

Original Article

Loader and Tester Swarming Drones for Cellular Phone Network Loading and Field Test: Non-stochastic Particle Swarm Optimization

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ABSTRACT

Cellular network operators have problems to test their network without affecting their user experience. Testing network performance in a loaded situation is a challenge for the network operator because network performance differs when it has more load on the radio access part. Therefore, in this paper, deploying swarming drones is proposed to load the cellular network and scan/test the network performance more realistically. Besides, manual swarming drone navigation is not efficient enough to detect problematic regions. Hence, particle swarm optimization is proposed to be deployed on swarming drone to find the regions where there are performance issues. Swarming drone communications helps to deploy the particle swarm optimization (PSO) method on them. Loading and testing swarm separation help to have almost non-stochastic received signal level as an objective function. Moreover, there are some situations that more than one network parameter should be used to find a problematic region in the cellular network. It is also proposed to apply multi-objective PSO to find more multi-parameter network optimization at the same time.

Keywords: Particle Swarm Optimization; Swarming Drone; Cellular Network; Radio Optimization; Loaded Network Test

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1. Introduction

Cellular networks have been growing rapidly over the last few decades. This technology is exceptionally beloved these days because people can be connected as they move around anyplace. Wireless communication was developed even before cellular networks, but radio communication always suffers from resource limitation (frequency spectrum as the main resource). Resource limitation was the main motivation to propose resource reuse in cellular networks^[1]. For example, if a frequency band is used in a certain cell in the cellular network to cover a particular area, it also can be used in another cell which is farther in the distance from the first one. The idea of resource reuse helps to increase the number of users being serviced. This idea of resource reuse is the main difference between cellular network technology and other radio networks. However, this adds to the complexity of fine-tuning of the network to achieve high-performance cells. The reason is that radio interference can decrease the quality of service in these networks. First-generation cellular networks started in the 1980s as analog radio communication. Later on, the 2G network was commercially launched around the

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1990s. 2G networks deploy frequency division for digital communication and are able to provide SMS, MMS services, and low-speed internet. Developed in the 2000s, 3G networks make use of spreading codes as main resources to reuse and can provide higher speeds than those of 2G networks^[2].

There is also 4G network started in 2008 which uses the Orthogonal Frequency Division Multiplexing (OFDM) to increase the bandwidth. OFDMA based radio access networks need frequency synchronization and channel estimation similarly to the other classic radio links^[3]. 4G networks cover more areas because they are more resistant to multipath fading channels and interferences. The 5G network has also been evolving very fast recently^[4]. They deploy millimeter waves and can provide more than one Gigabits per second. Further, there are more technologies added to the 5G network

which make it capable of providing faster speeds to the users such as massive Multiple Input Multiple Output (MIMO) and radio wave beamforming⁴. **Figure 1** shows the 2G/3G/4G network architecture. As it is indicated in this figure, cellular radio access and core are the two main parts of each network architecture. The 2G network uses Base Station Controller to transfer the phone traffic and Serving GPRS Support Node to transmit the user data traffic. It is almost the same for the third-generation network, however, the 4G network uses the Mobility Management Entity (EMM) to transfer both phone calls and users' data traffics.

