

## PhD dissertation evaluation

**Title of the dissertation:** A Comprehensive Optimization Model for Multi-hop Wireless Networks with Multicast Traffic

**Author:** Bartłomiej Ostrowski

**What scientific/research issue is considered in this dissertation (the aim and thesis of the dissertation) and was it formulated by the author in a comprehensible way?**

The dissertation of Mr. Ostrowski deals with the multicast transmission in wireless networks. The multicast transmission and its benefits are well investigated for fixed networks but here the author considers wireless networks where the gain is even higher due to the broadcast nature of the wireless transmission. An important setting of the presented work is focussing on the time-division multiple access (TDMA) to radio channel as one of the most used and advantageous among existing access control schemes in terms of throughput, quality of service, etc. The cornerstone of this work is the mathematical model introduced in the paper by Pioro, Tomaszewski and Capone published in Ad Hoc Networks in 2018. The dissertation extends that model in several important aspects, covering issues of throughput maximization, energy minimization and packet delay minimization, capturing the main aspects and criteria where the multicast transmission may find application. The first three chapters detail in a clear and comprehensive way the aim and thesis of the dissertation together with all elements that were necessary to develop the contribution. In particular, the first chapter motivates the work and poses of the main setting of the problem studied in the dissertation. It gives also a summary of the content and outline of the dissertation contribution.

**Does the dissertation include appropriate analyzes of past work, including world literature, state of the art, and industrial applications?**

The second and third chapters report a deep analysis of the literature and previous works, while the application field is detailed in Chapter 1. More specifically, the second chapter gives account of the existing literature on multicast transmission and wireless transmission networks. The state of art is huge in this area and surely cannot be covered in a single chapter, but the main works and aspects are cited. In particular the author is interested in works containing algorithms and/or mathematical modelling focussing on those using linear optimization. Chapter 3 is crucial for understanding the rationale behind all the models since it recalls the work cited above (by Pioro, Tomaszewski and Capone in Ad Hoc Networks) and describe in detail the main notation and optimization model used and extended throughout the dissertation. The optimization model is considered in two versions, the basic one where the routing trees are considered as given, and the second where the routing is a decision variable, both aiming at throughput maximization. We may notice here that the problem notably differs from the maximum throughput flow in fixed networks since one needs to take into account the TDMA assumption and the slot transmission pattern. At this point the model is general and captures the main features of multicast transmission on wireless media. The given formulations contain a family with a limited number of slot transmission patterns which cannot guarantee the optimality of the obtained solutions. Therefore, a column generation procedure, that is slot pattern generation, is formulated through a pricing problem. This is applied in both versions.

**Has the author solved the research issues defined in the dissertation, did he use an appropriate method and are the assumptions justified?**

The main solution method behind the problems considered in this dissertation is advanced mathematical programming. It should be noted that the author has shown how to deal with difficult optimization problems related to column generation. The column generation method is used in several settings throughout the dissertation. It is clearly an appropriate solution method given the highly combinatorial character exhibited by the compact formulations of the considered problems. Indeed, compact problem formulations have little chance to be effective for real size networks (the case of fixed networks has already confirmed this in several situations). The column generation method allows to alleviate this limitation and better handle the highly combinatorial character of slot transmission patterns or routing trees. Still, this may not be sufficient in some cases as for example when dealing with packet delay minimization problem. Such problems, involving scheduling, are considered inherently hard. An exact MIP formulation for the optimization problem in question is given but its capability to achieve a solution in reasonable time is limited to small size network instances. Then an efficient heuristic simulated annealing method capable of finding near optimal solutions in a reasonable time is proposed and extensively tested. Finally, the author has proposed an alternative formulation of the routing optimization problem. This is an enhancement of the work presented in Chapter 3. In contrast to the approach presented in Chapter 3, the author looks for generating both the c-sets and routing trees, which increases the difficulty as two separated pricing problems need to be solved. Also, two MIP versions are presented and compared. The second one provides a stronger formulation yielding a very small optimality gap. All the findings are supported by numerical results.

To summarize, the author has used appropriate methods, both exact (some of them based on extensions of past work and some new models) and heuristic (based on simulated annealing).

**What are novel elements of the dissertation, what are the author's independent and original accomplishments, what is the position of the dissertation in relation to the state of the art and the level of technology represented in the world literature?**

In general, the considerations of Chapters 4 to 10 are novel. In particular, the following novel elements deserve explicit mentioning:

- Several important extensions of the main model given in the work of Pioro, Tomaszewski and Capone in Ad Hoc Networks in 2018. This has allowed covering main aspects and criteria related to wireless transmission networks. This contribution is substantial and original.
- An efficient heuristic method to handle the packet delay minimization problem.
- Alternative mathematical formulation of the multicast traffic routing optimization problem.

**Has the author demonstrated capabilities to present the obtained result in a correct and convincing way (brevity, clarity, editorial correctness)?**

The dissertation is written in a fluent English and comprehensive for the scientific community. It is abundantly illustrated and supported with examples, figures and numerical results.

**What is the value of the dissertation for engineering and technical sciences?**

The main value of the dissertation stands on the optimization models which are sufficient to capture most of the technological aspects related to multicast traffic in wireless networks.

**In summary, I classify this dissertation as outstanding.**

Signature:

 Drita NACE

Date:

30.03.2022

