

Investigation on Deployment Planning of 5G Cellular Network UAV Base Stations for Stadium Sports Events

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Abstract

This paper proposes a promising solution to the flexibility and resilience requirement for serving cellular networks with low-altitude Unmanned Aerial Vehicle (UAV) Base Stations (BSs). The developed solution enables to assist terrestrial stations to increase the capacity and coverage of networks. The solution feasibility is highlighted by simulation of 5G cellular networks planning of sports events by using a metaheuristic algorithm. This approach aims to determine the UAV-BS minimum number covering a stadium, while taking into account the cell capacity and coverage constraints, the system spectral efficiency and the being utilized UAVs battery life. The computed modelling results show that the proposed algorithmic approach is effective for finding the minimum number of UAV-BSs. As results, fewer UAV-BSs of 33 were needed to serve all users throughout the day for the deployment using the Particle Swarm Optimization (PSO) algorithm compared to Genetic Algorithm (GA). For the night-time deployment, 20 UAV-BSs were needed for both planning methods. Moreover, the convergence speeds demonstrate that the PSO and GA algorithms can reach the coverage target during the day and the night. The results indicate that the quality-of-service targets desired for the 5G cellular network of UAV-BS are reached in each scenario.

Keywords: Unmanned aerial vehicles (UAV); UAV deployment planning; 5G network; Sports events; UAV base station (UAV-BS); Optimization model

Introduction

Today's lifestyle evolution depends more and more on mobile communication [1-4] with the Internet of Things (IoTs) [5] and smart objects [6-7]. Emerging wireless solutions have been deployed everywhere around the world to Information Communication Technology

(ICT) [1-6]. Different generations of ICT have been developed to provide a better Quality of Service (QoS) [8]. Recent surveys have been done on the reliability of the 5G network [9-14]. The success of modern society requires reliable surveillance and security ICT with 5G technology [15,16]. Society's requirement trends to deploying Unmanned Aerial Vehicles (UAVs) [17-19]. However, UAV-relevant modeling is needed to guarantee the Quality-of-Service (QoS) and remains an open challenge for the folk's scenario communicating with mobile devices. This paper proposes a positioning and placement optimization method of UAV Base Station (BS) and the forecast of the suitable count of the cellular network in stadium sports events. The feasibility of the developed method is highlighted by analytical-based innovative simulation and optimization techniques of the UAV network system. In other words, the overall goal of this research work is to develop an efficient and quick simulation method of UAV BS deployment. Before the simulation, cellular network planning is required. The following challenges and questions are addressed to attain the objectives:

- A. To understand the steps of cellular network planning with UAVs;
- B. To provide a simulation ground for the Particle Swarm Optimization (PSO) [20] and Genetic Algorithm (GA) [21] for the UAV-BS situation and;
- C. To evaluate the proposed approach performances based on the Signal-to-Interference-Noise-Ratio (SINR).

To reach these objectives, the UAV-BS system desired model

is proposed followed by the optimization problem based on the predefined constraints and the algorithm formulation. Doing this the paper is organized in four sections as follows:

- a. Section 2 describes the scenario of the sport event using the UAV-BS planning to be modelled for the present research work.
- b. Section 3 explains the methodology considered for the modelling of the sport event scenario UAV-BS planning deployment.
- c. Section 4 discusses on the computational results explaining the effectiveness of the 5G cellular network UAV- BS communication for sport event application.
- d. Then, Section 5 is the conclusion of the paper.

Scenario of Problem Statement for the UAV-BS System Modelling

The analytical geometrization and parametrization of the UAV-BS system representing the stadium sports events under consideration for the present research work are described in this section.

3-D perspective geometrization of study case

Figure 1 shows the considered scenario of the stadium sports event to be studied in this research work based on the UAV-BS cellular network system. The surface of a football pitch, including the open-air stands, needs to be covered by the network.

