

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

*Mohammed Jasim Obaid Khafaji*

**entitled:**

*The Use of Evolutionary Algorithms in the Next-Generation Wireless Systems*

## **1. Problem and its impact**

The thesis being assessed is authored by MSc Mohammed Jasim Obaid Khafaji and supervised by Dr. hab. inż. Maciej Krasicki. It is titled "The Use of Evolutionary Algorithms in the Next-Generation Wireless Systems" and consists of an Abstract; "Streszczenie" (in Polish); Acknowledgements; List of Figures; List of Tables; List of Abbreviations; an introductory Chapter 1; Chapter 2 overviewing optimization algorithms; three core chapters detailing the thesis' achievements (Chapters 3-4); a final Chapter 6; and a bibliography. The thesis is 103 pages in length.

The thesis proposes new methods to support wireless systems and uses simulation experiments to provide evidence of their effectiveness. The most important problem discussed in the dissertation is the adaptation of genetic algorithms metaheuristic as a useful heuristic for optimization in wireless systems, specifically in the areas of MIMO multi-user detection with and without successive interference cancellation and the selection of the best linear adaptive equalizer (namely: filter coefficients).

Indeed, these problems are scientific in their nature. The treated issues are challenging as the involved optimization tasks are not convex. Thus, traditional deterministic optimization algorithms may not be able to find solutions in a predictable time frame. The author employs a stochastic metaheuristic approach and specifically utilizes genetic algorithms, which are a well-established group of such methods. This path of research is frequently used to deal with difficult optimization problems and it is methodologically justified.

The problem discussed has important practical relevance as it relates to current telecommunications systems and can be applied in next generation wireless systems. Therefore, the title of the thesis is adequate (although the used term "evolutionary algorithms" is too broad). The proposed solution is shown to perform better than other approaches in certain situations, suggesting that further research on the proposed methods could be beneficial.

## 2. Contribution

The main, original contribution of the dissertation consists in the adaptation of genetic algorithms for certain optimization purposes in the design of wireless systems. The author presents the thesis in Chapter 2 with the statement: “The use of genetic algorithms can diminish the rate of erroneous MU-MIMO detector's decisions on transmitted symbols and boost the convergence of wireless channel equalizer.” This statement is valid in the context of the results presented, but it is quite broad and does not provide a specific technological context. Since the improvement (“can diminish”, “boost”) is perceived as the basis of the achievement, the questions can be posed: How is it measured? In comparison to what?

Fortunately, the thesis statement is then extended to give the precise meaning. This way, it can be really assessed that the author proposes an original approach of using genetic algorithms for multi-user detection in MU-MIMO systems with initialization using the result from a ZF detection (Chapter 3), also in the case of successive interference cancellation (Chapter 4). It is proven to improve the ZF-GA MUD performance by mitigating the error propagation effect. Similarly, the author's proposal of finding the estimated coefficients for the adaptive equalizer with a genetic algorithm based on a unique idea of populations changing synchronously with the signalling interval (Chapter 5) is able to outperform classical approaches based on least mean square and recursive least square algorithms.

I do agree that these are the main achievements given by the doctorate and here there is no distinction between my view and the one presented by the Ph.D. candidate. These improvements have not been presented in the literature and are also confirmed by the fact that the results have been published by the author internationally. Overall, the main achievement of the dissertation is improving the performance of wireless systems by adapting genetic algorithms for optimization purposes.

In regards to the quality of the proposed solutions, I will primarily focus on the optimization approach, as it is a field of my expertise. I will devote less comments to those related to wireless technology. From this perspective, I will first evaluate the practicality of the approach.

As said before, the problem addressed in the thesis is highly practical. Both the topic of decision making in the context of MU-MIMO and adjustment of wireless channel equalizers are of broad interest, usefulness and importance in the field of wireless communications. Although these are two different application topics, the author manages to connect them in a single thesis which can be perceived as an advantage (although they are mainly bound by the genetic algorithms and wireless networking umbrella). The proposed solution is also practical, at least from the perspective of its potential. The author compares the results obtained by the proposed approach to popular technological options (e.g., modulations in the context of the MUD in Chapter 3) or using performance indicators such as BER that are commonly used in the wireless field. Furthermore, the given solutions are compared with well-selected competitors.

