Flight Time Optimization in People Identification by Multidrone-Femtocell Systems

Roberta Avanzato[a], Francesco Beritelli[a] and Gabriele Nicotra[b]

[a]Department of Electrical, Electronic and Computer Engineering, University of Catania, Catania, CT, Italy
[b]Department of Mathematics and Computer Science, University of Catania, 95125 Catania, Italy

Abstract

The paper proposes an extension of a previous algorithm for the geolocation of missing people, which is aimed at a reduction in search times. The proposed technique involves the use of femtocells on board the drone, and therefore offers the possibility for identifying a mobile terminal based on the estimate of the power levels. In particular, a multi-drone system is proposed that allows for better performance in terms of reduction in localization times, which are halved in the case of simultaneous use of 4 drones.

Keywords

Multi-drone/Femtocell systems, Energy consumption, Mobile terminal positioning algorithm, 4G technologies, Reference signal received power (RSRP)

1. Introduction

The occurrence of a natural disaster in urban or suburban areas always poses a series of problems in terms of public safety, social and economic hardship.

The development in technological innovation is often able to provide support to the problems that must be faced in the event of a post-natural disaster. For example, on a social level it is of crucial importance to connect the areas affected by disasters and cover them with telecommunications systems [1, 2]. In this regard, many researchers have studied new solutions based on the use of UAV (Unmanned Aerial Vehicle) systems, proposing audio-video recording systems based on technologies for redundant connection in mobility [3, 4, 5], as well as drone-femtocell system solutions as an alternative to classic radio base stations when these are out of service [6, 7, 8, 9, 10].

Another research field is people identification and localization [11, 12, 13], in particular the techniques employed searching for missing persons in post-earthquake scenarios.

Several methods have been proposed to date including the localization of mobile terminals by radiofrequency (RF) signals, in scenarios where rubble is a source of significant attenuation to the propagation of the electromagnetic signal [14, 15, 16].

The idea of using the drone-femtocell system no longer as the only means for covering a disaster area but as a localization system leads to novel studies conducted in [17, 18, 19]. In these studies, the authors propose an algorithm capable of locating any mobile terminal in a given monitored area through the use of UAV systems. Through the femtocell cover, placed on the drone, it is possible to create a connection with the terminals and locate them using the received power values. In particular in [19] the authors present a new criterion for classification and geolocation in the presence of non-isotropic radio signal propagation using a 4G femtocell aboard a drone system. The authors also present a first study on the capacity and efficiency of a time-of-flight optimization and data processing algorithm performed by the drone. The purpose of this algorithm is to reduce rescue times in natural disaster scenarios as much as possible.

In this article, we propose the extension of the flight time optimization and processing algorithm using a multi-drone-femtocell system.
The use of multiple drones with femtocells on board allows scanning the monitoring area more rapidly; the algorithm is responsible for making the two or four drones cooperate, in order to follow their respective paths with the minimum overlap. This mechanism leads to a considerable reduction in the flight and processing times of each drone and therefore avoids considerable waste of flight energy [20].

The paper is structured as follows: section II describes the proposed method, i.e. the method of optimizing flight and processing times through multiple drone-femtocell systems; section III shows the performances obtained using this method as the number of drones used and the size of the monitoring area vary;

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roberta.avanzato@phd.unict.it (R. Avanzato);
francesco.beritelli@dieei.unict.it (F. Beritelli)