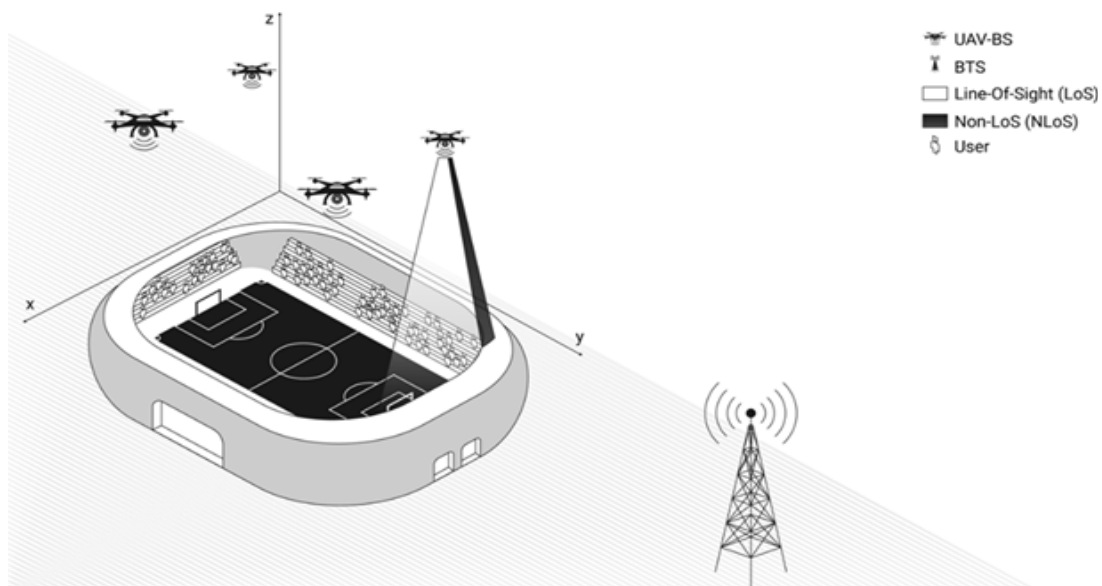


Figure 1: 3-D perspective view representing the UAV-BS system model under study.

The noun user refers to an owner of mobile devices that needs wireless access to the network. The air-to-ground [22] Line-of-Sight (LoS) and non-LoS communication are indicated. The total number of users is assumed to equal the stadium benches' capacity. The rectangular stadium with surface size 1000m × 100m is assessed

with 1000 seats (also referred to as users) as the area of interest. The objective is to find the minimum number of UAV-BSs and their respective optimal 3-D locations to serve all wireless mobile devices within the area effectively. Mobility is one of the essential features of the aerial BS, so it will help manage its deployment

based on the user's location. When the users move, the UAV-BS may have to relocate accordingly and take a better position to serve the user better, as depicted in Figure 1. The definitions of parameters constituting the air-to-ground channel model [20] are listed in Table 1. In the following subsections, we elaborate further on the system simulation parameters including the air-to-ground Downlink (DL) and ground-to-air Uplink (UL) communication associated with the UAV-BS cellular network system model.

Table 1: List of notations for the air-to-ground channel model.

Notation	Description
a, b	Constant values depending on the environment
θ	Elevation angle between users and a UAV-BS
h	Altitude of the UAV-BS
r	Horizontal distance between UAV-BS and user
f_c	Carrier frequency
c	Speed of light
η_{LOS}	Average additional loss of free space propagation for LoS link
η_{NLOS}	Average additional loss of free space propagation for NLoS link
BW	Channel bandwidth in Hz
α	Average spectral efficiency of the system in bps/Hz
R^{dl}	Users target data rate in the downlink
N_{uBS}	Maximum number of users served by each UAV-BS
N_U^x	Total number of users in the stadium at x time
t	Number of iterations
N_{BS}^x	Total number of UAV-BS needed to be deployed
N_{BS}^{Day}	Total number of UAV-BS needed to be deployed during daytime.

Description of considered simulation parameters of the proof-of-concept UAV-BS system

The proposed simulation enables to provide network coverage to a stadium during an event using UAV-BSs. We use GA and PSO algorithms to find the minimum number of UAV-BSs needed to serve the users based on their traffic requirements. We build the scheme while considering the capacity and coverage constraints, the UAVs' battery life and the average spectral efficiency. We have performed multiple simulations to evaluate the proposed approach performance. Table 2 presents the considered parameters of UAV-BS constituting the sport event scenario proof-of-concept. However, Table 3 addresses the parameters constituting the proof-of-concept during the DL and UL simulation. The site will be divided into two subareas with different densities of users. 10 percent of users will be distributed in the central region and 90 percent will be in the remaining area. We also adopt omni-directional antennas for UAV-BSs to allow full 3-D connectivity.

Table 2: UAV-BS system parameters.

Name	Value	Name	Value	Name	Value
a	9.61	f_c	2GHz	γ_{th}	-7dB
b	0.61	α	30bps/Hz	N_0	-174dBm/Hz
η_{LOS}	1	BW	100MHz	F	5dB
η_{NLOS}	20	ξ, τ	98%	V_{max}	500m
t_{max}	100	h_{max}	600	N_p	12
p_m	0.01	p_c	0.08	L	12

Table 3: UAV-BS DL & UL simulation parameters.

DL parameter		UL parameters	
Name	Value	Name	Value
R^{DL}	100Mbps	R^{UL}	50Mbps
P_t^{DL}	49dBm	P_t^{UL}	23dBm
G_t^{DL}	17.5dB	G_t^{UL}	0dB
G_r^{DL}	0dB	G_r^{UL}	17.5dB

Methodology of the UAV-BS Deployment Modeling

We assume the total number of users in the stadium during the daytime to be a thousand. To serve these users, the initial estimation of the number of UAV-BSs needed is 34. The users are uniformly distributed according to different stadium densities divided into two subareas, as shown in Figure 1.

Description of PSO and GA algorithms

As mentioned earlier, to serve these users based on the capacity, coverage constraints and average spectral efficiency, the UAV-BSs are deployed by two different methods. First, we used the PSO algorithm presented in the algorithm. Figure 2 shows the steps of that algorithm. The PSO algorithm applies the following settings: the initial population size L is set to 12 and the velocity $Vl\varphi \in [-Vmax, Vmax]$ with Vmax is the maximum achieved velocity. To limit the movement of UAV-BSs from one iteration t to another, we choose Vmax=500m. F1 is the utility function that satisfies the capacity constraint and finds the 3-D locations of the UAV-BSs. The utility functions F2 and F3 satisfy the coverage constraint and the average spectral efficiency while holding the capacity constraint. We continued the simulation using the genetic algorithm presented in the algorithm to find the 3-D placement of the UAV-BSs and the settings are applied to the GA to achieve the goal. Figure 3 shows the process followed by the GA. The initial population size N_p is set to 12, the iteration limit tmax is fixed to 100, the mutation rate pm and the crossover rate pc are configured to 0.01 and 0.08, respectively.

