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Solving optimization problems in the fifth generation of cellular networks by using meta-heuristics approaches

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Abstract

Meta-heuristics are a set of intelligent algorithms and techniques that have been used to solve various complex problems in several domains in particular in cellular networks and telecommunications. The complex problem tackled by a meta-heuristic approach should be modeled mathematically as an optimization problem where the aim is to optimize a certain objective function. Then, an iterative process is launched to search for high quality solutions i.e. those optimizing the objective function. In this paper, we are interested in the fifth generation of cellular networks. We start with highlighting some main concepts of the 5G mobile networks. Then we discuss important problems in 5G and show how these problems can be solved by using meta-heuristics approaches.

Keywords: optimization, meta-heuristics, cellular networks, 5G.

1. Introduction

In radio networks and telecommunications, 5G is the fifth generation of cellular mobile networks. 5G is the successor to the 1G, 2G, 3G and 4G standards in radio cellular networks. The fifth generation offers numerous advantages compared to the ancient generations of mobile networks. 5G network ensures a connectivity level which is very much higher than that offers with the 4G network. It offers low energy consumption and provides very high frequencies and wider bands compared to 4G thanks to sophisticated techniques such as millimeter waves (30GHz-300GHz), Massive MIMO and advanced beamforming techniques.

Massive MIMO (multiple input and multiple output) is a particular type of antennas which increases the sector throughput and the density of capacity by using a large number of antennas so-called Multi-user MIMO. Each antenna includes radio transceiver components and can be individually controlled. Beamforming is a technique that permits to increase the signal power received by users. It uses more complex systems to achieve higher density cells, with higher throughput.

Despite the success of 5G, there are numerous and important complex problems in 5G that needs to be solved efficiently. Among them, we cite: the problem of resource management [13, 29], the problem of planning and

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dimensioning [26], the problem of antenna positioning and selection [4], the problem of optimal routing [30], and so on. These problems can be modeled as optimization problems and can be solved by using meta-heuristics approaches.

Meta-heuristic techniques are intelligent tools that have been used with success for solving several optimization problems in particular in artificial intelligence and operational research. Meta-heuristics can be divided into two main categories: evolutionary and local search techniques [5, 16]. The local search techniques are single solution oriented methods. The single-oriented meta-heuristics work on a current single solution and explore intensively the search space for finding better solutions. Among the local search methods, we cite local search (LS) [2], Variable neighborhood (VNS) [14, 21], stochastic local search (SLS) [16], simulated annealing (SA) [18] and tabu search (TS) [9, 10].

The evolutionary techniques also called population-based methods maintain and evolve a population of solutions and apply reproduction operators for generating new improved solutions. Among the evolutionary approaches proposed for optimization problems, we mention the well-known genetic algorithms [12, 15], scatter search [11] and memetic algorithms [22, 23].

The rest of the paper is organized as follows: Section 2 presents the main concepts of the fifth generation cellular network. Section 3 gives a background on meta-heuristics techniques. Section 4 deals with some important problems in 5G. Finally Section 5 concludes and gives some future works.

2. Overview of 5G network

1. The fifth generation of wireless network is a packet switched wireless system with extended coverage and high speed. The 5G uses OFDM (Orthogonal frequency-division multiplexing) which is a multicarrier modulation scheme and a millimeter wireless technology [1].

2. In addition, the 5G network uses a variety of spectrum bands, including the millimeter wave radio spectrum (mmWave), It uses ultra-high broadcast frequencies (UHF) between 6-300 GHz) which permits to quickly transfer huge amounts of data. However, the broadcast range is limited; consequently 5G makes use of Beamforming technique via multi-user MIMO to ensure a continuous dissemination of data on several devices. It also uses a multi-cell handover process to ensure solo connections of the order of gigabit even when running.

