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Reviewer's opinion
on Ph.D. dissertation authored by
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entitled:
Dynamic Resource Allocation for UAV-Aided Networks

1. Problem and its impact

The most important problem discussed in the dissertation is the use of drone base stations (DBSs) to intelligently establish connections with the ground infrastructure (terrestrial networks) to improve the coverage and pave the way for the next-generation wireless networks.

The dissertation is of a scientific nature. The candidate proposes multiple scientific approaches for achieving the goals of the thesis. Among others, the candidate introduces novel simulation tools, modifies models known from the literature (e.g., the expectation-maximization clustering) for improved fronthaul-aware DBS placement strategies, proposes a multi-agent Q-learning-based algorithm for autonomous DBS placement, introduces a novel algorithm for DBS transmission power optimization, proposes novel strategies for backhaul-aware DBS placement, uses a modified hierarchical clustering algorithm for an innovative joint fronthaul-backhaul DBS placement, finally, he proposes a novel genetic algorithm for multi-hop wireless backhaul mesh design for DBSs.

The developed solutions have been tested in simulations; however, they have the potential of practical application, if validated in real environment.

2. Contribution

The thesis of the dissertation is formulated as follows: "*the combination of DBS mobility and altitude with advanced AI-based optimization techniques enables the realization of a highly ubiquitous and adaptable wireless system that ensures seamless coverage across broad service areas while dynamically responding to the changing demands of GNs.*" It partially differs from what can be expected based on the thesis title. The candidate clarifies that his dissertation focuses on *"placement, backhaul, energy, load balancing, and transmission power control"* which is then motivated in the following way: *"It is assumed that issues related to frequency-time resource allocation and mobility have been sufficiently researched and optimized within the literature on terrestrial networks."* Therefore, the dissertation focuses more on the improvement of network operation by introducing DBSs, which implicitly translates to the possibility of improved resource allocation. Additionally, Chapter 7 discusses potential resource constraints and the proper allocation of existing resources.

The candidate lists 13 publications which in his opinion contribute to the thesis. However, publications 1-4 and 10 are not explicitly listed later in the dissertation. Therefore, my review is based on publications

4-9 and 11-13. All publications include original contributions. Publication no. 5 is submitted to a journal. Publication no. 12 was published in an international journal. Publications no. 6-7 and 13 appeared at international conferences. Publication no. 8 was published in a national journal. Publications no. 8, 9, 11 appeared at a national conference. The candidate is the first author of all the listed publications. He lists only a single publication co-authored by his supervisor, which is surprising. The candidate currently has 114 citations in Google Scholar, which I believe is a good result at his level of scientific career.

The main contributions of the candidate are the following:

- Fronthaul-aware DBS placement: two novel DBS placement schemes are introduced (SINR-guided EM clustering method for known ground nodes (GNs) locations, a multi-agent Q-learning-based framework for unknown GN locations). Both schemes were shown to improve coverage, energy efficiency, and fairness in comparison to the selected baselines. Furthermore, a novel access probability model was introduced which outperformed another access probability model from the literature.
- Transmission power optimization: an adapted Monte Carlo tree search algorithm is proposed for DBS transmission power optimization (TP-MCTS) and compared with a particle swarm optimization (PSO) algorithm from the literature. The proposed solution was shown to outperform the baseline.
- Backhaul-aware DBS placement: given a map of obstacles in an urban environment a visibility-graph framework is proposed for the optimal (line of sight constrained) DRS deployment to maintain backhaul connectivity. The model is also extended to incorporate solar energy harvesting and reconfigurable intelligent surface (RIS)-based links in the cost function. The introduced changes were shown to reduce the number of required DBS charging trips as well as the number of hops needed to connect distant nodes.
- Joint fronthaul-backhaul placement: a modified hierarchical clustering (HC) algorithm is proposed for ground node (GN) clustering under two constraints (k-neighbors, disk radius) to guarantee that each GN is within the coverage range of the serving DBS. The proposed solution was shown to outperform the k-means baseline.
- Joint fronthaul and backhaul framework for DBS-assisted wireless networks: a novel framework is proposed in which DBSs rely on multi-hop wireless links for backhaul connectivity and their placement is based on a HC algorithm. A constrained graph optimization is formulated for the drone network problem and demonstrated to be NP-hard. As a result, a genetic algorithm is introduced, which maximizes throughput redundancy. It is combined with the proposed HC-based DBS placement to provide a comprehensive framework.