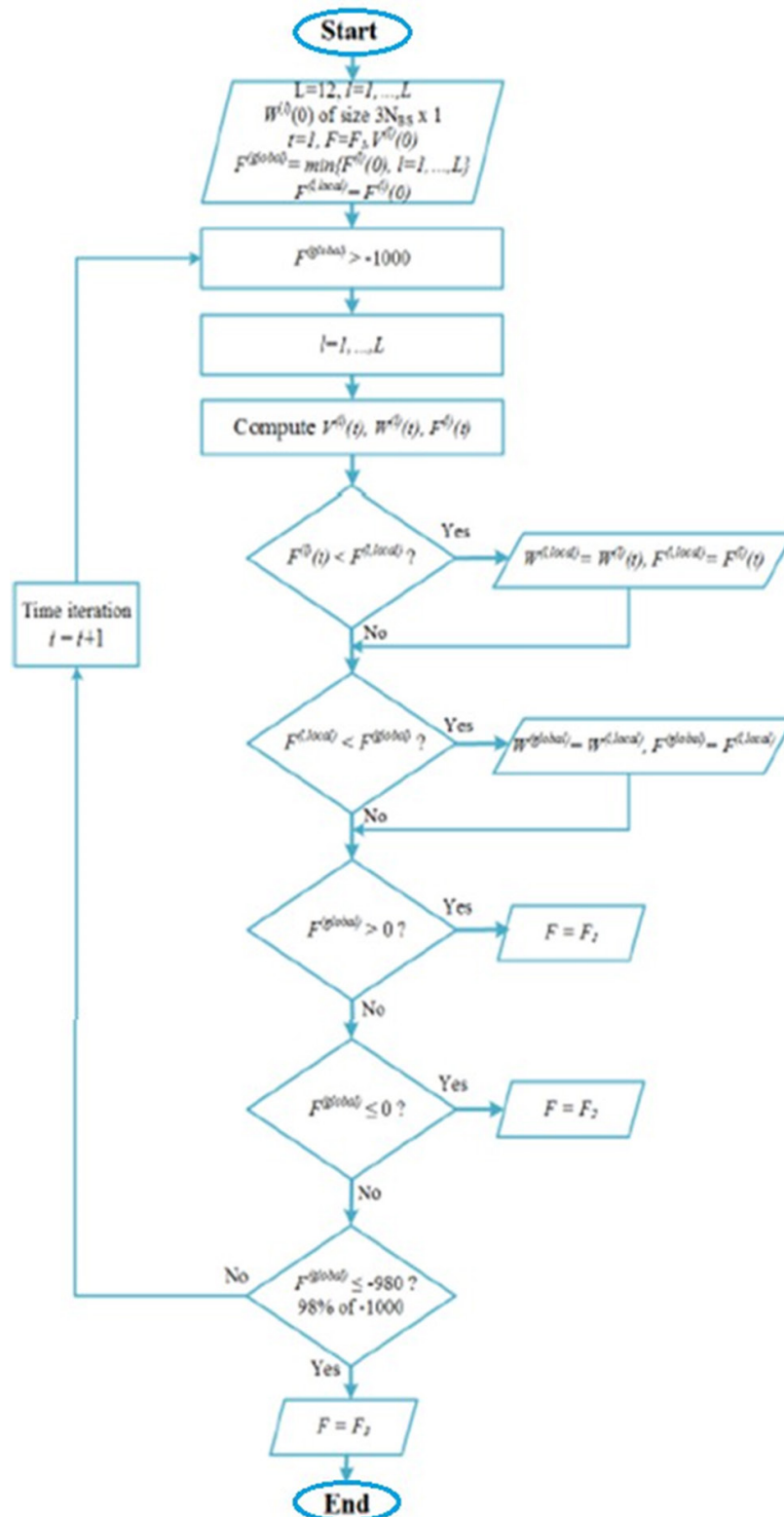


Figure 2: UAV-BSs deployment process with PSO algorithm.

