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Research Article

Genetic Algorithm for Mode Selection in Device-to-Device (D2D) Communication for 5G Cellular Networks

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Abstract

The widespread use of smart devices and mobile applications is leading to a massive growth of wireless data traffic. With the rapidly growing of the customers' data traffic demand, improving the system capacity and increasing the user throughput have become essential concerns for the future fifth-generation (5G) wireless communication network. In a conventional cellular system, devices are not allowed to directly communicate with each other in the licensed cellular spectrum and all communications take place through the base stations (BS) and core network. Device-to-Device (D2D) communication refers to a technology that enables devices to communicate directly with each other, without sending data to the base station and the core network. This technology has the potential to improve system performance, enhance the user experience, increase spectral efficiency, reduce the terminal transmitting power, reduce the burden of the cellular network, and reduce end to end latency. In D2D communication user equipment's (UEs) are enabled to select among different modes of communication which are defined based on the frequency resource sharing. Dedicated mode where D2D devices directly transmit by using dedicated resources. Reuse mode where D2D devices reuse some resources of the cellular network. Outband mode where D2D communication uses unlicensed spectrum (e.g. the free 2.4 GHz Industrial Scientific and Medical (ISM) band or the 38 GHz millimetre wave band) where cellular communication does not take place. Cellular mode where the D2D communication is relayed via gNode B (gNB) and it is treated as cellular users. In this work, the target was to reach the optimal mode selection policy and genetic algorithm method was used with the objective of maximizing the total fitness function. Optimal mode selection policy was presented and analysed amongst cellular, dedicated, reused and outband mode. In the present study of mode selection issues in D2D enabled networks, genetic algorithm was proposed for the case when the cellular user equipment (UE) moves in the network. Quality of service (QoS) parameters, mobility parameters and Analytic Hierarchy Process (AHP) method were used to define the mode selection algorithm. To evaluate the performance of the proposed genetic algorithm, a study of the convergence of the algorithm and the signal-to-interference plus noise ratio (SINR) was done.

Keywords

D2D Communication, 5G Cellular Network, Mode Selection, Genetic Algorithm

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1. Introduction

The fifth generation (5G) wireless cellular systems promise to improve the existing technology according to the future demands due to increasing number of mobile users and demand for high data rate proximity services. The device-to-device (D2D) communication is a radio technology that enables devices to communicate directly with each other, that is without routing the data paths through a network infrastructure and had been envisioned as an allied technology of the 5G wireless systems for providing services that include video sharing and live data [1]. D2D communication technique opens new horizons of device centric communications that is, exploiting direct D2D links instead of relying only on cellular links. D2D communication is viewed as a technology for proximity-based data sharing services, making it a suitable technology for the future 5G networks.

The mobile communications sector has experienced an explosive growth during the last decades, both in the number of mobile subscribers and in the data traffic demands [2]. The dramatic increase in data traffic is mainly due to the proliferation of smart devices and the massive usage of mobile applications. As reported in the previous study, some 136 million 5G subscriptions were added globally between October and December 2022, bringing the total to just above one billion [3]. Going forwards, according to Cisco's Annual Internet Report (2018-2023) White Paper [4], nearly two-thirds of the global population has internet access in 2023. There is 5.3 billion total internet users (66 percent of global population) in 2023, up from 3.9 billion (51 percent of global population) in 2018.

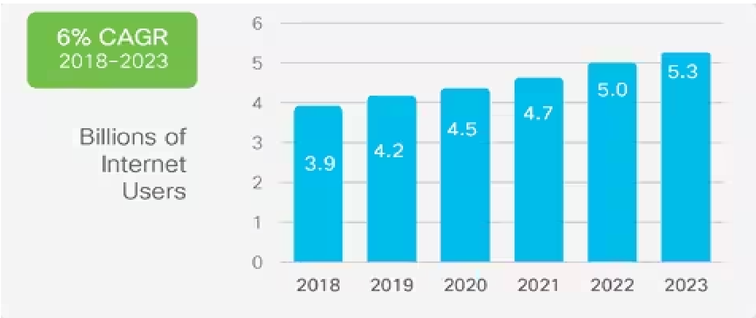

Figure 1. *Global Internet User Growth [4].*

The share of Machine-to-Machine (M2M) connections also grew from 33 percent in 2018 to 50 percent in 2023. There are 14.7 billion M2M connections in 2023.

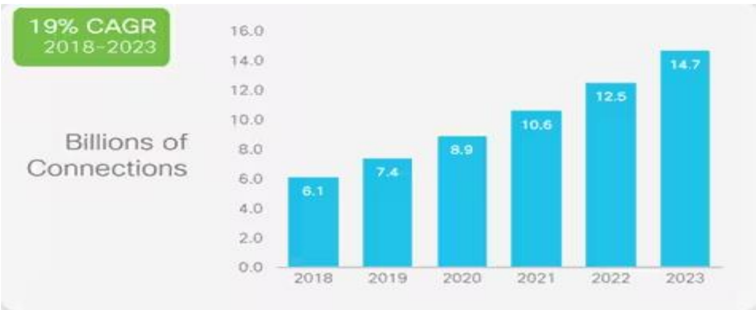

Figure 2. *Global M2M Connection Growth [4].*

In Cameroon, the use of smartphones has also grown exponentially in the space of a few years. Indeed, according to InverstirAuCameroun, access to high-speed mobile internet has increased significantly in the country from 18% to 39% in 2023 [5] and a total of 23.2 million cellular mobile connections were active in Cameroon in early 2023 [6]. Richer web content, increasing social networking applications, audio and, above all, video streaming are factors that will continue raising the amount of data traffic in cellular networks. In addition, the spread of wireless devices accessing mobile networks for new applications beyond personal communications (e.g. machine-type communication and wearable devices for home security, automotive, healthcare, etc.) are also contributing to the global mobile traffic growth. The need to support this traffic explosion is certainly the main challenge of the next generation cellular systems, referred to as the fifth Generation (5G). Therefore, in response to this rapidly growing demand for data traffic from users and the radio spectrum scarcity, the Device-to-Device communication technology (D2D) is proposed to reduce network latency and power consumption, improve the use of the cellular communications spectrum and the user experience for future fifth generation (5G) networks and expand network coverage.