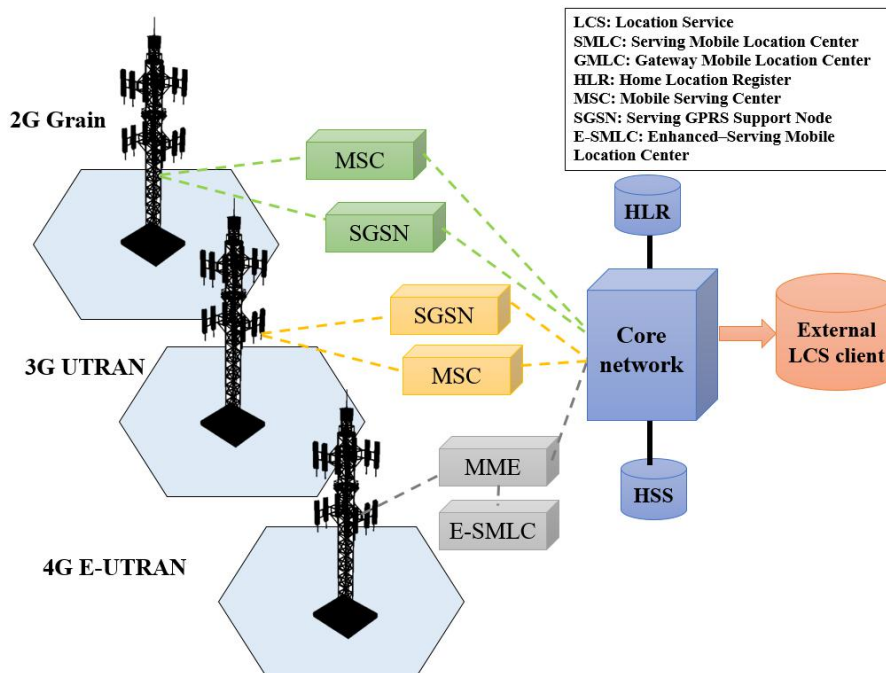


Figure 1. 2G/3G/4G cellular network architecture.

One of the most important techniques employed in all of these networks is scanning the covered area to tune and optimize the network parameters. This optimization helps to provide better coverage and higher speeds and higher capacities to the users. Network management tools can provide a network measurement called Key Performance Indicators (KPI) which can include user signal levels, user signal quality, number of call requests, number of rejected call requests, number of dropped calls,

and many more KPIs. There are also some ideas to add some more capabilities to every cell-base stations in order to capture the signal interference^[5-10]. To some extent, this idea helps to improve the performance of the network. In addition to all measurements that the network management and enhanced radio interference detection provide, scanning and testing the RF field is still a crucial test to find the gaps and interference between cells and other deficiencies in the

field. The effects of electromagnetic field on critical devices such as medical equipment is also another significant issue which makes the RF field measurement as a required test. Mariappan *et al.* reviewed the effects of electromagnetic interference of 2G/3G/4G cellular phones on the functionality of medical equipment^[6].

As previously noted, RF is a very common test that every network operator regularly deploys to find more information about the areas being covered. Network expansion is also another major aspect of the cellular network which occurs periodically. This periodical network expansion makes the regular network tuning and

RF test a required task of a network test engineer. **Figure 2(a)** shows a test vehicle equipped with tools to drive around and capture the signal strength, quality and many other parameters of a particular cellular network^[9]. The very first devices employed for this purpose are more complex. They need an external GPS, a laptop, and a phone connected together to capture the signal and location^[11]. The captured signal parameters are plotted on the map as the output results. Nowadays, it is possible to have all of them in only one tablet^[12]. **Figure 2(b)** and **2(c)** show a sample output plotted on the maps to demonstrate the captured information.

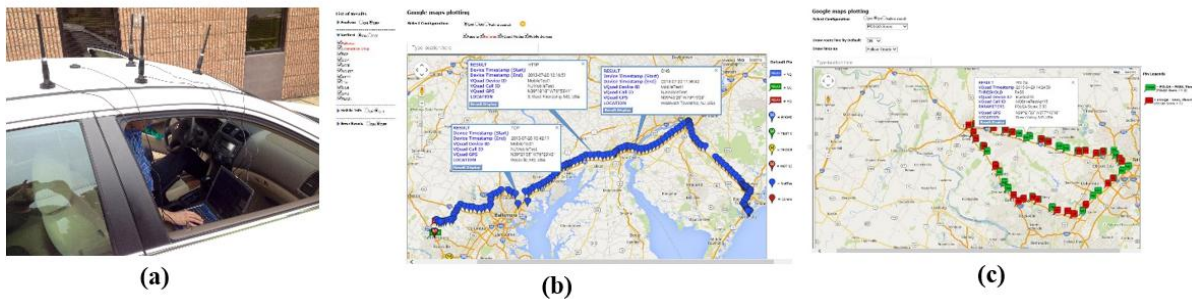


Figure 2. Sample required devices, (a) drive test car, (b and c) two sample output results.