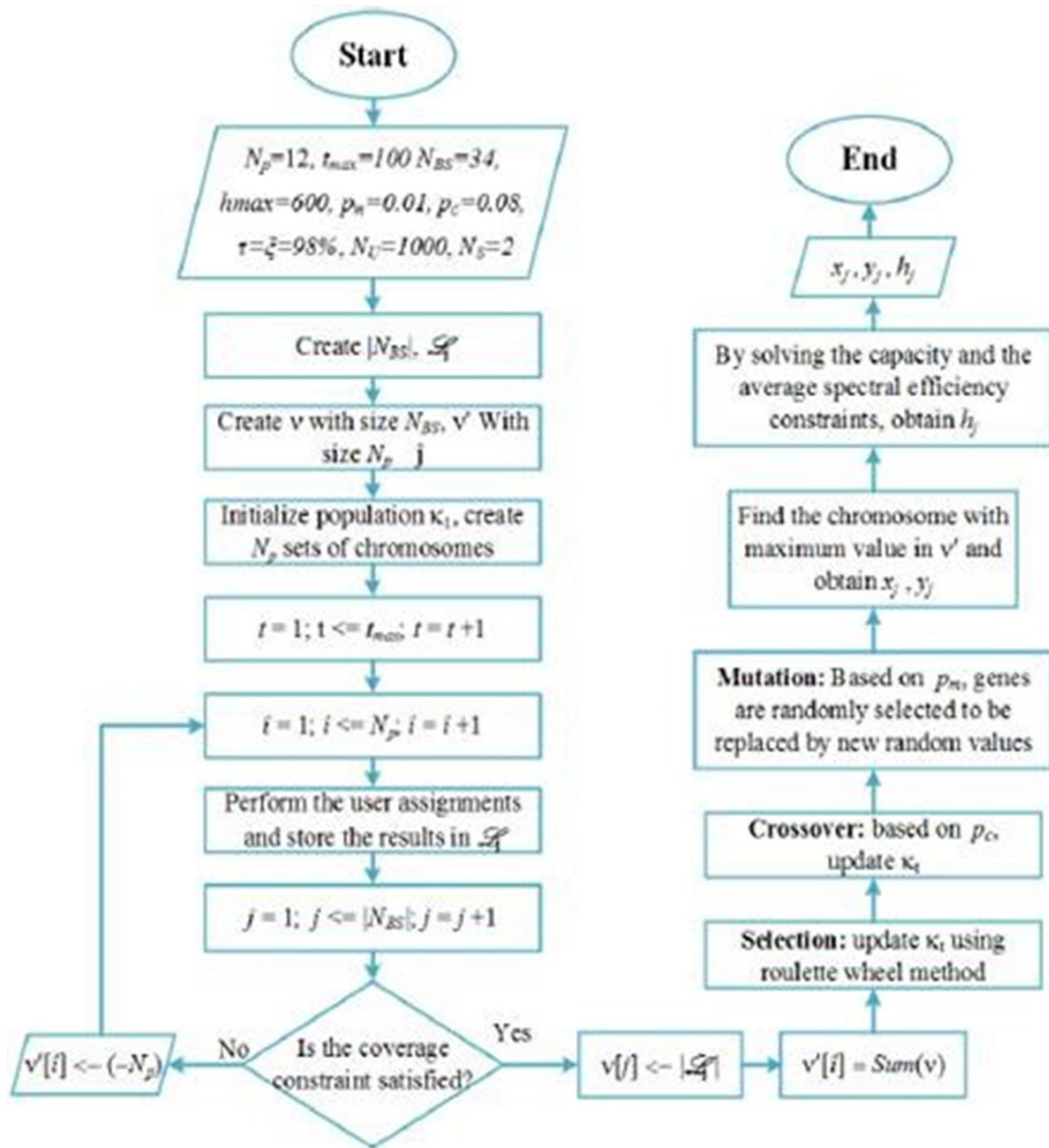


Figure 3: UAV-BSs deployment process with GA.

Redundant UAV-BS elimination and deployment process

After finding the 3-D location of UAV-BSs by the PSO algorithm [22] and GA [23], the algorithm detailed in Figure 4 was implemented to eliminate the redundant BSs in the deployment. The final number of UAV-BSs required to serve all users is different from each algorithm. As application, the users' distributions

(dotted in blue) during the day (case1) and night (case2) study cases shown in Figure 5(a) and Figure 5(b) were considered, respectively. Subsequently, the number of UAV-BSs from the PSO algorithm needed is 33. Among the 34 UAV-BSs proposed in the initial dimensioning, one BS was identified as redundant. From the genetic algorithm, all the 34 UAV-BSs were identified as essential to the deployment.