In 2011, the 4G standards were finalized and networks were installed. The communities of mobile researchers are now directing their attention towards new innovative technologies in wireless communication, which is referred to as the next generation of cellular networks technologies: The Fifth Generation (5G) technologies [7]. Based on history, every generation lasts around 10 years and the next generation is born, it was predicted that 5G networks are going to be installed around 2020 [8]. The 5G network presents itself as the disruptive generation, the generation that is no longer interested only in the world of large mobile operators and public communications, but which opens up new perspectives and allows the coexistence of applications and extremely diversified uses, unified within the same technology. In June 2015, The International Telecommunication Union Radiocommunication Sector (ITU-R) defined three types of 5G applications. 5G will support enhanced mobile broadband (eMBB) for connection with ultra-high speed in outdoor and indoor with uniformity of quality of service, even at the edge of the cell, ultra-reliable and low-latency communications (URLLC) for ultra-reliable communications for critical needs with a very low latency, for increased responsiveness, and massive machine-type communications (mMTC) for communications between a large number of objects with varied quality of service needs to meet diversified service requirements of network capability extremism, network capability differentiation, and network convergence. Vehicle-to-vehicle (V2V), Machine-to-Machine (M2M), and Device-to-Device (D2D) are examples of application of massive machine type communication.

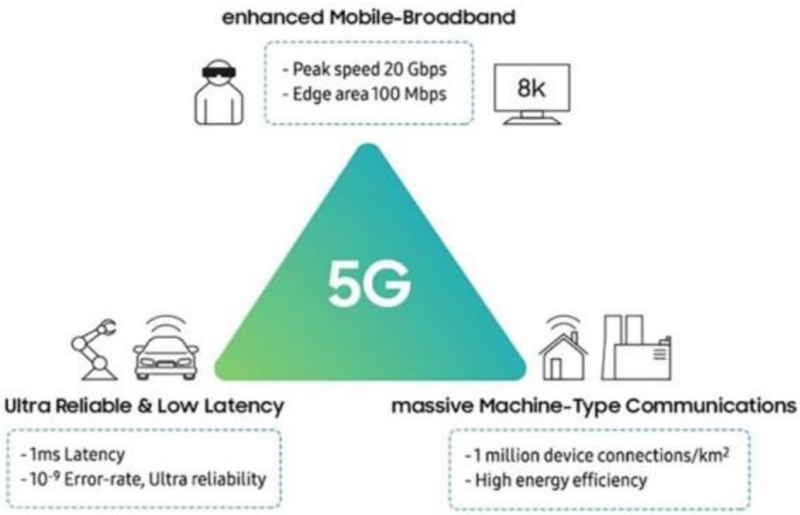

Figure 3. 5G Applications Types.

The idea behind D2D communication is not novel and several D2D based services already exist such as Bluetooth and Wi-Fi-direct. What makes D2D communication different is the utilization of the licensed cellular spectrum with QoS guarantees and seamless network detection [9, 10]. This new technology provides several benefits to both network operators and cellular users. On the user side, due to the close proximity feature of D2D communication, the D2D users will experience a high data-rate, low-latency, and energy-efficient communication link compared to the traditional communication link [9, 10]. From the network's perspective, D2D communication will help in better utilization of the cellular spectrum and increase the cell capacity without additional infrastructure cost. Moreover, D2D communication will bring new business opportunities to network operators with estimated revenue of 17 billion dollars as forecasted by the social networking service (SNC) research [11].

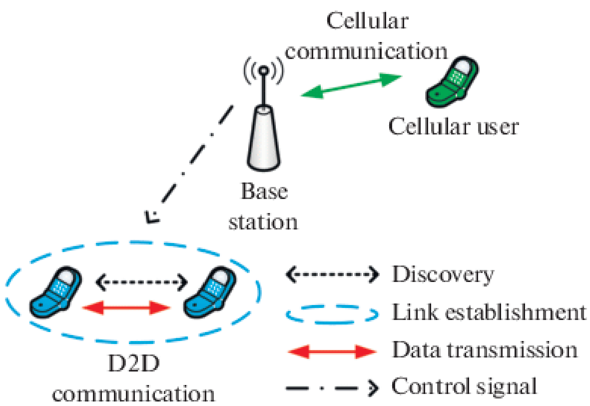

Figure 4. D2D Communication.

Despite the ambitions of D2D technology, several problems remain in its implementation. The main ones concern the synchronization of communications between terminals, the discovery of peers for communication, resource allocation, interference management, power management, QoS management, mobility management, billing, security and communication, mode selection [12]. In this work, we focus on solving the mode selection problem.

The mode that devices use to communicate between them is one of the most important issues of D2D communication since a suitable communication mode increases the throughput. Modes of D2D communications are categorized as following [13]:

1. Reuse mode (or Shared mode): D2D devices reuse some resources of the cellular network, thus the transmission is direct.
2. Dedicated mode: D2D devices directly transmit by using dedicated resources.
3. Cellular mode: D2D traffic passes through the base station (BS).

Accordingly, reuse mode improves the spectrum efficiency; dedicated mode and cellular mode reduce the complexity of interference management. Furthermore, D2D communication increases the overall throughput in cellular networks compared to D2D communication on cellular mode, which is the traditional communication between a cellular user and the BS.

In this work, we present the communication mode selection problem as nonlinear and limited by several nonlinear constraints and use the genetic algorithm to find an optimal solution. We chose as criteria to consider for the selection of a communication mode the QoS parameters such as throughput, delay, bandwidth, and the velocity of the user.

For our simulations we consider a single cell D2D enabled cellular network consisting of several D2D UEs (DUEs) and cellular UEs (CUEs) in which a gNB is at the center of the cell. We consider that the system is an Urban Micro System (UMi), presenting a small cell with a large user density and high traffic loads in a dense urban area. The initial mode of all users is the cellular mode and the users are walking according to the random waypoint mobility model. Only the DUEs can switch between cellular and D2D modes by selecting a communication mode at a constant time interval. To do so, we implemented a genetic algorithm taking the above-mentioned parameters as input and allowing each pair of D2D terminals to select the best mode for their communication. Thus, through simulations, we evaluate the performance of our proposed algorithm by studying the convergence of the algorithm and the SINR.