Although the driving test provides a lot of information in different network situations, there are still problems with this method which need to be addressed^[9]. These problems are described as follows:

First and the most important problem with today's drive testing systems is that it is impossible to simulate the crowd and load the network while testing. Network loading is very important in capturing the crowd effect in radio networks because radio networks behave differently when they are loaded. Sometimes cell radio coverage shrinks when it is loaded and as a consequence, the gaps between cells will grow. The crowd can always affect cellular radio network performance. Classic test vehicles are individual units going through the network and testing the radio network quality, which means testing the network when it is not fully loaded. Therefore, it will be a great achievement if the network operator can have some loaded radio network tests by swarming drones that are capable of crowd simulation. Using swarming drones, it is possible to simulate this situation and load the network to test.

Also, the drive test method is very time consuming in particular for testing inside large buildings, such as

theaters, stadiums, or congested streets. This vehicle involving method also needs to use numerous setup devices, to schedule the tester experts and sometimes to coordinate with the police department in order to be able to drive around the city with all testing tools installed on it.

Moreover, it is impossible to deploy this test method in mountainous or inaccessible areas. There are some areas that are not easy to drive through and test. Mountainous areas are sometimes very crowded because many climbers and skiers are present and they need to be connected via their phone network in multiple areas of the mountain. Additionally, it is not easy to cover blind zones using the driving test. There are many cases that people like to gather in certain places, such as national parks and other recreational places. Moreover, the Internet of Things (IoT) devices are growing very fast and these devices are mostly installed in inaccessible places. For example, they are most commonly installed on top of tall towers, traffic lights across the street, etc. Drones can help to test the cellular phone coverage and quality in this type of areas in much less time compared to testing vehicles.

Besides network providers, network device manufacturers and researchers need to have coverage and throughput test of the cell they are operating on. Therefore, drones carrying (or simulating) some network handsets are significant tools to simulate a real crowd and congested traffic for the individuals evaluating the network quality.

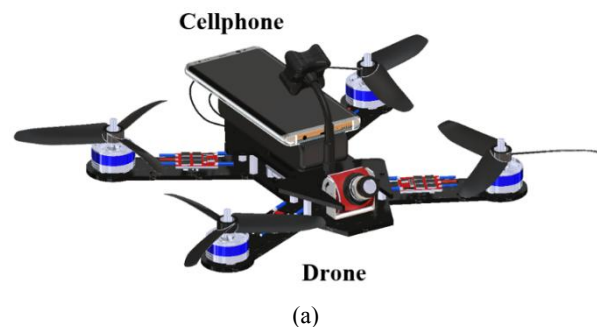
2. Equipped drones with network test handset to load the network and RF test

Over the past recent years, autonomous aerial vehicles have been growingly drawing attention and broadening their spectrum of specifications^[13-16]. Ranging from unmanned air vehicles (UAV) to smart dust, these flying robots can feature sophisticated equipment and functionalities^[13]. UAV drones are larger drones with more powerful engines that can fly for thousands of kilometers^[13,17]. Depending on their dimensions and configurations, they can operate in open-air or confined spaces then the size and the type of installed equipment differed consequently^[18]. Various cameras and other equipments can be mounted on them to assist with image acquisition or sensing other signals in different environments. Special sensors can enable them to detect biological, nuclear, chemical, radio and electromagnetic waves or other signals or threats. Different missions can change the requirements that drones have to meet including aerodynamic capabilities, functionality in hovering, high endurance, rapid maneuverability, and durability in collision with obstacles.

Drones can find a wide range of applications in civil or military missions^[13]. Their applications can be classified based on the flight environment (underwater, atmosphere, or space) or type of flight zones (outdoor/indoor)^[13]. Exceeding two hundred applications in our day to day activities in the near future, new developments in the drone industry are increasingly introduced^[19]. The missions assigned to them can be rescue operations, mail delivery, environmental protection activities, oceanic studies, quality inspections and planetary explorations^[20,21]. Performing mission with one single drone might be risky because it is always

possible to have a failure in a drone engine, navigation system, etc., or to encounter a predator attack. Therefore, the swarming drone idea is proposed to overcome this shortage. The main advantage of the swarming drone missions is that if one of the drones fails, there will be other drones to continue the mission^[22]. Some recent intelligence is devised to make autonomous swarming inspired by nature^[23]. Further, swarming drone can reduce the mission required time. For example agricultural swarming drones which are working to seed, spray or monitor a farm can perform the job much faster than individual.