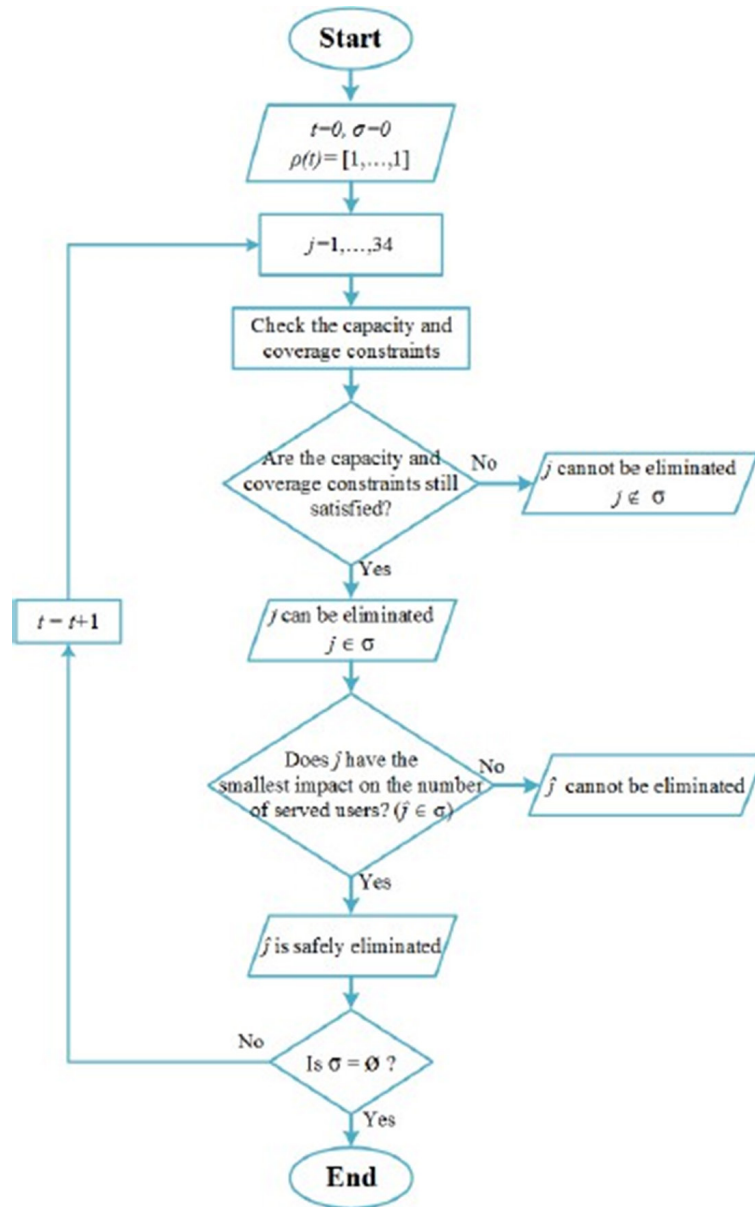


Figure 4: Redundant UAV-BSs elimination process.

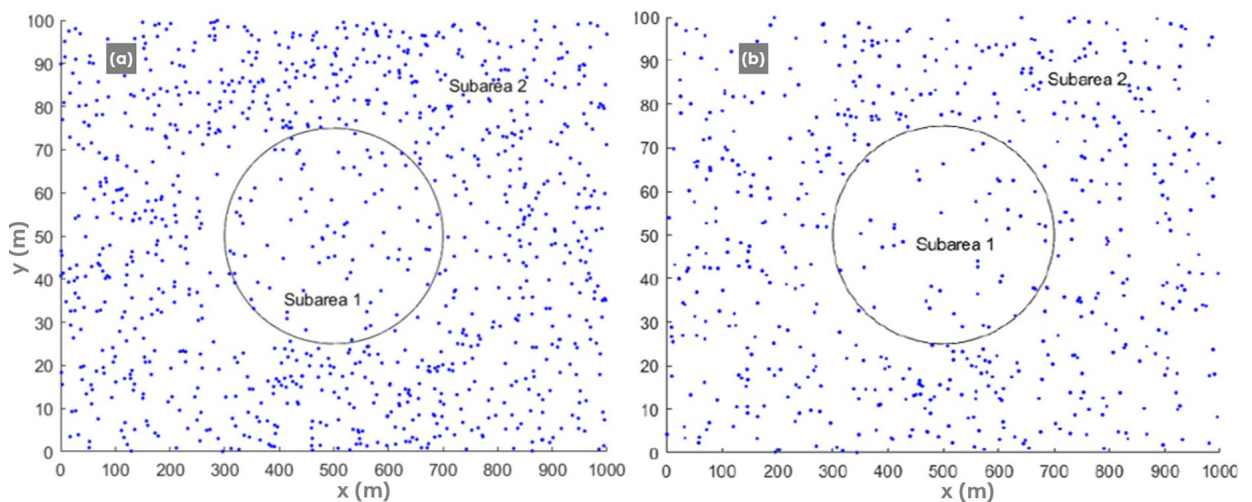


Figure 5: Distribution of users during the (a) day and (b) night study cases.

Simulation Results of Optimized UAV-BS Deployment

To evaluate the optimization approach performance, simulations were completed using the MATLAB® software. The different numbers of users during the day and night were considered. To serve 1000 dense users during the day and 600 at night, the stadium is divided into two subareas, and the users are distributed with different densities. 10% of users are distributed in subarea 1 and 90% of them in subarea 2, as shown in Figure 5. The optimization results are discussed in this section.

Results of UAV-BS distribution

The triangle colors red and magenta displayed in Figs. 6 represent UAV-BSs center tasked to cover the center and outer region of the stadium, respectively. The exact figure makes it easy to see the user density disproportion of the inner and outer area. Thus, making it clear about the need for more UAV-BS to cover this outer area to satisfy their users' DL and congestion. The final number of needed UAV-BSs required to serve all the users during the day was 33 for the deployment using the PSO algorithm and

34 for the genetic algorithm. For the night deployment, 20 UAV-BSs were needed for both planning methods. During the day (resp. night), the users' total number was equal to 1000 (resp. 600), which is 90% (resp. 60%) of the seating capacity of the stadium. Thus, 34 (resp. 20) UAV-BSs are needed to serve all the users according to the initial dimensioning. As in the deployment during the day, the users are uniformly distributed in the stadium. After this distribution, the deployment of UAV-BSs will follow the same process and will use the same deployment parameters during the day. By changing the total number of users that have to be covered in the PSO algorithm and the GA, we got the 3-D placement of the UAV-BSs.

