Poznan University of Technology

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

Mohammed Jasim Obaid Khafaji

Supervisor:
dr hab. inż. Maciej Krasicki

Faculty of Computing and Telecommunications

Poznań, 2022

Introduction

Wireless communication is a crucial aspect of the telecommunications industry. Together with its applications and underlying technologies, it is among the most active areas of technology development due to the increment in demand for wireless connectivity and the success of the fourth-generation (4G) digital wireless standard. The rapid evolution of wireless communication techniques presents considerable challenges arising from the demanding nature of the physical medium; interference and multipath-induced fading exemplify the dominant issues in wireless communications.

The use of Multiple-Input Multiple-Output (MIMO) wireless channels brings a significant increase in the system capacity. To retrieve the individual signals, transmitted over a MIMO channel, Multi-User Detection (MUD) techniques are indispensable. Complexity is the main challenge associated with MUD and can take two forms: computational and informational complexity. The number of resources required to perform a particular receiver algorithm is referred to as the computational complexity. Informational complexity refers to the amount of knowledge a receiver requires to process the received signals effectively. The optimal Maximum-Likelihood (ML) MUD, typically, consists in an exhaustive search, which imposes computational costs increasing exponentially with the number of simultaneous users, thereby making its implementation unfeasible in high-user-load scenarios. Another benchmark is a simple but poor Zero-Forcing (ZF) MUD.

Several suboptimal nonlinear MUDs have been proposed in the literature, such as the MUDs that utilize the SIC technique or parallel interference cancellation (PIC) that require iterative algorithms to reduce the impact of the interfering signals during each detection stage.

As the wireless market continues to grow, which brings a higher number of users and higher capacity demands, dealing with the wireless channel fading and multipath effects is becoming a more and more challenging task. Channel equalization is essential for reliable communication. A desirable equalizer should be capable of achieving high performance while maintaining low computational costs. The high computational complexity of ML equalizer was the reason for which the researchers focused their attention on suboptimal receivers with lower complexity, like Least Mean Square (LMS) and Recursive Least Square (RLS).

Over the years, metaheuristics, such as Evolutionary Algorithms (EAs), have attracted increasing interest of scientists as a tool for solving many complex optimization problems. The EAs consist in a guided random search, independent of the details of the optimization problem to be solved. They model a rudimentary form of memory to archive the best solutions encountered. Therefore, they provide reasonable solutions under all conditions. One of the most widely used metaheuristics is Genetic Algorithm (GA), which has gained the attention as an optimization framework in the field of wireless communication systems.

GAs have been applied for optimization of a wide variety of parameters in wireless networks for many reasons. GA is a powerful search engine, capable of solving optimization problems with large search spaces. It can adapt to unknown environments, which is crucial in wireless networks, where the uptime decisions must be made automatically.

Different approaches to the MUD and adaptive equalizer based on a computationally efficient GA are the topics of this thesis.

Thesis and Main Goals

The thesis of the dissertation is as follows:

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.

Based on the above-stated thesis, the research focuses on two issues, namely:

- *Improving the ZF-GA MUD performance by mitigating the error propagation effect.* The author of the thesis has proposed an original GA-aided solution to the MUD problem, in which one individual of the initial population represents the result outputted by a simple ZF detector. In the dissertation, he revisits that concept. The new strategy bases on the Successive Interference Cancellation (SIC) idea. An employed ZF detector assesses the reliability of signals transmitted by individual stations to give an initial direction to a good search region when the optimization algorithm starts.

- *Boosting the convergence and tracking capability of the adaptive equalizer performance.* Slow convergence and complexity are the major disadvantages of LMS and RLS algorithms, respectively. A novel UCGA is proposed as a learning tool to optimize the coefficients of the adaptive linear equalizer. In the proposed GA scheme, the individual represents the estimated equalizer coefficients. The algorithm is optimized for working on a real-time basis. To meet such needs, it considers only one population generation per one signalling interval, which has not been practiced, yet.

Achievements

This dissertation discusses the use of GA for MUD purposes in a Multi-User Multiple-Input Multiple-Output (MU-MIMO) scenario, in which the receiver is equipped with a few antennas and individual users transmit their signals concurrently in the same bandwidth.

As an evolutionary algorithm, GA can try to find the optimal solution starting from scratch. However, the author observed that loading a single well-fitted seed individual into the initial population brings faster convergence and better optimization result in general. At the first attempt, he proposed to run the simple ZF MUD before launching GA to obtain the seed individual. The resultant combined ZF-GA strategy appeared to outperform both pure ZF reference and basic GA-driven MUD in terms of BER, especially for low-order modulations [1].

The current author’s contribution is a new population initialization method that resembles the SIC approach. In brief, it consists in retaining the ZF detector’s decision with respect to the most reliable out of all interfering signals. The novel approach exhibits the ability to improve the performance of GA-driven MIMO multi-user detector at no cost in comparison with the previously considered ZF-GA MUD [2].

The second scope of this dissertation is the use of GA as a learning mechanism to improve the performance of an adaptive channel equalizer. A novel Uni-Cycle Genetic Algorithm (UCGA) is designed with the aim of working in real time. The proposed solution has the advantage of requiring only one generation per signalling interval, which reduces computational costs, significantly, when compared to other GA-driven channel equalizers.

Several simulation experiments have proven that the proposed UCGA-driven channel equalizer is able to converge quickly and track the channel state, significantly outperforming the benchmarks: RLS and LMS. The UCGA may, therefore, be considered as a reliable channel equalization engine for the next wireless systems [3, 4].

Taking into account the above conclusions, the author believes that the dissertation thesis has been proven, i.e., the performance of the GA-based MU MIMO detector has been significantly enhanced at no extra computational cost through the application of a new GA initialization technique based on the SIC approach. Besides, the performance of an adaptive channel equalizer has been improved by employing a low-cost GA-driven adaptation engine that boosts the convergence rate and improves the channel tracking ability.

Publications

[1] M. J. Khafaji, and M. Krasicki. “Genetic-Algorithm-Driven MIMO Multi-user Detector for Wireless Communications.” International Conference on Dependability and Complex Systems. Springer, Cham, 2018. **(40 pts.)**

[2] M. J. Khafaji, and M. Krasicki. “Successive-Interference-Cancellation-Inspired Multi-user MIMO Detector Driven by Genetic Algorithm.” International Conference on Dependability and Complex Systems. Springer, Cham, 2020. **(40 pts.)**

[3] M. J. Khafaji, and M. Krasicki. “Uni-Cycle Genetic Algorithm to Improve the Adaptive Equalizer Performance.” *IEEE Communications Letters*, vol. 25, no. 11, 2021, pp. 3609-3613. **(100 pts.)**

[4] M. J. Khafaji, and M. Krasicki. “Uni-Cycle Genetic Algorithm as an Adaptation Engine for Wireless Channel Equalizers.” *Electronics*, vol. 11, no. 2, 2022, p. 171. **(100 pts.)**