Guidance, Navigation, and Control (GNC) system of the drones is another topic that has been researched recently^[13,24]. There are mechanisms that have been proposed, such as flight controllers, autopilots, and path planning algorithms to guide, navigate and control the drones^[25]. In other words, GNC can be divided into three classes as radio control, video-assisted control, and autopilot^[24]. The common characteristic of all GNC methods is that they need to contact the radio station to send and receive some data to navigate. **Figure 3** shows two different types of drones designed for the swarming cell phone testing systems. **Figure 3(a)** is using an actual cell phone handset which is ready to use but not very efficient in our testing scenarios. The reason is that the cell phone handsets are heavy to use; therefore the carrier drone cannot endure for a long time. Besides, a larger drone to carry a cell phone handset is more problematic and distracting to use in urban area networks. Hence, **Figure 3(b)** is designed to carry a minimally functional system which is an electrical board to use a Sim Card to connect to the network. This board is able to do the handset functionality without extra parts such as a big screen which consume too much power.



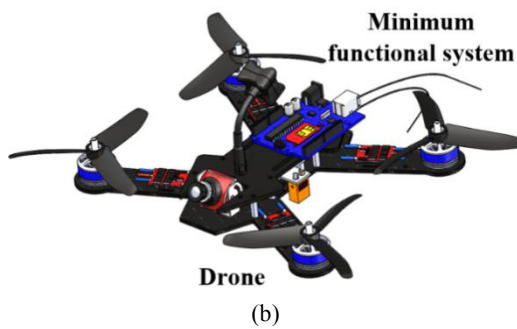


Figure 3. Designed drones for swarming flight; (a) carrying a cell phone for measurement and (b) carrying minimum functional system

3. Proposed methodology for loading and testing the RF

As discussed before, deploying the swarming drone

in cell phone network areas helps to load the network and then scan the network performance. **Figure 4** demonstrates how swarming drones can be used to load the cell phone network to test the network under more realistic conditions. Nowadays, network field drive tests are more individual testing which is not very realistic due to the changes in the network performance. These changes happen because of the receiving more user connection request and the traffic transmissions through the radio. In **Figure 5**, Loader and tester swarming drones are playing the role of the users to load and tester to test the network. As it is shown, the victim drone gets interference noise from base stations (BS1 and BS2) and from other drones. As the number of drone increases, then victim drone will suffer more and receive lower quality services.

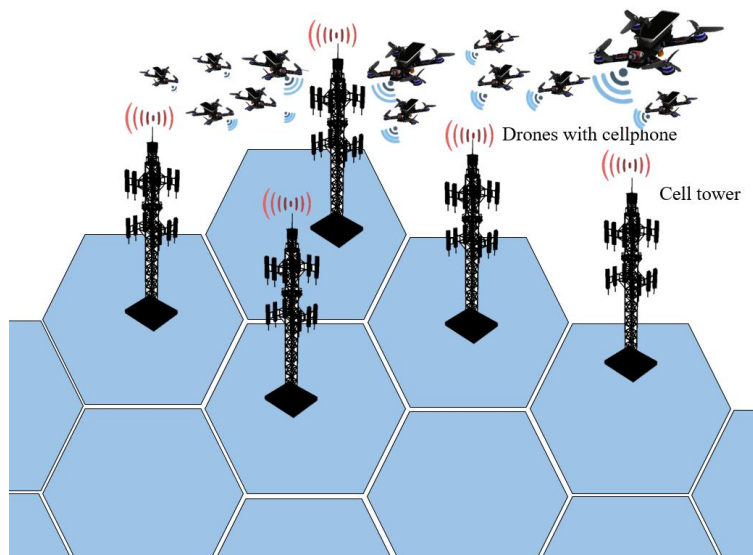


Figure 4. Loading cellular network using swarming drones to test the network in a loaded situation.

