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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 dissertation written by M.Khafaji consists of six chapters, an abstract in English and Polish version, a list of figures, a list of tables, a list of abbreviations and a bibliography. The first chapter is a brief overview of the general possibilities of using genetic algorithms, with particular emphasis on their use in radiocommunication. From these examples the thesis is drawn: "*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*". In the introduction, the author defined two separate applications of evolutionary algorithms and research topics. The first one is a simultaneous detection of signals transmitted by several users at the same time in a Multi-User Multiple-Input Multiple-Output (MU-MIMO) radio channel, while the second topic is the use of a genetic algorithm to estimate coefficients of adaptive linear equalizer for reduction of inter-symbol interferences. The introduction ends with a brief overview of document organization.

The chapter number 2 is devoted to optimization algorithms in general and the genetic algorithm (GA) in particular as a representative of a wider class of evolutionary algorithms (EA). The evolutionary cycle is presented with many details regarding its components and the possible implementation of evolutionary procedures, such as population initialization, selection, crossover and mutation. This chapter also includes an example of finding global minimum of a Rastrigin function using a genetic algorithm that converges well to correct results, although the selected function has many local minima that make it difficult to find the global minimum for other kind of algorithms, e.g. gradient-based.

The third chapter begins with an introduction to Multiple-Input Multiple-Output (MIMO) radio channels and the problem of multi-user detection (MUD) in systems and radio interfaces that utilize non-orthogonal access to radio resources. The optimal multi-user detection algorithm is defined, but as it is known for high computational complexity, suboptimal solutions such as zero-forcing linear detection and minimum mean square error algorithms are also presented by the author. The main contribution of this chapter is the development of multi-user detection method based on a genetic algorithm, tested in two variants: with random initialization and with initialization based on the results from a zero-forcing detector.

The investigation on multi-user detection is continued in the fourth chapter, which focuses on successive interference cancellation algorithms that improve the quality of detection of low-power signals by earlier detection and subtraction of signals characterized by higher power levels. Taking this principle into account, the author proposed GA-based MUD algorithm in which the chromosomes in the initial population contain the channel state information for the user with the highest power level obtained from zero-forcing detector from successive interference cancellation MUD detector.

The fifth chapter presents the problem of inter-symbol interference mitigation in radio links using equalization techniques. As the radio channel characteristics are time-varying, an effective channel equalizer must be adaptive and the author focused on a linear adaptive equalization structure in the form of a finite impulse response (FIR) filter with variable coefficients and presented examples of iterative algorithms for selection of equalization coefficients, widely described in the literature. Next, a genetic algorithm is proposed for estimating and tracking current channel state. Although the general concept of using GA in ISI mitigation is not new, the author proposed to reduce number of genetic cycles to only one generation per signalling interval in form of Uni-Cycle Genetic Algorithm (UCGA). The chapter contains details of the algorithm implementation and results of simulations that show better performance of proposed solution compared to the LMS algorithm in various channel models.

The chapter number six contains the conclusions from all the studies, along with possible topics for future work, such as the evaluation of other evolutionary algorithms, e.g. particle swarm optimization and ant colony optimization in the same areas of radiocommunication.

The content of the second chapter is primarily a comprehensive explanation of principle of the operation and methods of using genetic algorithms in general. While this chapter is well written as a theoretical background, it does not contain any new ideas or scientific advances. On the other hand, the content of the next three chapters is important both from the scientific and practical point of view because both problems investigated by the author (multi-user detection and inter-symbol interference mitigation) are constantly analysed in the scientific literature due to growing demand for high data rates and high capacity of wireless communication systems. Both research areas, defined in the thesis of the dissertation, are well defined in terms of optimal solution, but since it is known that searching for or calculation of the best results is impractical due to the high computational cost, suboptimal solutions, such as the genetic algorithms proposed by the author, are still interesting alternatives. Therefore, presented dissertation has practical meaning as the proposed ideas may lead to the implementation of fast and efficient algorithms of multi-user detection in MU-MIMO systems and channel equalizers for receiving radio signals in time-varying propagation conditions.