Then, we pass on the step of redundant BS elimination. For both methods, all the UAV-BSs were identified as indispensable for a safe network operation of the deployment. So, the final number of required UAV-BSs to serve the users remains 18. Figure 6(a) and Figure 6(b) show the 2-D projection of the UAV-BS locations corresponding to case 1 with users from PSO and GA, respectively. Then, Figure 6(c) and Figure 6(d) represents the results from case 2 of UAV-BS locations with users, respectively.

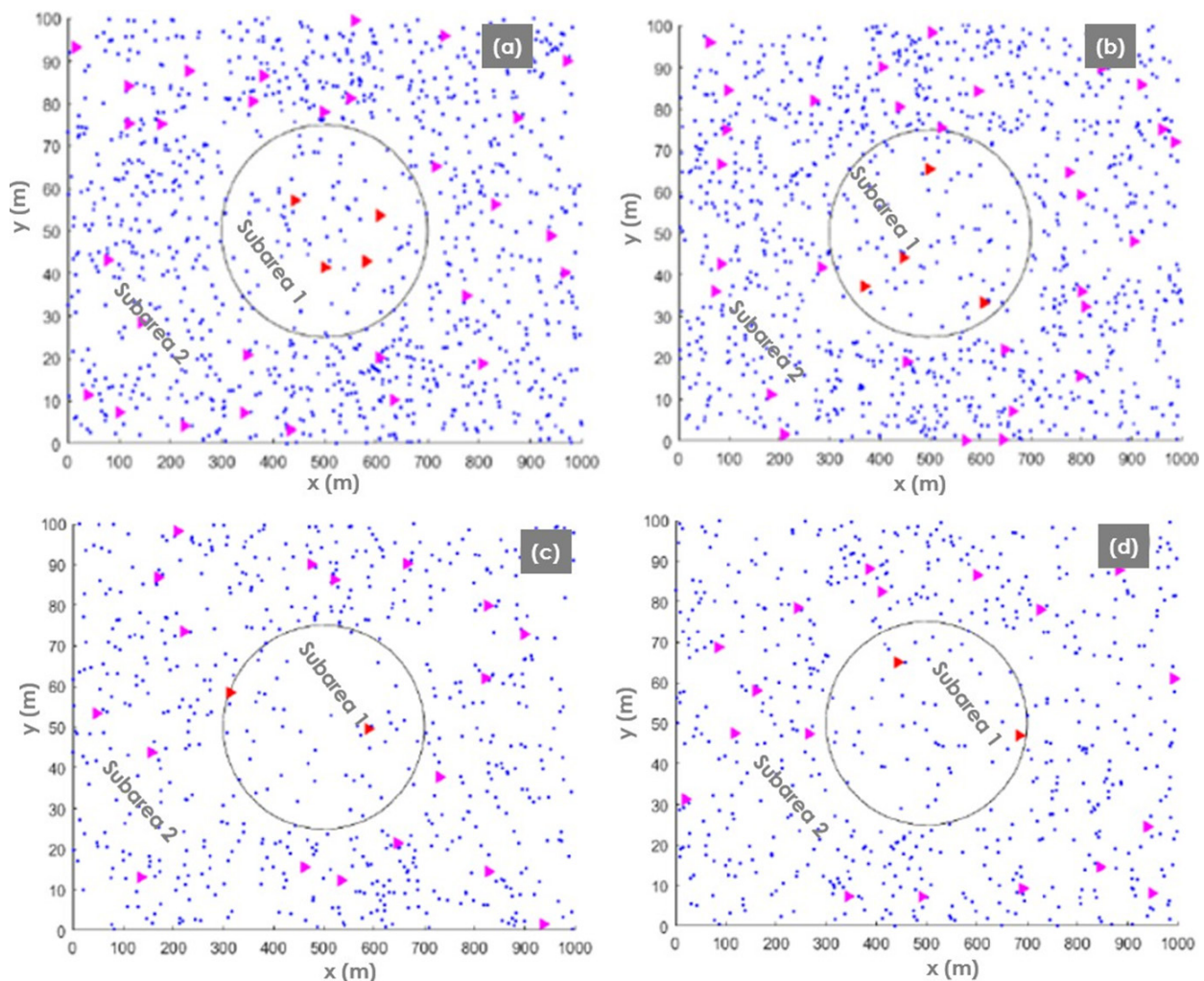


Figure 6: 2-D distribution of UAV-BS locations and user distribution from deployment during the day using (a) PSO and (b) GA, and night using (c) PSO and (d) GA.