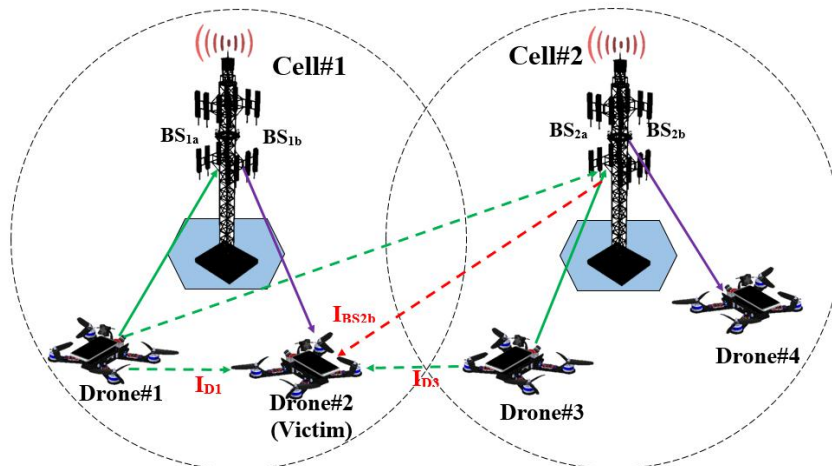


Figure 5. Victim drone affected by more users and network load.

4. Particle Swarm Optimization (PSO)

Sometimes applying multiple drones to perform a defined mission is more efficient than having one drone^[26-30]. The flight of multiple drones which is inspired by nature is called swarming. Swarming drones can be used to load the network without any burden on network users^[31]. They also can be used to scan the network performance. However, swarming drones navigation in cellphone area to find the performance of the system is another time consuming and challenging issue. Therefore, it is a good idea to apply the particle swarm optimization (PSO) mechanisms on swarming drones. Thus, the swarming drones can be programmed to be automatically navigated to find the problematic

regions. In PSO, there are some particles interactively working together to find the maximum or minimum value of an objective function. **Figure 6** demonstrates the PSO flowchart. In swarming drone network testing, each drone can play the role of one PSO particle. Then the testing swarming drones system can move and converged to the problematic region. Swarming drones can load the network and scan the performance of the network while it is loaded. Cell phone radio access networks have very different key performance indicators that effect on user service qualities. In some cases, performance improvement is about optimizing only one parameter as an objective function. For example, finding the low coverage region means using the Rx level as an objective function and try to find the minimum value of it.

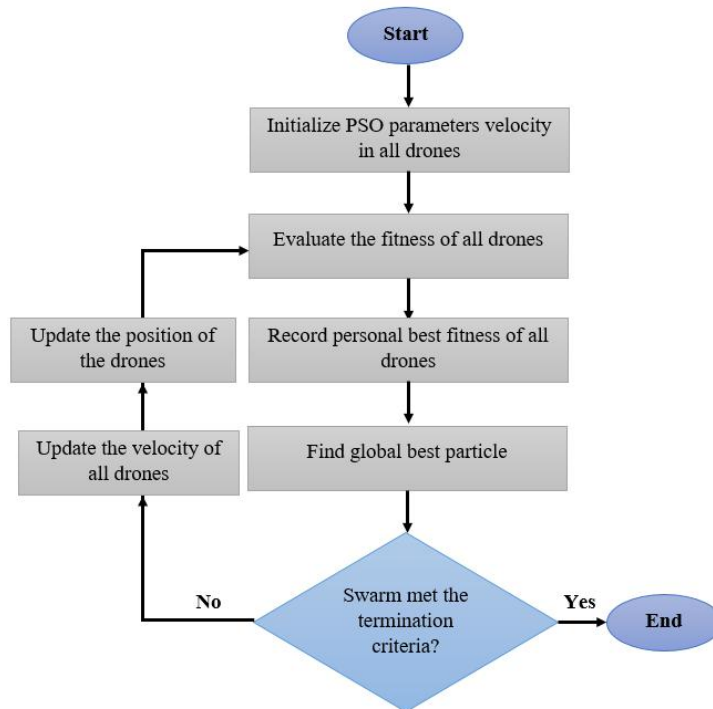


Figure 6. Swarming drones optimization flowchart.