2. Review of Literature

In the following, a discussion on some works related to the work presented are done here, with emphasis on those investigating mode selection problems of D2D communications in cellular networks. Recently, a lot of research work has been proposed for mode selection of D2D communications under the required quality of services (QoS) constraints. A new game-theoretic mode selection algorithm for D2D UEs (DUEs) for D2D communications was proposed to maximize the total reward in the network within a single cell [12]. Here, each transmitting DUE is considered as a player capable of selecting the appropriate mode for its communication according to the quality of service (QoS) parameters and its mobility, while guaranteeing the QoS of the other network users. The proposed algorithm improves the spectrum utilization as the number of DUE pairs increases in the network but interference caused by the spectrum sharing also increases, limiting system performance. A probabilistic integrated resource allocation strategy and a quasi-convex optimization algorithm based on channel probability statistical characteristics were also proposed by others authors [14]. This strategy and algorithm guarantee D2D communication and maximized total system throughput while maximizing access. The analysis results showed that this algorithm can significantly optimize the total throughput of the system and reduce the communication interference between the users, which proved the rationality and efficiency of the communication model. A bee's life algorithm (BLA) for resource allocation and power control in D2D communications was proposed by BENBRAIKA et Al [15]. They considered a single cell in their system in an urban micro system (UMi). They formulated the joint resource allocation and power control problem with improving network throughput as their objective. To evaluate the performance of their BLA algorithm, they compared the convergence of their algorithm with the particle swarm optimization algorithm and genetic algorithm and showed that their proposed algorithm provides better results compared to particle swarm optimization algorithm and genetic algorithm with a slight difference with genetic algorithm. However as the number of D2D pairs increase in the network, the network throughput drops due to increase in interference between users.

3. Mode of Communication

The consideration was done on four D2D communication modes in this work, cellular, dedicated, shared or reuse and outband mode of communication. The following details the four modes of communication in D2D communication.

Cellular Mode

Cellular mode is where the D2D communication is relayed via BS and is treated as cellular users.

Dedicated Mode

The dedicated mode is where the D2D communication is direct and data is transmitted through the D2D link by the orthogonal frequency resources to the cellular users, so there is not any interference.

Reuse Mode (or Shared Mode)

Here, the data is transmitted through the D2D link by reusing the same frequency resources that are considered for a cellular user, so reused mode causes interference at receivers. However, the system spectrum efficiency and user access rate may be increased.

Outband Mode

Here, D2D communication uses unlicensed spectrum (e.g. the free 2.4 GHz Industrial Scientific and Medical (ISM) band or the 38 GHz millimetre wave band) where cellular communication does not take place. This eliminates interference between D2D users and conventional mobile phone users, although interference is still present from other electronic devices operating in this band (such as Bluetooth and Wi-Fi).

3.1. Quality of Service Parameters

The communication networks support a wide variety of services ranging from voice and data to multimedia services. The service quality requirements from these services are different. Some are sensitive to delays experienced in the communication network, others to loss rates, and others to delay variation. Therefore, the QoS concept is becoming an ever more critical issue in telecommunication [16]. The main QoS parameters considered in telecommunication networks are delay, throughput and bandwidth.

Delay

Delay is an essential parameter in telecommunication because the information should transit between two points and it takes time to reach another side. End-to-end delay or one-way delay is the total time that information is sent to the destination. The one-way delay from source to the destination plus the delay from destination to the source is called round-trip delay. In our problem, it is considered one-way delay for each connection, and we would like to minimize it. The following formula can be used to calculate the delay [12]:

$$d = \sum Ts + \sum Tp + \sum Tf + \sum Tt \tag{1}$$

Where:

$T_s = P/R$ is the serialization time. P is the size of the packet to be transmitted (in bits) and R is the transmission rate for the link (in bits/s);

$T_p = D/V$ is the propagation time. D is the distance between the two devices that wish to communicate and V is the average propagation speed in the propagation medium (V = 3*108 m/s in free air and in the optical fiber);

$T_f = Q/R$ is the average time spent in queue. Q is the queue depth (in bits). (When there is no daughter queue, Q = 0);

T_t is the average processing time by a network node.

It is considered that the time spent in queues and the time spent for processing by the different nodes of the network are negligible therefore ($T_f = 0$ and $T_t = 0$).

Bandwidth

Bandwidth management depends on the type of the service that the user is using and policy rules that are predefined to manage available bandwidth. The minimum (min) bandwidth, maximum (max) bandwidth, priority and parent designation are four parameters for bandwidth classes. The minimum bandwidth factor shows the guaranteed bandwidth for service and maximum bandwidth limits the amount of bandwidth for a kind of service also, the classes of services can be prioritized, and specific classes can receive bandwidth before others as well as prioritization and defining the bandwidth limits a class hierarchy should be used for. Class hierarchy determines classes' priority and the max or min bandwidth requirements.

Throughput

Throughput is the amount of data moved successfully from one point to another in a given time period. The overall throughput for each mode is almost equal to the network's overall. According to shanon's equation, the equation of the throughput, T is expressed as:

$$T(i) = B\log2(1+SINRi) \tag{2}$$

Where:

B is the available bandwidth;

$SINR_i$ is the signal-to-interference-plus-noise ratio of a communication mode i.

The SINR equation is given as follows:

$$SINR_i = \frac{PiGi}{\sum_{k=1}^{K} PiGi + WGN} \tag{3}$$

Where:

P_i represents the transmission power in a communication mode i, G_i is the channel gain of a communication mode i, k is the channel resource, and WGN is the White Gaussian Noise.

It is adopted the Urban Micro System (UMi), the same model used by BENBRAIKA [15] where the UMi presents a small cell with great user density and high traffic loads in a dense urban area, and follows the Rayleigh fading path loss model. Path loss is the weakening of power density while the wave spreads through space. The path loss model equation is given as follows [17]:

$$PLM = 36.7 log_{10}(d) + 22.7 + 26 log_{10}(F) \tag{4}$$

Where:

d means the distance (measured in meter) between sender and receiver and,

F is the communication medium frequency (measured in GHz). Thus, the channel gain between two UEs in a communication mode i is expressed as [18]:

$$Gi = 10^{-PLM/10} \tag{5}$$

The network throughput is the sum of cellular user's throughput and D2D throughput which is:

$$T = \sum_{1}^{nbc+nbD} Blog2(1 + SINRi) \tag{6}$$

Where:

nbc is the number of cellular users and nbD the number of

D2D users.

Subject to the following constraints:

$$P_i \leq P_{cm} \text{ for all i, with } 1 \leq i \leq nbc$$

$$P_i \leq P_{dm} \text{ for all i, with } nbc+1 \leq i \leq nbc+nbD$$

The two constraints specify that the transmission powers of Cellular Users and D2D pairs cannot exceed upper limits power P_{cm} and P_{dm}, respectively.

3.2. Mobility Model

In D2D communication, the UEs can be connected directly to other UEs or they can use the cellular transmission mode. If the UEs are independent of each other, the entity mobility model is defined for them. On the other side, if they are dependent on each other the group mobility model is defined for them [16]. Generally, for simulation the mobility models of the UE two factors are considered: speed and direction. After the T time or D distance, the UEs change the speed and direction (Hong, 1999) [16].