3. The main techniques used in 5G technology are given in following.

- **Millimeter waves:** which are radios waves covering frequencies from 30 to 300 GHz. The new 5G network is then able to transmit very large amounts of data, but only a few blocks at a time.

- **Small cells** are portable and low-power base stations that can be placed in any city. A small cell is a device which offers the increase in the spectral efficiency of the area. Indeed, the total capacity of the network increases considerably by reducing the cells and by reusing the spectrum.

- **Massive MIMO**: that refers to the large number of antennas that can be used in a MIMO network. A MIMO concept means that both the transmitter and the receiver have multiple antennas which maximize efficiency and speed. However, A potential drawback of MIMO is interference, which needs a beamforming technique to enhance the performance.

- **Beamforming: is** the possibility of adapting the radiation pattern of the antenna array according to a certain model. Beamforming helps massive MIMO arrays to use the spectrum around them more efficiently.

- **Full-Duplex**: that allows the reception and the transmission of data simultaneously. It is a way to accelerate the wireless communication where only one channel is enough to transmit data to and from the base station, rather than two.

Table 1 compares the 3rd, 4th and 5th generations of cellular networks. The 3G is the Universal mobile telecommunication system. It was launched in year 2001. It provides multimedia services with streaming possibility. It uses the W-CDMA technology. The 4G cellular network developed in 2009. It is faster and more reliable than 3G. The speeds are highly increased compared to the 3G. The 4G norm provides easy roaming and high uploading and downloading speeds. The 5G is the new generation of cellular networks. 5G was introduced in late 2018. The 5G offers very high speeds to users. It offers an efficient exploitation of bandwidth. It is 10 times faster than 4G [1, 26].

Table 1: 3G versus 4G versus 5G

Features	**3rd generation**	**4th generation**	**5th generation**
Title	Universal Mobile Telecommunications System (UMTS) - **3G**	Long Term Evolution (LTE) **- 4G**	New Radio (NR) **- 5G**
Data Bandwidth	2mbps	200 Mbps to 1Gbps	>1gbps
Year	2001	2009	2018
Latency	100-500 milliseconds	20-30 milliseconds	<10 milliseconds
The frequency band	2Ghz	2 à 8 GHz	3 à 300 GHz
Multiple access	Code division Multiple Access (CDMA) W-CDMA (Wideband Code Division Multiple Access,) a variant of CDMA.	Orthogonal frequency-division multiple access (OFDMA) single-carrier frequency division multiple access » (SC-FDMA)	OFDMA and Beam-design-multiple-access (BDMA)
Technologies	Broadband CDMA, IP technology	Unified IP, seamless integration of broadband LAN / WAN / PAN and WLANUnified IP, seamless integration of broadband LAN / WAN / PAN and WLAN	different wireless networks, including wireless LAN technologies LAN, WLAN, PAN and WWWW (world-wide wireless web), unified IP

3. Background on Meta-heuristics

As shown in Figure 1, a meta-heuristic is an iterative algorithm that should be run for a certain stopping criterion (a maximum number of iterations) for searching appropriate solutions optimizing (maximizing/minimizing) the objective function.

As already said, a meta-heuristic is an intelligent technique that can be used to solve optimization problems. To evaluate a solution, the meta-heuristic uses a certain function called "*objective function*". A quality of a solution is measured by using the objective function also called *fitness function*. The fitness is then a measure related to the problem to be solved. The aim of a meta-heuristic is to optimize such function. Solutions with high quality are those

having highest fitness value in the case of maximization problems or those having lowest objective function value in the case of minimization problems.