As from the optimization perspective, I would say that the practicality is not doubtful, although I cannot say that it is fully convincing. The practicality of the method would be related to the general character of a given method. In the case of optimization heuristic there are many (hyper)parameters (such as population size, crossover probability, mutation function, etc. in relation to genetic algorithms) that are related to the algorithm and to ensure the practicality, we should have some

method to adjust the approach to a specific case. While I do not doubt that the used configurations proved to be useful (this is confirmed by the given results), it is not clear how they were obtained and how to change them. For instance, the author assumes some population sizes (or other fixed values as for instance presented in Tab. 3.1), but very little information is given, how this size was obtained, what happens if it is increased or decreased (namely: what is the sensitivity of the obtained results to size modifications) or what exactly is the influence of the size on the calculation times. To provide a fully practical method, this discussion on hyperparameter selection (in fact here I use the term characteristic by analogy to a different field, i.e., machine learning, where this type of problems is broadly discussed) should have been given. At least a thorough justification of the selection should have been added. I must say that the discussion on these aspects is not satisfactory.

To the best of my knowledge, the presented approach is new and has not been applied in software or hardware yet. The author chose to evaluate the performance of the approach through simulations, which is an acceptable method of research in this context. I believe that the quality of the approach has been confirmed to some extent by the good publications co-authored by the PhD candidate. The results presented in the thesis have been previously published in four international publications: two at the “International Conference on Dependability and Complex Systems”, one in the “Electronics” journal, and one in the “IEEE Communications Letters”, which is a reputable periodical in the field of wireless communications.

### **3. Correctness**

The original results are presented mainly in the following sections:

- 3.6 “Application of GA in MIMO Multi-user Detection”.
- 4.3 “The Application of the SIC Concept with GA-MUD”.
- 5.4 “System Model”.

The organization of these sections follows a consistent pattern: first, the new proposed method (i.e., the way a specific genetic algorithm heuristic is to be applied) is presented, followed by a simulation-based evaluation of its effectiveness in comparison to other techniques. In Section 3.6, this structure is repeated, with the introduction of an additional approach for initializing the population when the initial method proves to be insufficient. I find this method of presenting new results to be effective, particularly in the context of the diverse technological applications covered in Chapters 3-4 and Chapter 5.

I have no reason to doubt the claims made in the dissertation regarding the concrete methodologies, cases and numerical examples presented and conclusions drawn from them. It appears that the PhD candidate was able to achieve the improvements stated in the important cases reported and this is a support to claim that the thesis given in Chapter 2 was proven. The arguments used are generally valid, although I must say that they are limited from an optimization perspective. Aside from my abovementioned concerns (from pt. 2) about the general methodology for selecting parameters for the genetic algorithm heuristics (which, it must be noted, appear to have been successful in the presented cases), I am somewhat sceptical about the generalizability of the approach. I do not have counterarguments, but I would like to emphasize that the author has not proven the universal generalizability of the approach. The issue is that the author has presented a limited set of experiments. For optimization heuristics, it is typically necessary to present a wide range of settings to increase the level of certainty that the method provides useful results. Here, in Chapters 3-4, the detection problem

is limited to a four-user uplink communication system with one transmit antenna for each user. The question then arises: Will the presented methods perform as well in other technological settings? A similar situation occurs in Chapter 5, where the author only deals with three simulation scenarios (although in this case the author at least strives to convince that these scenarios are realistic in terms of GSM propagation models). While I understand that the experiments can be exhaustive and they must be somehow limited, I do believe that a broader set should be studied to be sure that the proposed methods really work.