Random Waypoint Mobility Model: Random waypoint mobility model has pause time, it means that the mobile user before chooses the new speed and direction and has a constant pause time. If the pause time is set to zero this mobility model is similar to the Random walk mobility model. In this work, the random waypoint mobility model is considered because it is a mobility model widely used in the characterization of mobile Ad Hoc networks.

3.3. Analytic Hierarchy Process

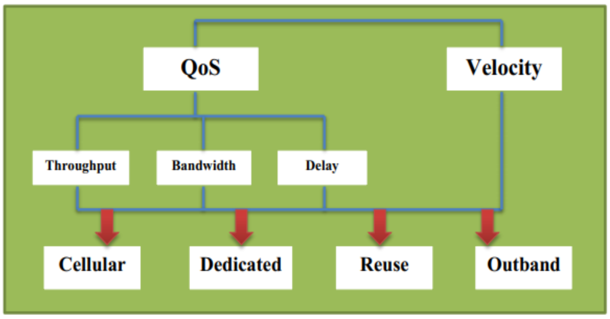

Figure 5. *Analytic Hierarchy Process.*

The Analytic Hierarchy Process (AHP) is a multi-criteria decision making. The AHP is a decision support tool which can be used when multiple and conflicting objectives and criteria are present. In this technique, the processes of rating alternatives and aggregating to find the most relevant alternatives are integrated. The technique is employed for ranking a set of alternatives or for the selection of the best in a set of alternatives. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives and it generates a weight for each evaluation criterion. In our case, the criteria and sub-criteria are QoS parameters and velocity of the user.

4. Genetic Algorithm

The bio-inspired algorithms are an effective optimization approach. The bio-inspired algorithms can solve any problems in the most efficient and optimized way. Bio-inspired optimization algorithm is an emerging method, which is based on the basics and inspiration of the biological evolution of nature to improve or to create new and strong optimization. One of those algorithms is the Genetic Algorithm, which is inspired by natural evolution. Many authors have used bio inspired algorithms to solve complex problem, Deussom and Tonye have used Particles Swarm Optimization Algorithm to optimize propagation model [19], the same authors have used Artificial Bee Colony algorithm [20], Social Spider Algorithm [21], Ion Motion Optimization Algorithm [22], Magnetic Optimization Algorithm [23], Genetic Algorithms [24] and many of those algorithms [25] to propose various solutions for propagation model optimization. Eric Michel Deussom et Al in [26], have also proposed the utilization of artificial bee colonies algorithm for load sharing in a cloud RAN. Similarly to these authors, genetic algorithms are used in this paper to solve the problem of mode selection in D2D communications in a 5G network.

4.1. Motivation

Mode selection problem is nonlinear and limited by several nonlinear constraints, which causes problems to solve it with traditional methods. Many solutions have been proposed to solve this problem and among those propositions, the bio-inspired algorithms provided low complex and better solutions such as Genetics algorithms (GA), Bees Life Algorithm (BLA) and Particle Swarm Optimization (PSO). A bio-inspired method is used because of its efficient properties like self-organization, autonomy, scalability and adaptation. Although every bio-inspired optimization algorithm has been designed in a generic way to deal with any optimization problem, each bio-inspired algorithm has its own particularities that make it a better choice over other algorithms to solve a specific problem. Genetic algorithms are a good choice in a general way as long as complex solution reconstruction methods do not have to be developed when obtaining infeasible solutions after applying evolutionary operators. They use a process of “evolution” to generate and evaluate a large number of candidate solutions, allowing them to search a large portion of the problem space. For those reasons, it is proposed to use the GA to solve the mode selection problem for D2D communication in 5G cellular networks.

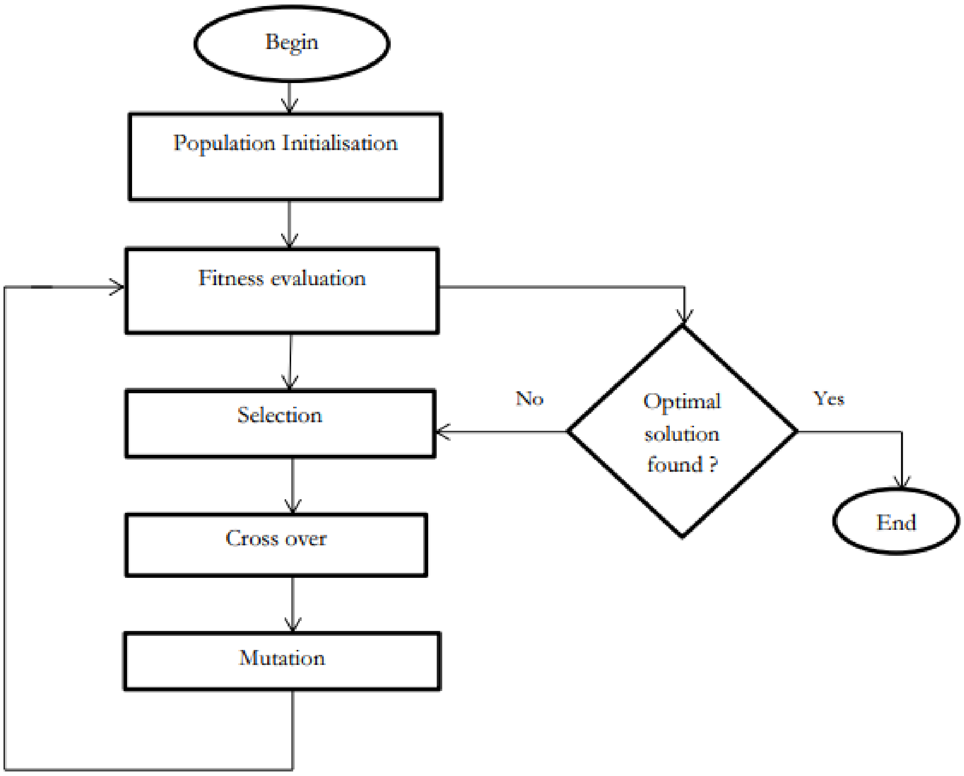

Figure 6. *Genetic Algorithm Flowchart.*

4.2. Flowchart

The genetic algorithm process for the selection of a suitable communication mode for a D2D pair is made according to the following flowchart:

Population Initialization

Population initialization is the first step in the genetic algorithm process. Population is a subset of solutions in the current generation. The initial population P(0), which is the first generation is usually created randomly. In our case, we randomly generate four individuals representing the four modes of communication.