There have been different methods to find the optimum value of an objective function. In some applications, it is possible to use derivation to find the optimum value. Practical applications have more complex objective functions, in some cases it is not possible to use mathematical derivation to find the optimum value. Therefore, some meta-heuristic methods are devised to find the optimum point of the complicated objective functions. Particle swarm optimization is one of these meta-heuristic methods. In PSO agents measure

their objective values and communicate with each other to navigate towards the optimum values. In swarming drone loaded network optimization, the drone can communicate to find low-performance regions such as regions which are not properly covered and regions where there is high interference.

The objective function in cell phone testing and optimization application is the received signal level. This can be captured through the sensors that will be installed on swarming drones. Objective function is an identical

term as the cost function in PSO literature. Therefore, in this paper, there are some cases in which, objective function also called cost function. Every optimization techniques have a pre requirements to consider for the objective and constrain functions. In PSO optimization technique, non-stochastic objective function is the main requirement because too much fluctuation of objective function will degrade the PSO results. There are many research papers published to present the modified version of the original PSO technique in order to be able to run on stochastic objective function. Averaging possible outcomes, deploying the expected value of the objective function are the two techniques to address some stochastic objective functions and constrains^[32]. In our problem, we deploy the loading swarm, not only to load the network but also to minimize the stochasticity of the objective function. The network receive signal level can be stochastic because the number of users increase or decrease randomly. However, when we load the network using the loading swarm there will be no increase or decreasing users then received signal level can be considered as deterministic function. Moreover, boundaries or the optimization constrains are another major factors in PSO optimization. However, in our optimization problem, boundaries of objectice function are not a real concern because high load cells (or overloading) always happen in crowded city centers. In these places, there is no lack of signal coverage problem.

Figure 7 shows how swarming drones can fly around a cellphone network try to load and find that problematic regions in that specific part of the network. **Figure 7(a)** indicates how Rx level changes around four cell phone towers and how this Rx level can be used as an objective function. **Figure 7(b)** shows the contour diagram of the Rx level of the same region. Another significant advantage of PSO is used not only for single-objective optimization but also for multi-objective optimization as well which will be discussed in section IV.

In the current optimization problem, particles are seeking the optimum location in the 2D search space. The location of the i^{th} drone is represented as^[33]:

$$X_i = (x_{i_Lat}, x_{i_Long}) \quad (1)$$

The best position of i^{th} particle is represented as:

$$P_i = (p_{i_Lat}, p_{i_Long}) \quad (2)$$

Velocity of the particle is expressed as:

$$V_i = (v_{i_Lat}, v_{i_Long}) \quad (3)$$

The index b is used to represent the best particle among all the particles in the population. Then each particle and its velocity will be updated in each iteration as:

$$V_{id} = V_{id} + c_1 \times rand(*) \times (p_{i1} - x_{i2}) + c_2 \times rand(*) \times (p_{bd} - x_{bd}) \quad (4)$$

$$x_{id} = x_{id} + v_{vd} \quad (5)$$

where c_1 and c_2 are two positive constants, $rand(*)$ are a random function and d is the iteration number.

Inertia weight is used in PSO to find a balance between global and local search; therefore, after modifying the Eq. (4) with weight, we have:

$$V_{id} = w \times V_{id} + c_1 \times rand(*) \times (p_{i1} - x_{i2}) + c_2 \times rand(*) \times (p_{bd} - x_{bd}) \quad (6)$$

It should be noted that in the above equations the capital variables are vectors.