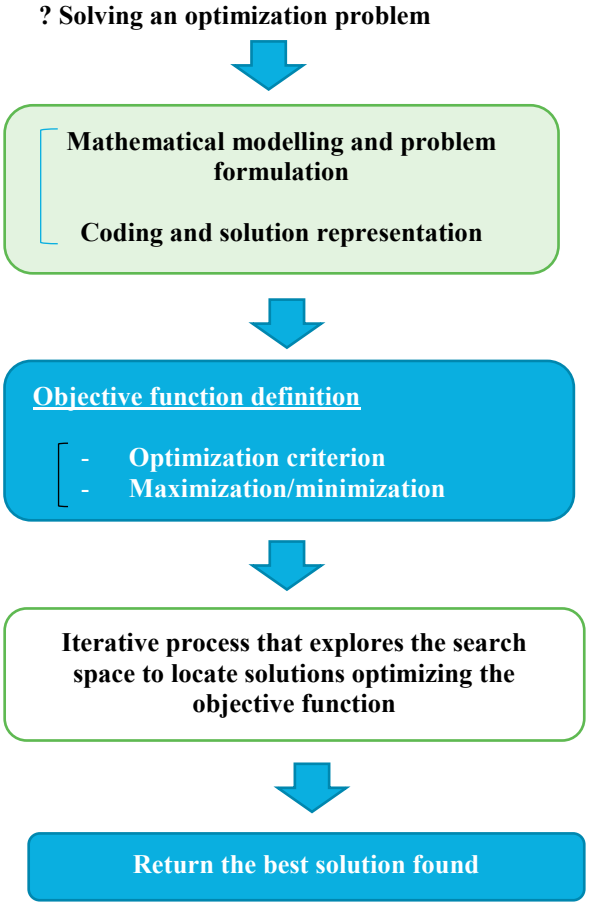

Figure 1 Main steps of a Meta-heuristic.

The meta-heuristics can be classified into two main categories: the single-oriented meta-heuristics and the population-oriented meta-heuristics. In the following, we present some well-known meta-heuristics techniques.

A. Single-oriented meta-heuristics
Here we present four well-known local search methods.

1) Local search based method
The local search method (LS) [2, 6] is a simple hill-climbing technique. LS starts with a randomly generated solution and tries to find better solutions in the current neighborhood. Neighborhood solutions are obtained by modifying one position from the solution vector. LS is an iterative process that should be repeated until a certain number of iterations called *maxiter*.

2) Stochastic Local Search
The Stochastic Local Search (SLS) is a local search meta-heuristic which has been applied with success to several optimization problem such as satisfiability and optimal winner determination problem (WDP) in combinatorial auctions [16].

SLS starts with an initial solution generated randomly. Then, it performs local steps that combine diversification and intensification strategies to locate good solutions.

- The diversification is the strategy of selecting a random neighbor.
- The intensification is the strategy for selecting a best neighbor solution based on objective function value.
- The diversification is applied with a fixed probability $wp > 0$ and the intensification with a probability $1 - wp$, where wp is probability fixed empirically.

The SLS process is repeated until a certain number of iterations *maxiter* is reached.

3) Variable Neighborhood search method

The variable Neighborhood Search (VNS) is a local search meta-heuristic proposed in 1997 by Mladenovic and Hansen [14, 21]. Various variants of VNS have been proposed since then, but the basic idea is a systematic change of neighborhood combined with a local search.

4) Tabu Search

Tabu search (TS) is a local search meta-heuristic. The method was proposed initially by Fred Glover in 1986 [10, 9]. TS starts with an initial random solution. Then, it tries to locate good solutions by applying iterative modifications on the current solutions. In order to avoid the local optima effectively, TS uses a list to store solutions already visited. This list permits the storage of solution trajectory which avoids local optima.

B. Population based method

. Unlike a local search method which works on a current single solution, an evolutionary method builds, maintains and evolves a set of solutions. Here we present three well-known evolutionary methods.

1) Genetic Algorithm

Genetic Algorithm (GA) is a population based meta-heuristic that starts with an initial population generated randomly [12, 15]. Then it applies reproduction operators to create new individuals for the next generations. The main operators in GA consist of selection, crossover and mutation. The selection identifies statistically the best individuals of population and eliminates the worse ones. The crossover takes two individuals called parents of the population and combined them to obtain a new individual called child. The mutation is an arbitrary modification in the individuals. The reproduction is the way in which the individuals combine and match during the reproduction phase. These operators permit to ensure a high degree of diversity in the population. The GA process is repeated for a certain number of generations fixed empirically.