Fitness Function

The fitness function determines how well each individual solves the problem. It assigns a numerical value or score to each individual based on their performance. The fitness evaluation guides the selection process and influences the probability of an individual being chosen as a parent. For the mode selection problem with maximizing the total fitness function as objective, the individual fitness function is expressed as follows:

Delay function: As the delay for a transmission mode *i* is *d* the delay function is defended as follow:

$$f\text{d}(i) = \begin{cases} 1 & if\ 0 < d \leq dmin \\ d_{max} - d/d_{max} - d_{min} & if\ dmin < d < dmax \\ 0 & if\ d \geq dmax \end{cases} \quad (7)$$

Where d is the delay for mode i and d_{max} and d_{min} are the maximum and minimum delay requirements.

Bandwidth function:

The bandwidth function for a transmission mode *i* is β and the bandwidth function is defined as:

$$f\beta(i) = \begin{cases} \frac{\beta - \beta_{min}}{\beta_{max} - \beta_{min}} & if\ \beta_{min} < \beta < \beta_{max} \\ 1 & if\ \beta \geq \beta_{max} \end{cases} \quad (8)$$

Where β_{min} and β_{max} denote the minimum and maximum bandwidth requirements of user.

Throughput function:

When the throughput for mode *i* is *T* the throughput function is defined as:

$$f\text{T}(i) = \begin{cases} 0\ if\ T < T_{THi} \\ 1\ if\ T > T_{THi} \end{cases} \quad (9)$$

Where T_{THi} represents the threshold for mode i.

Connection Dropping Penalty function:

The call dropping penalty function is defined as:

$$fV(i) = \begin{cases} \frac{V_{max} - \text{v}}{V_{max} - V_{min}} & if\ V_{min} \leq \text{v} \leq V_{max} \\ 0\ if\ \text{v} > V_{max} \end{cases} \quad (10)$$

Where the V_{max} and V_{min} are the maximum and minimum velocity thresholds of user and v is the current velocity of user. When the mobile user is moving fast the probability of dropping connection will be large so the connection dropping penalty function is defined based on this fact.

Handover function:

The handover function is defined as:

$$fH(i) = \begin{cases} 0 \; if \; RSRPmin \leq RSRP \leq RSRPmax \\ 1 \; else \end{cases} \quad (11)$$

Where $RSRP_{min}$ and $RSRP_{max}$ are the minimum and maximum reference signal received power respectively. We would like to reduce the unnecessary handover number so this function aims to do that.

Total Fitness function:

The total fitness function considers the functions that are defended for all parameters also the weights for each factors are added by using AHD method. The fitness function F(i) is computed as follows:

$$F(i) = W_d f_d(i) + W_\beta f_\beta(i) + W_T f_T(i) + W_V f_V(i) - f_H(i) \quad (12)$$

Where W_T, W_β, W_d, and W_V denote the corresponding weight of each attribute, obtained by AHP algorithm.

Selection Operation

The selection process in genetic algorithms involves choosing individuals from the population to become parents for the next generation. This process is typically based on the fitness of each individual, where fitter individuals have a higher probability of being selected.

Crossover Operation

Crossover is the process of combining genetic information from two parents to create offspring. In genetic algorithms, this is often done by randomly selecting a crossover point and exchanging genetic material between the parents' chromosomes. The resulting offspring inherit traits from both parents.

Mutation Operation

Mutation introduces random changes into the offspring's genetic material to maintain diversity in the population. It helps prevent the algorithm from converging to a suboptimal solution by exploring new areas of the solution space. Mutation typically involves randomly modifying certain genes or attributes of an individual.

Pseudo Code

The following pseudo code allows us to have a simpler understanding of the steps of our algorithm.

Inputs:

QoS parameters: (Delay; Throughput; Bandwidth)

EU position

Mobility parameters: VelocityUE

Output:

The best mode of communication for DUEs.

Begin:

GA(n, χ, γ)

// Initialise generation 0:

k = 0;

P_k = a population of n randomly-generated individuals;

// Evaluate P_k:

Compute fitness(i) for each i ϵ P_k;

do

{ // create generation K+1:

// 1. Selection:

*Select (1- χ) * n members of P_k and insert into P_{k+1};*

// 2. Crossover:

*Select χ * n members of P_k; pair them up; produce offspring; insert the ofspring into P_{k+1};*

// 3. Mutate:

*Select γ * n members of P_{k+1}; invert a randomly-selected bit in each;*

Evaluate P_{k+1}:

Compute fitness(i) for each i ϵ P_k;

// Increment:

k = k +1;

} while fitness of fittest individual in P_k is not high enough;

return the fittest individual from P_k;

where:

n is the number of individuals in the population;

χ is the fraction of the population to be replaced by crossover in each iteration;

γ is the mutation rate

5. Results

It is briefly described below the simulation tool used as well as the simulation parameters and setup.

5.1. Simulation Tool

The tool used for this simulation is the "*Matlab 2016a*" software installed in a "*Windows 10*" environment.

5.2. Simulation Parameters

The parameters are listed in the following table with corresponding values.

Table 1. *Simulation Parameters.*

Parameters	Values
Population Size	4
Number of Generation	100
Cross over Rate	0.8
Mutation Rate	0.2
Delay [min; max]	[0; 10] ms
Bandwidth [min; max]	[10; 100] MHz
Throughput [min; max]	[100; 1000] Mbits/s
RSRP [min; max]	[-95; -60] dB
Velocity [min; max]	[0; 10] m/s

5.3. Results and Discussions

The simulation is based on the objective of selecting the best mode of communication amongst the four modes of communication considered for a D2D pair in a 5G cellular network. To evaluate the performance of our algorithm, we first studied the fitness function of each mode after simulation and went further investigating on the convergence of the algorithm.

In our system, the values of the fitness function for a communication mode vary from 0 to 1 for a communicating pair of UEs. A communication mode with a fitness function of 1 would mean that the conditions are perfect for communication in that mode. This result is difficult to achieve in practice due to interference between the communications of each user, the movement of users, or simply power impairments caused by the distance between the pairs wishing to communicate.

5.3.1. Best Mode of Communication

Based on the input parameters (delay, throughput, bandwidth, velocity, RSRP) and after simulation of 100 generation, we obtain that the best mode of communication in this scenario for a D2D pair willing to communicate under 5G cellular network is the dedicated mode of communication. Figure 7 shows the best mode of communication after 100 generation.