Furthermore, the UAV-BS 3-D positions of case 1 during the day are located in Figure 7(a) and Figure 7(b), respectively. The UAV-BSs in the central region and the remaining region are represented by red and magenta right-pointing triangles. The 3-D positions of UAV-BSs for night test case 2 are indicated in Figure 7(c) and Figure 7(d), respectively. The UAV-BSs in the central region and the remaining region are represented by red and magenta right-pointing triangles. As seen in Figure 6(c) and Figure 6(d), for the

night deployments, the number of UAV-BSs needed in the central region is only 2. They are more distant compared to the UAV-BSs in subarea 2, which has higher user density. In terms of height, also like in the deployment during the day, in the area with higher user density, the average altitude of UAV-BSs is lower to reduce interference for the users served by other UAV-BSs, as presented in Figure 7(c) and Figure 7(d).

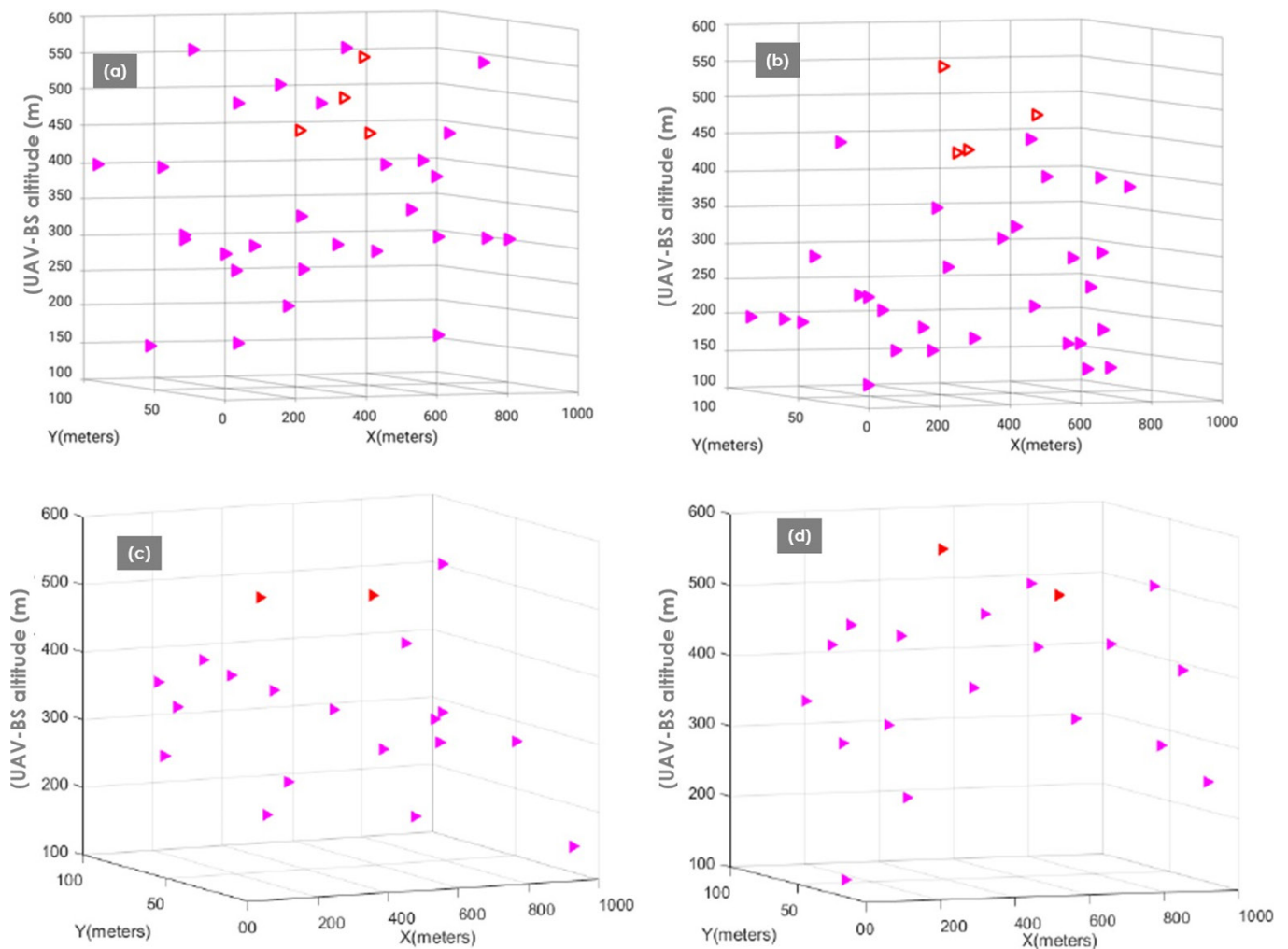


Figure 7: 3-D distribution with UAV altitude with deployment during the day using (a) PSO and (b) GA, and at night using (c) PSO and (d) GA.

Discussion on SINR vs convergence and UAV-BS optimized performances

After simulations, the optimized UAV-BS communication system QoS and performance were computed based on the SINR

distribution. There is a probability of association between the user and the UAV-BS transmitter if the user receives a SINR higher than -7dB. The executed algorithm convergence speeds for case 1 and case 2 are illustrated in Figure 8(a) and Figure 8(b), respectively.