The dissertation is very broad and presents a bottom-up approach, which is very positive.

3. Correctness

In general, the developments presented in the dissertation are trustful and the arguments are correct. However, the following critical comments can be identified:

- Several of the chosen models/baselines are quite old and/or limited/simplistic, e.g., the obstacle mobility model on page 20, DBS-GN channel model on page 21. Are there any novel solutions in the literature? How do they impact the presented conclusions?
- Related works presented at the beginning of Chapters 3-7 do not always seem up to date, e.g. [107-110] on page 107.
- In the description of Figure 3.2 one could expect more details on the optimal number of clusters.

- The multi-agent DBSs Q-learning proposed in Section 3.3.8 collects information from all DBSs – what is the overhead and how is the exchange of this data implemented?
- Figure 3.12 shows the number of cycles required for the reward convergence – how does it translate to the time domain?
- The Q-learning-based approach introduced in Section 3.3.8 is compared with the "Alternating" and "Fixed" approaches – aren't there more advanced algorithms present in the literature?
- What is the time of solving the MILP proposed in Chapter 3?
- Regarding the DRS placement proposed in Chapter 5 – why wasn't the location of DRS directly above the hotspot centre and MBS considered? Additionally, are there other ideas in the literature that could be compared with the developed solution to better evaluate the results obtained, e.g. those shown in Figure 5.8?
- What is the time of operation of the HC algorithm proposed in Chapter 6?
- Why is the number of GNs per cluster set to only two in Table 6.1? Is this practical?
- The HC algorithm proposed in Chapter 6 was shown to outperform the *k*-means algorithm. Are there any other baselines that could be considered in this case?
- The GA proposed in Chapter 7 was compared to random sampling only. It is not clear why.
- Additionally, it is not clear why the operation of the defined DNP problem was not shown for small instances.
- It is not clear what was the size of the area considered in Section 7.6.

Additionally, I regret that none of the developed solutions was tested in real environment.

The above comments do not change my overall positive assessment of the dissertation.

4. Candidate's general knowledge

The candidate has a general knowledge and understanding of the **Information and Communication Technology** discipline. In Chapter 1, the candidate presents unmanned aerial vehicle (UAV) classification, critical regulations related to development and deployment of UAVs, the role of UAVs in wireless connectivity, as well as, the most important challenges in deploying drone base stations in real environments (placement in space, DBS backhaul, UAV energy, load balancing, transmission power control, mobility handling, integration with terrestrial networks, frequency-time resource allocation). Additionally, in Chapter 2, the candidate presents the user distribution and mobility models (i.e., static, mobile, with obstacles) and assumptions (related to fronthaul, backhaul, and reconfigurable intelligent surface channel modelling as well as energy modelling for energy consumption and harvesting) underlying in the subsequent chapters. Furthermore, Chapters 3-7 include sections related to the state of the art and comprehensively explain the developed solutions.

In general, the presented theory is valid and constitutes a solid basis for the research performed by the candidate. It also confirms the candidate's good understanding of the topic researched. However, many of the cited works are not recent. Furthermore, the simulators developed by the candidate have not been comprehensively described and have not been made available to the public, which makes their assessment difficult.

Other remarks

An important remark is that the statistical analysis of the presented results is missing. This is an important shortcoming. Especially when the average results obtained with different approaches are close to each other, statistical analysis shows the importance of the potential gains of the developed solutions over their baselines.

Other minor comments are the following:

- Not all abbreviations and symbols are defined in the main text of the dissertation (e.g., RV on page 16). Sometimes they are also not present in the list of abbreviations (e.g. NEP, EEP).
- The list of symbols is not alphabetical.
- Colouring could have been added in Figure 2.3 for better explainability.
- The operation of the GN location selection mechanism presented on page 19 could have been illustrated in a figure.
- There is a conflict in the naming of variables, e.g., h is used both for height and channel gain.
- The choice of constants was not always well justified, e.g., α_{mm} on page 28, ηNLOS on page 43.
- Not all equations are appropriately explained, e.g., (3.27) on page 54.
- The font size in Figure 3.18 and Figure 4.1 is too small.
- The readability of Figures 5.6 and 5.7 is poor.
- Unnecessary indentation occurs when defining equations.

5. Conclusion

Considering 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 UAV-Aided Wireless Networks?

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*

W. Holt

Signature

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