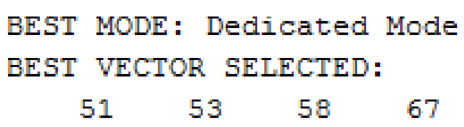

Figure 7. Best Mode of Communication.

5.3.2. Fitness Function Evaluation

To prove the pertinence of the result obtained on the best mode of communication, we investigated the fitness values of each mode of communication. The best mode of communication is the one having the highest fitness function showing that it is the fittest individual of the population. The equation below recalls the fitness function used to calculate the fitness values of each individual in the population.

$$F(i) = W_d f_d(i) + W_\beta f_\beta(i) + W_T f_T(i) + W_V f_V(i) - f_H(i) \quad (13)$$

Where W_T, W_β, W_d, and W_V denote the corresponding weight of each attribute, obtained by AHP algorithm.

AHP Algorithm

Step 1: Classification of criteria in terms of priority

Table 2. Classification of Criteria.

Delay	Bandwidth	Throughput	Velocity
80%	40%	30%	10%
0.8	0.4	0.2	0.1

Delay is 2 times as important as bandwidth;
Bandwidth is 4/3 times as important as throughput;
throughput is 3 times as important as velocity;
Delay is 8 times as important as velocity;
Delay is 8/3 times as important as throughput;
Bandwidth is 4 times as important as velocity.
Step 2: Pairwise comparison of criteria

Table 3. Pairwise Comparison of Criteria.

Criterion	Delay	Bandwidth	Throughput	Velocity
Delay	1	2	8/3	8
Bandwidth	½	1	4/3	4
Throughput	3/8	¾	1	3
Velocity	1/8	¼	1/3	1

Step 3: Calculation of the overall weight for each criterion
Calculate the total of each row

Table 4. *Total of each Criterion.*

Criterion	Delay	bandwidth	throughput	Velocity
Delay	1	2	2.67	8
Bandwidth	0.5	1	1.33	4
Throughput	0.38	0.75	1	3
Velocity	0.13	0.25	0.33	1
Total	2.01	4	5.33	16

Divide each entry by the total of its sum

Table 5. *Division by the Total of each Criterion.*

Criterion	Delay	Bandwidth	throughput	Velocity
Delay	0.5	0.5	0.5	0.5
Bandwidth	0.25	0.25	0.25	0.25
Throughput	0.19	0.19	0.19	0.19
Velocity	0.06	0.062	0.06	0.062

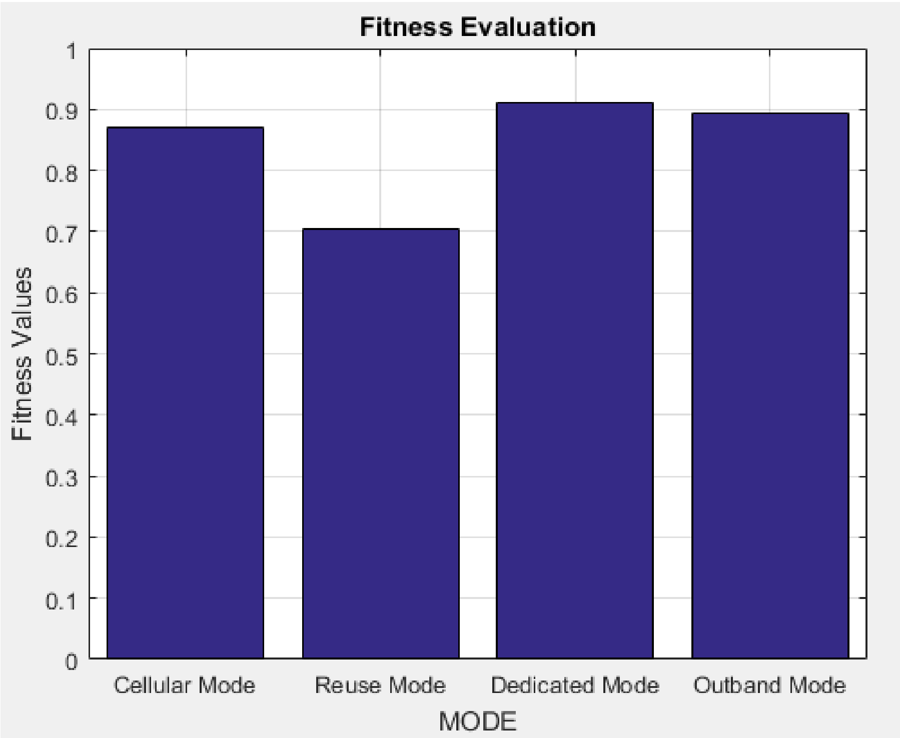

Figure 8. *Fitness Function Evaluation.*

Calculate the average of each row; this represents the final weight (priority vector)

***Table 6**. Total Weight of each Criterion.*

Criterion	Delay	Bandwidth	throughput	Velocity	Total weight
Delay	0.5	0.5	0.5	0.5	0.5
Bandwidth	0.25	0.25	0.25	0.25	0.25
Throughput	0.19	0.19	0.19	0.19	0.19
Velocity	0.06	0.062	0.06	0.062	0.061

The weight obtained from the AHP algorithm is used in the fitness function to calculate the fitness values of individuals in the population. Figure 8 shows that the dedicated mode has the highest fitness value hence, is the best mode of communication in this scenario.

5.3.3. Convergence of the Algorithm

The convergence is considered as a metrics of evaluation for iterative algorithms. An algorithm converges when it reaches the optimal solution and do not improve this solution for the next generations. Therefore, the best algorithm is the one that quickly reaches a state of convergence. Figure 9 shows the algorithm converges after 70 generation showing that after 70 generation, the algorithm obtained the optimal solution and hence prove the convergence of the algorithm.

We went further to optimize the performance of D2D communication in 5G by adjusting the delay, throughput and bandwidth values. Optimization by genetic algorithm makes it possible to find the best combinations of these parameters to maximize the SINR and improve the quality of communication. The code starts by defining the parameters of the GA optimization, such as population size, number of generations, mutation and crossover probabilities, and weights for the different variables (delay, throughput, and bandwidth). It also sets the initial delay, throughput, and bandwidth values. Then, the algorithm calls the ga_optimization function to perform GA optimization. This function takes into account the parameters defined previously and returns an optimized population. Next, the algorithm calculates the signal-to-interference plus noise ratio (SINR) for each individual in the optimized population. It uses each individual's delay, throughput, and bandwidth values to calculate signal power, interference and noise power, and ultimately SINR. The algorithm then displays the best delay, throughput, and bandwidth values found.