2. Contribution

The main contribution of the dissertation is divided into two parts, just like the dissertation thesis. The first part is investigation on the possibility of using genetic algorithms in multi-user detection, in which the author proposed structure of GA and two methods of population initialization for faster algorithm convergence and higher quality of signal detection. The second topic is channel equalization and inter-symbol interference mitigation, which has also been studied using suboptimal genetic algorithm. The author's contribution in this field is design and implementation of a channel equalizer in which only one iteration of the genetic cycle is needed per one symbol in received signal. The presented simulations and comparisons with other structures of adaptive linear equalizers (RLS, LMS) proved that the equalizer based on the genetic algorithm can achieve a lower bit error rate under similar conditions.

The author's contribution in both fields: multi-user detection and interference mitigation by channel equalization is significant at the scientific level and may lead to the implementation of effective signal processing algorithms in radiocommunication devices. However, the work done in both fields of research does not add up to one great contribution to the radiocommunication. The content of chapters 3 and 4 and the content of chapter 5 of the dissertation are connected only by the use of the genetic algorithm, which is only a kind of generic tool used to solve two separate problems. This is not the right way to prepare PhD dissertation, as it should contain extensive investigation and comprehensive solution to well defined scientific problem, not a review of possible solutions to smaller problems selected arbitrarily from entire range of tasks that can be solved by using genetic algorithms.

3. Correctness

The author of the dissertation mainly uses computer simulations as a tool for experiments. This is fully justified by the research areas and the proposed solutions to scientific problems, based on algorithms implemented as a software. However, I have some doubts about how the simulations were run and the results presented in chapters 3 to 5. For both areas of experimentation: multi-user detection and inter-symbol interference cancellation, the optimal solution can be found using the methods and algorithms presented in literature, mentioned by the author in the dissertation. If so, why are none of the results from simulations compared to the optimal solution in terms of their performance metrics? For example, adding the BER plot obtained with the maximal likelihood detector to the plots in Figures 3.6 and 3.8 would allow to estimate degradation of detection quality using suboptimal detection by genetic algorithm. In addition, although results presented in chapter 3 show the quality of detection of signals for three different modulations: QPSK, 16-QAM and 64-QAM, widely used in modern radiocommunication systems based on OFDM technique, in chapter 4 results are presented only for 16-QAM modulation. Interestingly, comparing Fig. 3.6 for 16-QAM and Fig. 4.5, the plots for GA are the same while the results for zero-forcing algorithms differ significantly. In chapter 3, the BER for ZF is always lower than that obtained for the genetic algorithm while in chapter 4 for the lower SNR, the BER for ZF is worse. Such a difference without comment puts the presented results into question. Additionally, simulations of MU-MIMO are performed with assumption that the channel matrix **H** is perfectly known. What level of performance degradation should be expected in case of imperfect **H** estimation?

Due to lack of comparison of quality of detection using GA with optimal solution, the only argument in favor of using genetic algorithm is its lower computational complexity. Unfortunately, the exemplary results from chapter 4 show that the genetic algorithm, implemented by the author, may require much more operations than simply checking all possible solutions in the search of optimal detection. The author proposed to simulate a case with four users, who use 16QAM modulation. Therefore, the total number of possible solutions is 2^{16}=65536, but initialization of population using results from zero-forcing detector allows to calculate most probably value of 4 bits of the chromosome, so remaining 12 bits gives only 2^{12}=4096 possible combination of bits to check in the search for the optimal detection. However, the author assumed that the genetic algorithm uses a population size of 2000 individuals and since the number of stall generation is 20 (page 57), the minimum number of genetic iterations in the best case is 21, which gives 21×2000=42000 genetic operations. Additionally, the GA does not guarantee convergence to the optimal solution, therefore the example presented in chapter 4 makes the usage of genetic algorithm questionable.

Also for the inter-symbol interference mitigation study in chapter 5 I have some doubts regarding computational complexity of the proposed genetic algorithm. Although the author proposed to use only one iteration of genetic evolution per signaling interval, the population size used in the simulation was set to 200. Does this mean that for every received symbols 200 possible solutions of equalizer coefficients were tested against only one result of equalizer coefficients calculated using LMS or RLS algorithms? Therefore, computational complexity of GA is for sure higher. To make fair comparison of equalization quality, results from one iteration of GA should be compared with results from other algorithms while allowing for such number of iterations per signaling interval that gives the same total number of computationally expensive mathematic operations as one iteration of GA with 200 individuals in population. Otherwise, the conclusions on computational complexity or convergence time presented in the chapter 5 are questionable.