On the other hand, I appreciate that the author decided to address topics that have been previously tackled using genetic algorithms and was able to obtain new results of good quality. I appreciate the new idea on the initialization of the population (a very useful concept applied in Chapters 3-4) and the new idea to synchronize populations with dynamic channel states (with good results in Chapter 5). Additionally, I can see that the author is aware of the problems of selecting various configuration options for genetic algorithms, as he presents many of them in Chapter 2, where a comprehensive discussion of the covered optimization approaches is given. In fact, some hints on how to select, for instance, the representation are discussed therein. I suspect that the author experimented with many different (hyper)parameters but did not include the initial (and further skipped) results in the thesis. However, I would like to discuss this aspect further during the defence. This omission might be also related to the concept of the thesis construction (I comment on this issue further in my review in pt. 5).

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

As concerns the elements of the dissertation that resemble a tutorial and thus confirm a general knowledge of the candidate in the discipline of Information and Communication Technology the following can be enumerated:

- Entire Chapter 2 “Genetic Algorithm”: provides a thorough overview of the general optimization context and offers a comprehensive introduction to evolutionary algorithms, with a specific focus on genetic algorithms. The chapter covers the principles of optimization and explains how to select options when adjusting specific heuristics of interest. It is clear that the author has a deep understanding of the topic and presents the information in a clear and informative manner.
- Throughout the text, there are several sections (typically: introductory in chapters) that cover various aspects of wireless technology (for which the genetic algorithms are later used in these chapters as an optimization approach); in particular:
  - In Chapter 3 “GA-Based MU-MIMO Detector”: sections 3.1 “Introduction to MIMO system”, 3.2 “Multi-User Detection”, 3.3 “Optimal MUD Method”, 3.4 “MIMO Multi-user Detection Problem Formulation”.
  - In Chapter 4 “SIC Driven GA MU MIMO Detector”: sections 4.1 “Successive Interference Cancellation, The Idea and its Drawback”, 4.2 “Basic SIC Detector”.
  - In Chapter 5 “Chapter 5: Adaptation Mechanism for Wireless Channel Equalizer”: sections 5.1 “Equalization Technique”, 5.2 “Equalizer Structures and Algorithms Classification”, 5.3 “Linear Equalizers”.
- These sections provide a thorough and current view of the technological details and demonstrate that the PhD candidate has a deep understanding of wireless technology.

In my opinion, the presented state-of-the-art is complete. As evident from the content, the thesis covers various aspects of communication technology and employs practical applications of optimization algorithms. In my opinion, the author demonstrates a thorough understanding and knowledge of the field of Information and Communication Technology (particularly, the area of optimization in wireless networks), as is expected at the doctorate level, across a wide range of topics related to this very broad discipline.

The mentioned chapter and sections are well-written and of high quality, indicating that the research behind the thesis is valid and timely. The author provides supporting literature for his statements (especially as concerns potentially controversial statements) and includes a total of 141 unique references, 5 of which are co-authored by him (apart from the mentioned 4 scientific papers, also his MSc thesis). The literature references used in the thesis are mostly relevant and cover the most important results, particularly in the field of optimization with genetic algorithms. However, some of the citations are outdated. Nearly 35% (49) of the references were published before the year 2000. This does not mean that the literature references are outdated, but rather that the author presents the willingness to cite historical papers (e.g., giving the origin of a specific technological concept) or too many older textbooks on optimization, that could be simply replaced with more recent publications (sometimes with only one new textbook). Additionally, some citations are not entirely relevant to the topic being discussed (e.g., when some statements related to introduction of a general aspect of an optimization method are supported with a paper giving the example of usage – instead of a textbook-like reference). Despite these drawbacks, the literature review is comprehensive and provides a good foundation for the thesis. It is unfortunate that the literature review is dispersed throughout the thesis and not presented in a single separate chapter. Overall, with some refinement the literature review can be more useful.

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

Here, I am providing my assessment of the thesis from a technical writing perspective. I have one positive and two critical comments to make.

Firstly, I appreciate the quality of the English language used in the thesis. Although this is not my first language, I hope to be correct when I say that I find the text to be well-written with good grammar and clear presentation of ideas. I also noticed very few typographical or punctuation errors (except for references formatting, see my comments below).