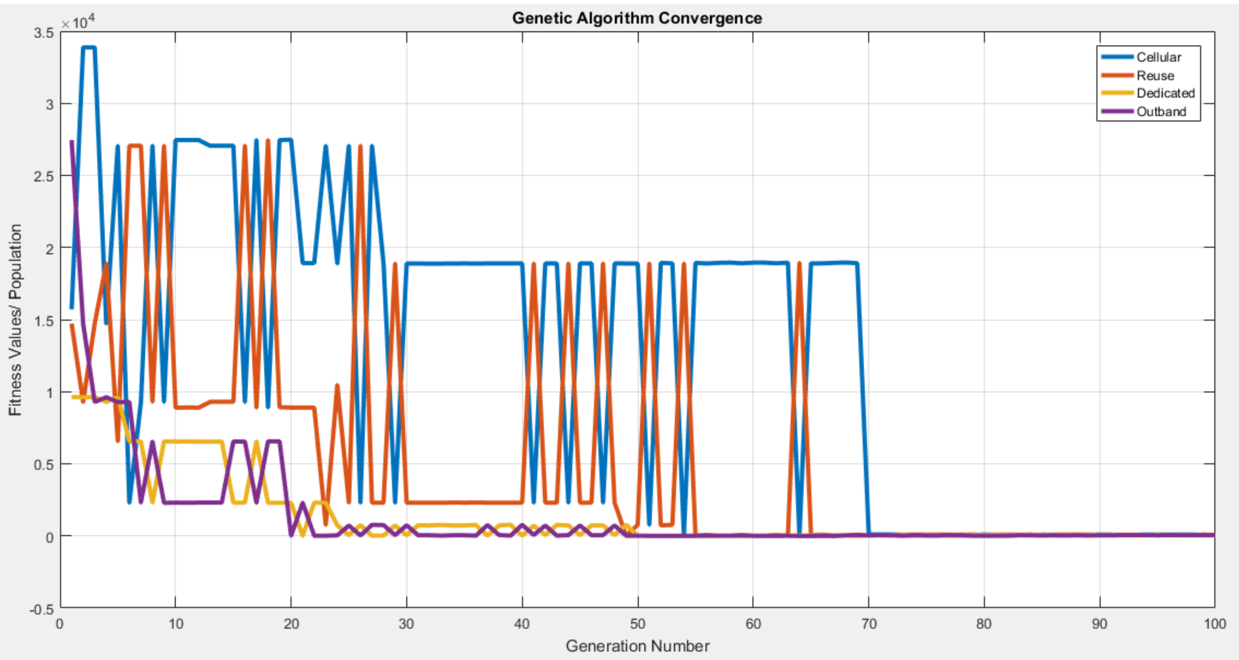

***Figure 9**. Convergence of the Algorithm.*

5.3.4. Variation of Delay, Bandwidth, Throughput of the GA Optimization

The figures below show the variation of delay, bandwidth and throughput as a function of the population parameter of the Genetic Algorithm (GA) optimization. Figure 10 shows that the delay of the optimized population varies between 0ms and 1ms compared to the initial delay that varied between 0ms and 10ms hence, proving the optimization of the Genetic Algorithm (GA).

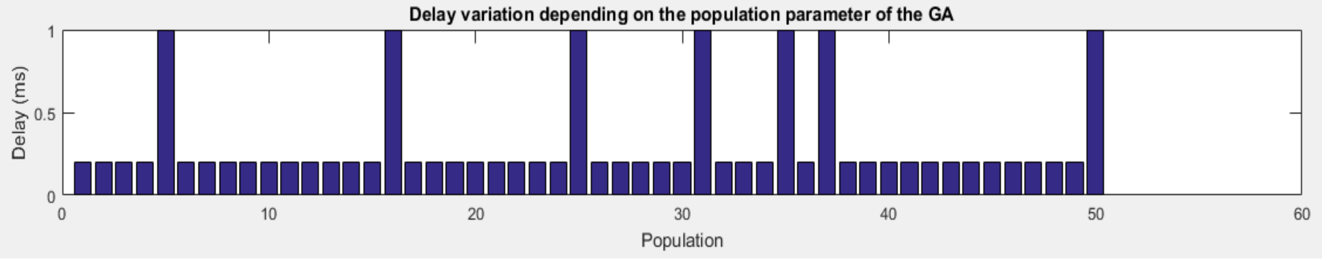

Figure 10. *Variation of Delay of GA Optimization.*

Figure 11 below shows that the bandwidth of the optimized population varies between 30MHz and 100MHz compared to the initial bandwidth that varied between 10MHz and 100MHz hence, proving the optimization of the Genetic Algorithm (GA).

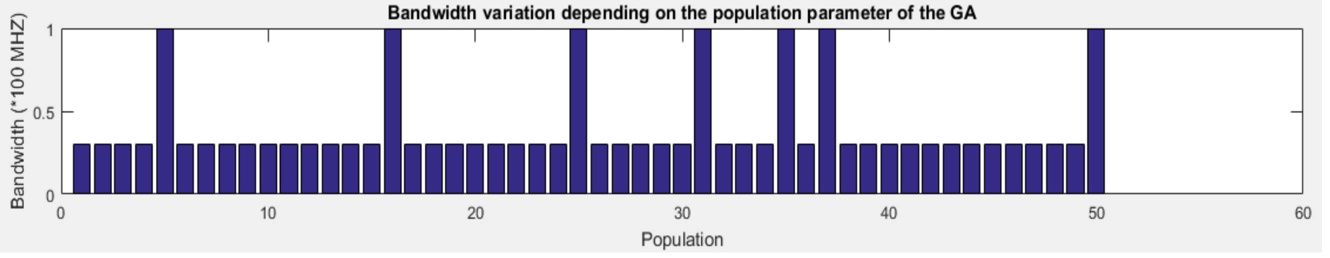

Figure 11. *Variation of Bandwidth of GA Optimization.*

Figure 12 shows that the throughput of the optimized population varies between 0.1Gbits/s = 100Mbits/s and 1Gbits/s = 1000Mbits/s compared to the initial throughput, it is seen that the throughput remains the same hence, the initial population offered the best throughput values.