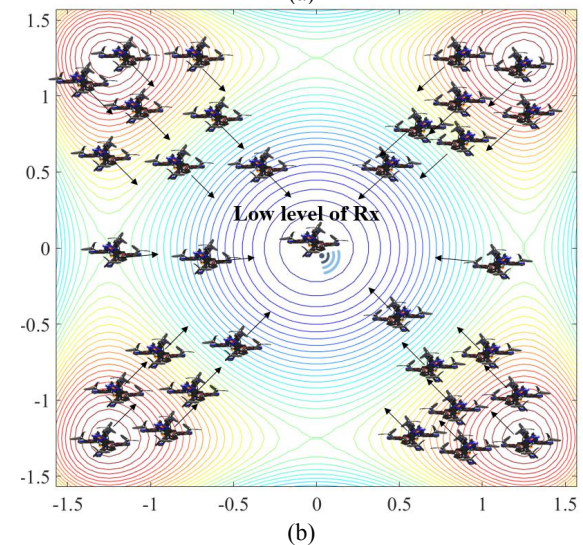
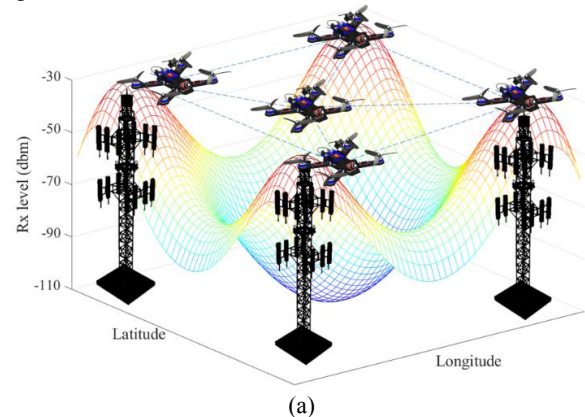
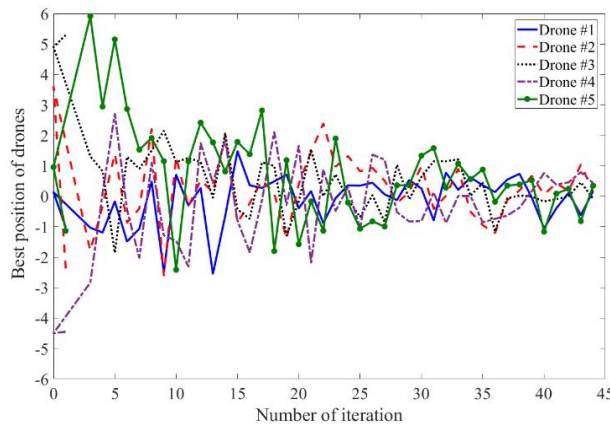


Figure 7. Views of (a) Particle swarm optimization of swarming drones for Rx level testing and (b) Rx level contour view.

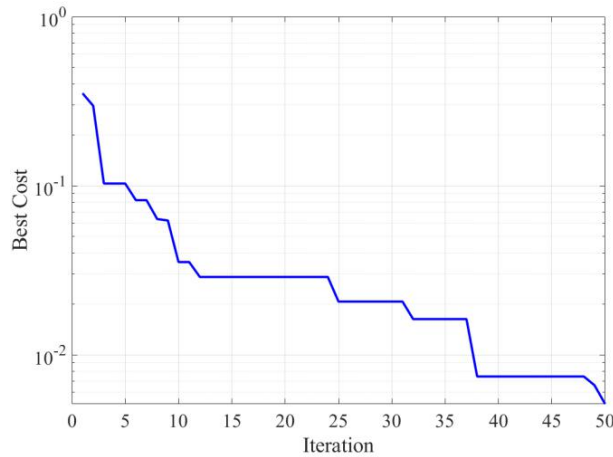
Deploying PSO needs a lot of iterations to make sure the output can be converged in very fine grain steps. For example, in PSO literature, it is shown that deploying fifty particles in a thousand iterations can be converged to a fine grain optimum point. However, in this paper, a simulation scenario with only five drones and fifty iterations are conducted in the spherical surface which is mostly similar to the middle part of Figure 7(a). Considering the physical size and dimension of a drone, it is not easy to increase the number of drones. Increasing the number of drones is distracting for the public and

could be not secure to implement. Therefore, the main objective of this paper is to present the idea and demonstrate the effect and results of PSO performing on limited number of drones (five) and iterations (fifty). Additionally, it is not required to have very accurate result (like ten decimal value) in our problem.