2) *Scatter search (SS)*

The scatter search [11] is a population-based meta-heuristic like genetic algorithms. It is an evolutionary method which constructs solutions by combining others. The approach starts with an initial population (a collection of solutions) generated by using both diversification and improvement strategies, then, a set representing the best solutions (a reference set which includes both diverse and high quality solutions) is selected from the population. This collection of solutions forms the basis for creating new solutions by combining subsets of elements of the current reference solutions. Four methods are involved to achieve the scatter search template:

1) A diversification generation and reference set method which generates diverse solutions, then, improves them and selects the most elite and diverse to create the reference set of solutions.
2) An improvement method which is used in (1) and in (4) to enhance the quality of solutions.
3) A subsets generation method which creates new solutions based on deterministic of subsets of the reference set solutions.
4) A solution combination method which produces solution inside and outside of the regions spanned by the reference set.

3) Memetic Algorithm

Memetic algorithm (MA) is a hybrid genetic algorithm combined with some kinds of local search. MA is a population based meta-heuristic that was first proposed by Moscato [22, 23]. MA is a framework that combines the population based methods with local search methods. The population based method is used to ensure diversification

while the local search method performs intensification. MA can be obtained by combining for example a Genetic Algorithm (GA) and Local Search methods (LS, SLS, VNS, TS, or SA for example). The role of GA is to explore the search space and detect potential regions with good solutions. The role of the local search, in this case, is used to produce an effective exploitation on the potential regions obtained by GA. The local search is applied on the new individuals to improve their quality. As in GA, the MA process is repeated for a certain number of generations fixed empirically.

4. A summary on some important problems in 5G

Various complex problems are studied in 5G by using optimization techniques. The objective in general is to find an optimal configuration of the network with optimal parameters that ensures a good quality of services. Among these problems, we give a summary about the most popular ones:

Resource Management: Resource management (RM) in 5G networks is a crucial problem in 5G where the aim is to ensure a high level of the Quality of Service (QoS) of users. RM includes various issues in particular spectrum allocation, interference and power management and user association. Resource management in 5G is a difficult task due to the rapid increase in network demand. Several works have been proposed to handle this problem. Among them we cite those based on machine learning [8, 3, 27, 7, 25] and those using meta-heuristics techniques [13, 20, 29]. The objective here is to satisfy the QoS. For instance, authors in [31] give a performance analysis and optimization for non-uniformly deployed mmWave cellular network where the objective is to maximize the sum rate while satisfying quality of service (QoS) and power consumption constraints.

Energy Saving problem is another important problem in 5G. It consists in reducing the energy consumption of mobile communication networks 18, 28]. The objective is to find a good configuration of the network that minimizes the energy consummation.

Radio network planning and dimensioning is a core problem in cellular network: It includes coverage, capacity, and parameter planning [19, 26]. We note that nowadays there is a big growth in number of mobile users as well as the services demand. This number continues growing hence the need in increasing the network capacity and coverage in order to ensure a high the quality of service. In [24], authors give a study on coverage and rate analysis in the uplink of millimeter wave cellular networks.

Antenna positioning problem: also called antenna placement and localization that consists in selecting from a set of candidate sites, the best locations to install the base stations where the aim is to maximize the network coverage and to reduce cost (i.e. the number of stations to be used)[4].

5. Conclusion

In this paper we were interested in the fifth generation of cellular network. We gave main concepts of this new technology and presented the meta-heuristic techniques that may be used to solve complex problem in several domains in particular 5G cellular networks. We plan to propose a series of meta-heuristics techniques for resources management in 5G it is the aim of a future work.

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