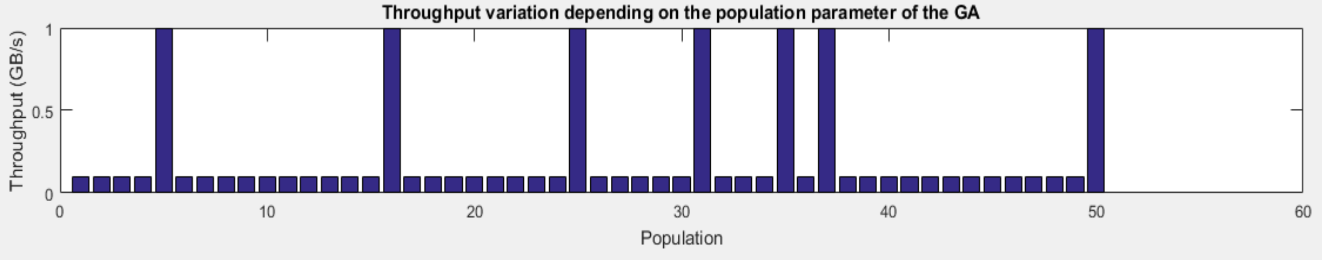

Figure 12. *Variation of Throughput of GA Optimization.*

5.3.5. Signal-to-Interference Plus Noise Ratio

SINR (Signal Interference + Noise Ratio) is the ratio of the signal level to the noise level (or simply the signal-to-noise ratio). The SINR value is measured in dB. It's simple: the higher the value, the better the signal quality. At SINR values below 0, the connection speed will be very low, since this means that there is more noise in the received signal than the useful part, and the probability of losing a connection also exists [27]. Figure 13 shows the different values of the SINR, which correspond to very poor (Cell Edge), poor (Mid Cell), good (Good) and very good (Excellent) signal quality.

RF Conditions		RSRP (dBm)	RSRQ (dB)	SINR (dB)
RF Conditions	Excellent	>=-80	>=-10	>=20
	Good	-80 to -90	-10 to -15	13 to 20
	Mid Cell	-90 to -100	-15 to -20	0 to 13
	Cell Edge	<=-100	<-20	<=0

Figure 13. *Comparison of SINR [19].*

From figure 13 above, an excellent signal quality has a SINR >= 20dB. Figure 14 below shows the SINR of the optimized population varies between 28dB to 29dB hence, proving the optimization of the Genetic Algorithm.

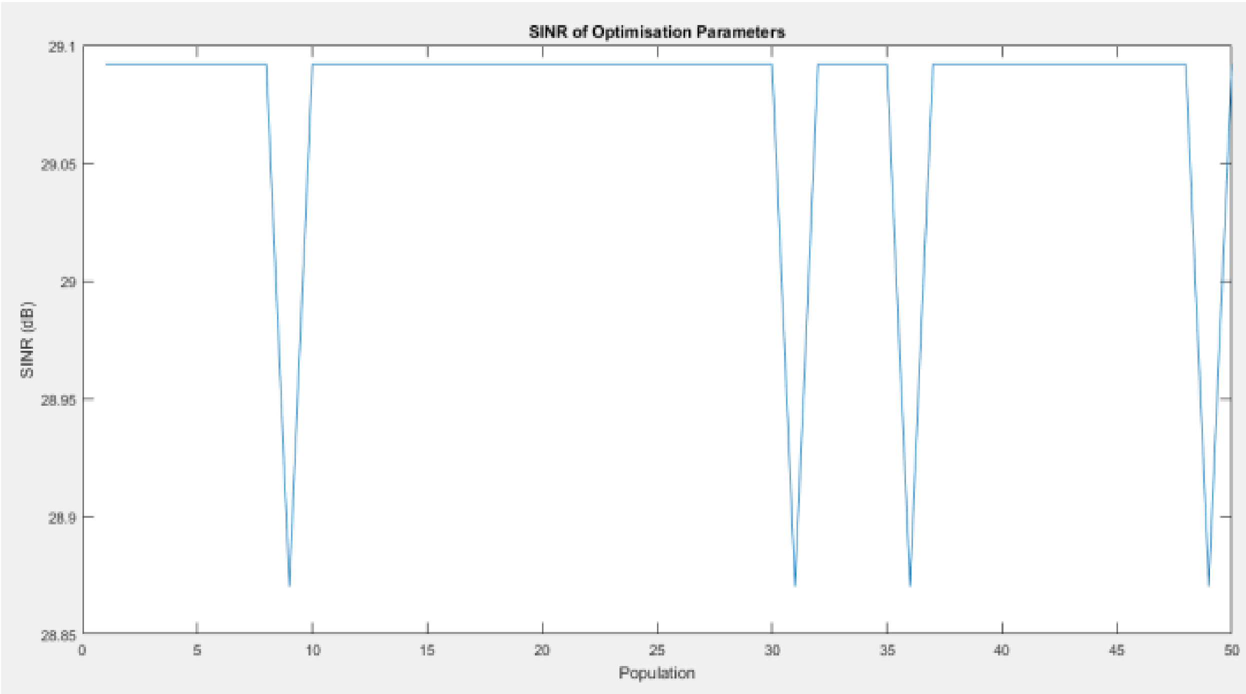

Figure 14. *Variation of SINR of Optimization Parameters.*

6. Conclusion

D2D communication is a key technology for 5G cellular networks and beyond (B5G). It promises to offload network core, improve network throughput and expand cell radius. One of the most important challenges facing D2D communication is mode selection. In this work, we focused on solving this problem for D2D communication in 5G cellular networks. It was perceived that the mode selection problem is nonlinear and limited by several nonlinear constraints, which is not easy to solve with traditional methods. Therefore, a proposition was presented for the use of Genetic Algorithm (GA) to solve the problem for D2D communication in 5G cellular networks. The GA is a bio inspired algorithm based on natural evolution. D2D terminals in the scenario we studied can choose between cellular, dedicated, shared and outband mode. After having selected and defined the parameters to be taken into account in the selection of the communication mode, our approach consisted in defining a fitness function and in using the formalism of the genetic algorithm so that the DUE chooses the most appropriate mode for its communication. An investigation related to the performance of our proposition was done by studying the total fitness function of each individual (mode of communication) after 100 population generations and realized that the dedicated mode offered the best mode of communication. Next, the convergence of the proposed algorithm was investigated and it was shown that GA algorithm does converge after 70 generations. We went further optimizing the performance of the D2D communication by adjusting the values of the delay, bandwidth and throughput and maximizing the signal to interference plus noise ratio (SINR) and showed that the optimized population presented better results.

Conflicts of Interest

The authors declare no conflicts of interests.

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