Simulation results in **Figure 8** demonstrate that swarming drone optimization can also converge to an optimum point and it can reach close to the optimum values. **Figures 8(a)** and **8(b)** show the best position of the drones, and best cost in each iteration respectively.



(a)



(b)

Figure 8. View of (a) best positions of the drones and (b) best cost based on the number of iterations.

5. Multi-objective PSO deploying in swarming drones

In our cellular networking scenarios, there are cases that external interferences are affecting on quality of the service in addition to intra-network interference performance problems. For example, when external interference happens in a specific region then Rx_{Level} is

high in that region but $Rx_{quality}$ is not properly high value. The reason for this low quality is problematic decoding in both Radio Access Network (RAN) and in User Equipment (UE). Then users suffer from low-quality network although they are receiving high Rx_{Level} . Rx quality depends on different parameters and network tuning techniques such as modulation, channel coding and so on. In 3G and 4G networks,

$Rx_{level}, Rx_{quality}$ are named differently such as RSSI, RSRP, RSRQ, SINR because they have different radio communication channels; however, the concept are the same.

Multi-objective PSO optimization method can be deployed to find the problematic region in this kind of situations. For example, Eq. (7) can be used to find location where Rx_{level} is highest and $Rx_{quality}$ is the lowest value in that specific region. Eq. (7) shows the multi objective swarming drone optimization.

$$\min(-Rx_{level}, Rx_{quality}) \quad (7)$$

Eq. 7 can be used to find locations where there is high Rx level but low Rx quality. This locations usually happen when an external interferer is affecting the service quality of the network users. There exist various techniques to solve the multi objective particle swarm optimization. In this paper, we propose to use a weighted combination of the objective functions to be able to optimize the multi objective functions.

6. Separating swarming loaders and testers

Stochastic received signal level is a problematic objective function to apply particle swarm optimization. Therefore, the idea of loader and tester swarming drone is proposed to have close to deterministic received signal level as an objective function. To this end, if the number of loader swarming drones consider being many more than testers, then this condition would be met.

7. Future work: Bayesian Optimization (BO)

A big positive point for PSO is the fact it can be parallelized significantly. However, in our specific application, parallelization means an increasing number of swarming drones in the testing area. Increasing the number of drones is very distractive to the public, costly to deploy and hard to manage. In our specific problem, we are not dealing with a very high dimensional problem; therefore, the idea of Bayesian optimization can be applied which is easier than PSO in this case. Deploying the same loader and tester division, we will deal with the non-stochastic objective function. BO is a sequential design technique to find global extremum values of

a black-box objective function that does not need derivations. Therefore, this technique is a proper choice for the more practical optimization problem. BO considers a statistical surrogate model to represent the initial belief about the objective function. BO needs a sequence of query points to increase its information about the unknown objective function. BO deploys an acquisition function to find the best next query point to maximize the information that can be captured. The best next query point in each iteration tradeoff exploration of the search space and exploitation of the current promising areas. Improvement-based, Optimistic, Information-based, Portfolios of acquisition functions policies are the main classes of acquisition functions that have been published^[34]. A centralized server is needed to process the captured objective function value, process them and reply back their results to drone to forward them to new points to perform objective function sampling.

8. Conclusion

Using swarming drones to load a cellular network and test the performance is very desired to have more realistic testing situations. Swarming drones manual navigation to scan the network performance and find the performance problematic region is time-consuming and not very efficient to deploy. Therefore, inspired by particle swarm optimization, swarming drone optimization is proposed. Loader and tester swarming drone separation help to have a non-stochastic objective function to optimize. In this proposed method each tester drone works as particle agent. Swarming tester drones communicate to deploy the PSO in all drones. This helps to find the network problematic regions. Bayesian optimization can also be used to achieve more efficient optimization than PSO, which will be considered in our future work. Besides, there are cases in cell phone network optimization which need multi-objective optimization. In other words, multi-objective PSO/BO can be applied in swarming drone to find more complicated problematic regions.

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