4. Knowledge of the candidate

The content of chapter 2 of presented dissertation is a comprehensive description of general problem of optimization with focus on evolutionary algorithms and particular emphasis on genetic algorithms. Although this chapter presents broadly understood optimization problem without direct references to the discipline of Information and Communication Technology, the application of optimization and random search algorithms in telecommunication and radiocommunication is very wide. Therefore, the high quality summary of evolutionary algorithms presented by the author show broad understanding of the optimization problems and methods, not limited to ICT. On the other hand, the topics discussed in chapters 3 to 5 of the dissertation are closely related to radiocommunication in general, with focus on the non-orthogonal access to radio resources, the theory of estimation and signal processing. The entire research presented in the dissertation is preceded by an extensive literature review which proves that the author has a general knowledge of the current state of the art in radiocommunication. The bibliography list contains143 sources, including four articles co-authored by the PhD candidate and his MSc thesis. The reference list contains both publications from the 80's and 90's, containing general knowledge in the field of optimization and genetic algorithms, as well as publications from the last few years, mainly focused on application of evolutionary algorithms in various parts of digital radio links and receivers. The selection of literature is adequate to the subject of the doctoral dissertation.

In conclusion, the presented works confirm that the candidate has general knowledge and understanding in the discipline of Information and Communication Technology with special focus on radiocommunication, estimation theory and optimization.

5. Other remarks

During the reading of the PhD dissertation, several minor editing problems were encountered. The most important ones are listed below:

- The table of contents does not show titles of main chapters. For example the first chapter is marked only "Chapter 1" while true chapter title, which is "Introduction", is printed only later in the page headers. Moreover, the table of contents present only three levels of subchapter numbering, therefore some subchapters (e.g. 2.3.5.1, 2.3.5.2) are not listed at all. Also the list of abbreviations is not mentioned in the table of contents.

- There is no list of symbols used in the dissertation. It caused several problems. For example in the Fig. 3.1 on page 35 transmitting and receiving antennas are numbered by symbols n and m respectively while in the equation below symbol j and i is used for the same reason. Moreover, on page 53 reversed convention is used: index j is used to number receivers and i for transmitters. Other problem: symbol η on page 40 denotes signal constellation set while the same symbol on page 38 is "set of potentially transmitted multi symbols" – it is not the same.
- UMTS is the Universal Mobile Telecommunications System, not service (page ix and 8).
- Definition of the metaheuristic algorithms on the page 7 is unclear.
- Reference to equation (2.6) at the bottom of page 25 is incorrect.
- Comment on linear reduction of standard deviation defined by equation (2.5) is probably incorrect as current result is calculated from the previous iteration.
- Equation on page 35 is not numbered. **H** should be bold as it is matrix.
- Fitness function defined by (3.7) on page 42 returns the lowest value for the best fitted individual. Therefore, probability of selecting this individual using roulette wheel selection rule should be the highest, but on page 43 author refers to equation (2.2) where result from (3.7) is directly used to calculate probability. As a result, probability of selecting the best fitted individual is the lowest instead of the highest. The same problem is repeated on page 56 with equation (4.3) and on page 74 with (5.23).
- The text on page 43 refer to section 2.4.4 which does not exist. Did you mean section 2.3.5.2?
- Function $\delta(t)$ on page 61 is not defined. Is it the Dirac function?
- Variable T in the paragraph below (5.3) is not defined. Is it a sampling interval?
- Typically, small bold symbols denote vectors and capital bold symbols are reserved for matrices. Unfortunately this convention is not followed in dissertation. For example: page 65, symbols in equation (5.4) are not the same as in the paragraph below.
- In equation (5.10) one variable parameter α can be found, but in the paragraph below equation (5.13) the author mentioned adjustable parameter Λ which is not defined anywhere. Is it the same parameter?
- On the page 76 number of equalizer taps is defined to be 15, which means equalizer impulse response duration of 10μs. It is shorter than maximal delay of signal in case of hilly terrain channel model. Is it correct?
- On the page 81 a statement can be found: "It makes the results below 10^{-4} quite worthless". It is a PhD candidate's job to ensure that all the presented data are reliable and valid.

However, these minor problems did not affect the overall scientific quality of the presented work and should be treated only as a discussion on the form of the presentation, not as a criticism of the content of the dissertation.

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), 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 **radiocommunication**?

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*

Signature