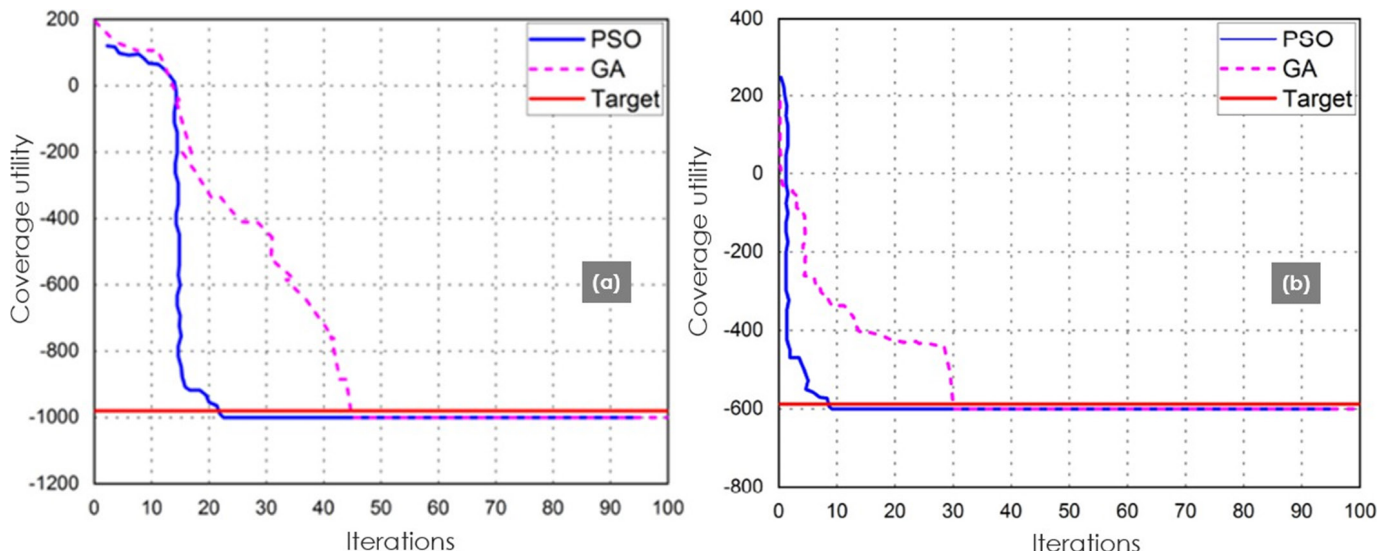


Figure 8: Coverage utility illustrating the PSO and GA algorithm convergence speeds from study (a) case 1 and (b) case 2.

One can emphasize that:

- A. During the day, the target was fixed to 980, which is 98% of the total users 1000. With PSO, the target was reached at the 22nd iteration during the day, whereas it is met at 44th iteration with GA.
- B. However, during the night, the target was fixed to 588, corresponding to 99.7% of the total users fixed to 600. With PSO, the target was reached at the 9th iteration during the night. But the target was obtained only after 30th iteration with GA.

As highlighted by both the day and night deployment results, the PSO algorithm is faster than GA. However, compared to the deployment in the day, the convergence speed is higher than at night. The UAV-BSs are deployed into their 3-D placement using PSO and genetic algorithms. Then, a third step has been put in place to verify the UAV-BSs deployment and eliminate the redundant BS while respecting the satisfaction of the capacity, the coverage constraints and the average spectral efficiency of the system. Considering that users are connected to the UAV-BS, which offers the highest pleasing signal, the cumulative distribution function of the SINR shows that these approaches satisfy the quality of service required. PSO converges faster than GA based on our setup and the iteration number necessary to achieve the optimal solution depends on the study scenario.

Conclusion

Today, one assists to continuous growth of involvement and omnipresence of new technologies in our daily lives. Therefore, the need for constant connection to the network at any time and from anywhere is elicited. A robust, efficient and effective network is required to satisfy this ever-growing number of users. Diverse works suggested UAVs as BSs as they can bring a reliable and efficient alternative to coverage and capacity requirements for the 5G network. In this work, we present the use and planning of UAV-

BSs while minimizing the number of devices deployed and covering an entire stadium full of users. We achieve this goal and can serve the users with their traffic requirements. An optimization problem was carried out, which considers the capacity and coverage constraints and the average spectral efficiency of the system.

Metaheuristic algorithms based on PSO and GA were proposed to solve the optimization problem and find the 3-D placement and to determine the optimal number of UAV-BSs needed by eliminating the redundant ones. However, we ensured that UAV-BS discarding from the nodes does not affect the quality of the network. The number of users inside the stadium was considered different during the day and night for the simulation. Also, to circumvent the limitation set by the UAV flying time, with their battery life, we suggested creating a cycle where the UAV-BSs deployed during the day are recharged at night and those used during the night are charged during the day. By considering the subareas with different user densities, the simulation results confirmed the acceptable performance of the proposed approach by indicating the PSO algorithm and GA convergence speeds. The number of UAVs deployed in each scenario is proportional to the number and density of users. The UAV-BSs could change their altitude to address coverage and capacity issues.

This work can be extended to 6G (e.g., AI-driven optimization, hybrid UAV-BS models, etc...). For example, the UAV-BS system performance is limited by the signal latency. To overcome the issues related to the latency and signal propagation delay, we plan to further study UAV-BSs' innovative technique with delay synchronization [23-25] in our future work.

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