Second, I have the impression that the thesis is structurally composed primarily of the content from the previously mentioned four publications. The author does not clearly elaborate on this (although he does emphasize that some concepts were presented in previous papers). However, this is not necessarily a problem. In fact, it is common for a PhD thesis to be a compilation of previously published papers. The issue in this case is that the author has not been able to create a sufficiently comprehensive text – as I said before, it is likely that some initial results were not able to be put to the short papers, but for sure it could be possible for such results to be shown in the thesis to cover the whole study of (hyper)parameters. The author failed to present a fully cohesive text either – I find that

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<sup>1</sup> Optional

the presentation of concepts is not always natural. For example, in Chapter 2, the author discusses optimization issues but presents them in an unnatural order, as it would have been more logical to first introduce the technological context of the application and the need for optimization, before introducing genetic algorithms as a solution. The technological context is only introduced later on in Chapters 3 and 5, after the optimization approach and its usage are discussed in depth. Additionally, there are some minor inconsistencies. For example, the way ideas are presented in Chapters 3, 4, and 5 differ and are not always consistent. In some cases, the operation of the proposed genetic algorithms or the used simulations (and their assumptions) are described in more detail than in other cases. Moreover, some redundancies happen (e.g., the roulette-wheel selection is explained at least two times). I would say that it would be simply better to present this doctorate as a cycle of publications.

Third, the editing of the thesis is not of very high quality. Some parts appear to have been rushed and not thoroughly reviewed. Here are a few examples:

- The chapter titles are presented in an unorthodox manner, being only included in the heading. For example, on page 1, it can be observed that the title of Chapter 1 is not prominently displayed.
- I do not think it makes much sense to generate subsection 3.3.1 if 3.3.2 is not present (the same concerns 5.3.1 and 5.4.1.).
- It happens that mathematical variables are not always given in a mathematical mode (e.g., “ $f_d$ ” in titles of figures in p. iv).
- Unnecessary blank spaces are present (e.g., “Square -based” in p. vii).
- Abbreviations not typical to formal language can be met (e.g., “can’t” in p. 1).
- While there is a very useful list of abbreviations, all of them should be expanded when they appear for the first time. The author is not coherent with that (e.g., sometimes he does it, as is the case with LMS in p. 3, and sometimes – not, as is the case with UCGA in the same page).
- Different font sizes are used (or different fonts) in some paragraph titles, e.g., in “B. Replacement (Survivor Selection)” in p. 21.
- Equation (4.3) seems to unnecessarily repeat equation (2.2).
- It is not clear what is represented by “ $v(t)$ ” in Fig. 5.1 (although it is later explained in Fig. 5.3).
- Some figures are not fully legible (they should be simply larger), what is problematic when overlapping results are present, e.g., Figs. 5.7 and 5.8. Additionally, in the case of these figures the legend signs are not consequently used (e.g., various marks for “GA, fd:0Hz”).
- Many mistakes in bibliography description; a few instances:
  - Not consequent description of positions of the same type (e.g., journal papers in [AM84] and [APA15] use various conventions).
  - Double entries for [CW98] and [Hol92].
  - Not clear character and source of a few documents (e.g., [Jal04] or [Tad11]).
  - Many punctuation errors.

The aforementioned drawbacks do not significantly impede the understanding of the presented content or my appreciation of the research results, but it is unfortunate that they were not addressed with more care during the editing process.

## 6. Conclusion

Taking into account what I have presented above and the requirements imposed by Article 13 of *the Act of 14 March 2003 of the Polish Parliament on the Academic Degrees and the Academic Title* (with amendments)<sup>2</sup>, 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 **optimization in wireless networks**?

*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*

PIOTR CWOŃKA  
  
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*Signature*

<sup>2</sup> [http://www.nauka.gov.pl/g2/oryginal/2013\\_05/b26ba540a5785d48bee41aec63403b2c.pdf](http://www.nauka.gov.pl/g2/oryginal/2013_05/b26ba540a5785d48bee41aec63403b2c.pdf)

