This should not surprise, since PSO does not optimise any of those parameters. The fact is that PSO searches the optimised location of the DBSs in a 3D space, whereas the TP-MCTS searches the location within a 2D space. Therefore, if we optimise the same parameters, PSO will normally find a better location than TP-MCTS since the hyperspace of possible solutions is wider in the case of PSO. The unique case where TP-MCTS could outperform PSO is in the case that PSO is not able to find the optimised solutions, but this is not the case, or, at least, it has not been proved by the author. Therefore, I have doubts about the validity of the conclusions exposed in Section 4.5 or, at least, about the generalisation presented by the author about the outperformance of the proposed solution.

At last, a couple of questions arise when reading the details of the work:

In Section 3.2.3, the author uses Gaussian mixture models for the location of the drones. Gaussian mixture models jointly with the expectation-maximisation algorithm find local optimisation. In the case of SINR (Signal-to-Interference-and-Noise Ratio), we start from input parameters which, in any case, reassure us on the global optimisation. How can we be sure that the results of Algorithm 1 are a global optimum point and not only a local optimum one?

The second thing is the optimisation of the drone altitude proposed by the author. On the one side, I agree with the author that such an optimisation depends on non-technical factors such as administrative limitations. On the other hand, the author uses the proposed optimised altitude for the placement of DBS in the location-unaware approach (e.g., during the selection of possible locations). Is the DBS placement then realistic with any administrative framework?

4. Knowledge of the candidate

The candidate has demonstrated a deep understanding of mobile communications, particularly in the area of signal propagation. I have no doubts that he deserves recognition for his knowledge and understanding of the Information and Communication Technology discipline. Research on drone-based networks and drone communication is one of the most modern and prolific areas of study in the global research community. Therefore, it is not strange that some works in this area have not been considered by the author. Among them, I previously cited Khayat et al.'s work, but there are other authors omitted in the Thesis.

A lack in the Thesis is the fact that the author has omitted some 3GPP standards that are relevant to the candidate's work. For example, it is difficult to understand why the author uses the propagation model deployed by ITU [*ITU, "Recommendation ITU-R P.1410-6 (08/2023) - Propagation data and prediction methods required for the design of terrestrial broadband radio access systems operating in a frequency range from 3 GHz to 60 GHz," P Series, vol. Radiowave Propagation, Geneva, Switzerland, Rec. P.1410-2, 2003. [Online]. Available: https://www.itu.int/rec/R-REC-P.1410-6-202308-I/en*], but he does not consider the 3GPP propagation models (e.g., TR 38.901, 2022) that are much more adapted to mobile communications in urban and suburban environments. In my opinion, the work could be improved if the models considered the propagation proposed by 3GPP (much more adapted to frequencies and interference patterns of cellular communication).

In any case, the aforementioned absences do not discredit the demonstrated candidate's knowledge to any degree. As mentioned above, the author possesses advanced knowledge and understanding of the matter he researches.

5. Other remarks[1]

Not Applicable.

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)[2], 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*

[1] Optional

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

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 **mobile network radio propagation**?

[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*

Moreover, taking into account the level of the publications, his contributions to those publications and the depth of the research demonstrated in the PhD Thesis, I **recommend to distinguish** the dissertation for its quality.

Ferdinand Manga y Beballa,

Signature

Note of the Reviewer: Copilot has been used to enhance the language and, hopefully, improve the text's readability.