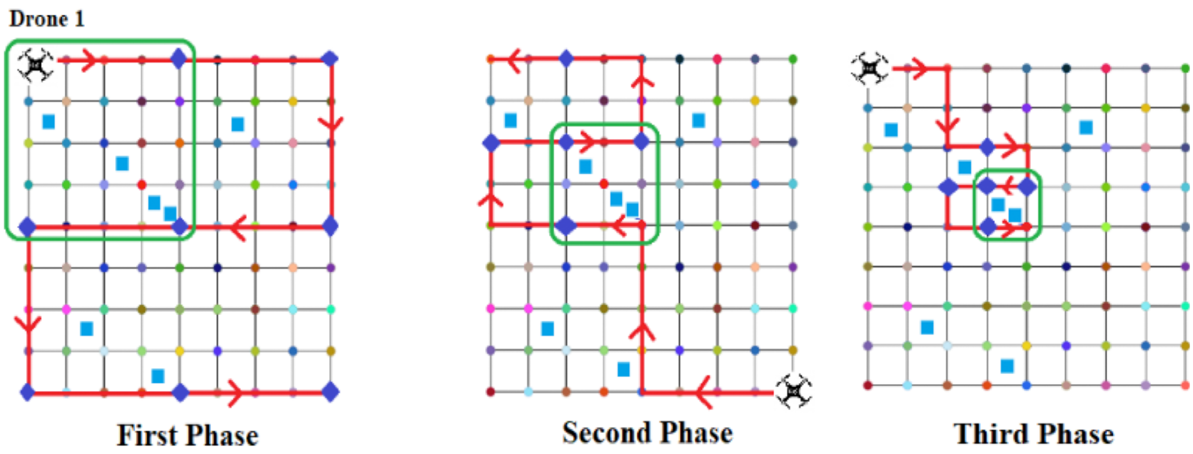

Figure 1: Optimized root in the case 1 drone is used.

the final section is dedicated to conclusions.

2. Proposed Method

In this paper, the "Cluster-based Fast Proximity Algorithm" proposed in [19] is extended to the use of two or more cooperating drones, optimizing flight time and areas to be covered. This mechanism leads to a reduction in the energy consumed by drones and also in rescue times.

Therefore, by using multiple drone-femtocell systems, the need arises to remodel the algorithm for optimizing the drone flight time, in order to intelligently cover each sub-area of the monitoring area. To this end, once the optimization algorithm is applied, the graphs relating to processing times, flight times and energy expenditure are obtained as the number of drones used and the size of the matrix that defines the monitoring area vary. To apply the algorithm, the following constraints were introduced:

- coverage radius of the femtocell on board the drone equal to half the diagonal of the starting grid;
- the terminals hook onto the first femtocell they detect;
- the drones depart from the edges of the grid with a time lag of one minute, to prevent them from passing through the same point at the same time;
- uneven distribution of terminals.

The drone-femtocell system and the details of the classification and localization algorithms are defined in [19], the main hypotheses for the application of this algorithm are summarized below:

- The grid must be an $M \times M$ matrix where $M = 2^n + 1$ and $n = 2, 3, \ldots, N$;
- The matrix must not be 2×2 or 3×3;
- The number of iteration phases of the algorithm must be given by:

$$F = n = log_2 (M - 1) \quad (1)$$

The equations that determine the processing time, flight time and energy, respectively, in the case of two and four drones are the following:

$$T^o_{P-tot} = t_p * (5 * F_{max} + 1) \quad (2)$$

$$T^o_{V-tot} = \delta_t * \left[20 + 2^{F_{max}} \left(\sum_{F=2}^{F_{max}} \frac{3}{2^{F-2}} \right) \right] \quad (3)$$

$$E^o_{TOT} = P * (T^o_{P-tot} + T^o_{V-tot}) \quad (4)$$

The processing, flight and energy expenditure times in the case of two drones are defined, respectively, by (2), (3), and (4). However, in the case of 4 drones, the processing, flight and energy expenditure times are defined by (5), (6), and (7), respectively.

$$T^o_{P-tot} = t_p * \left\{ 5 * \left\lceil \frac{F+1}{2} \right\rceil + 4 \right\} \quad (5)$$

$$T^o_{V-tot} = \delta_t * \left[2^{F_{max}} \left(2 + \frac{3}{2^{F_{max}-2}} \right) \right] \quad (6)$$

$$E^o_{tot} = P * (T^o_{P-tot} + T^o_{V-tot}) \quad (7)$$

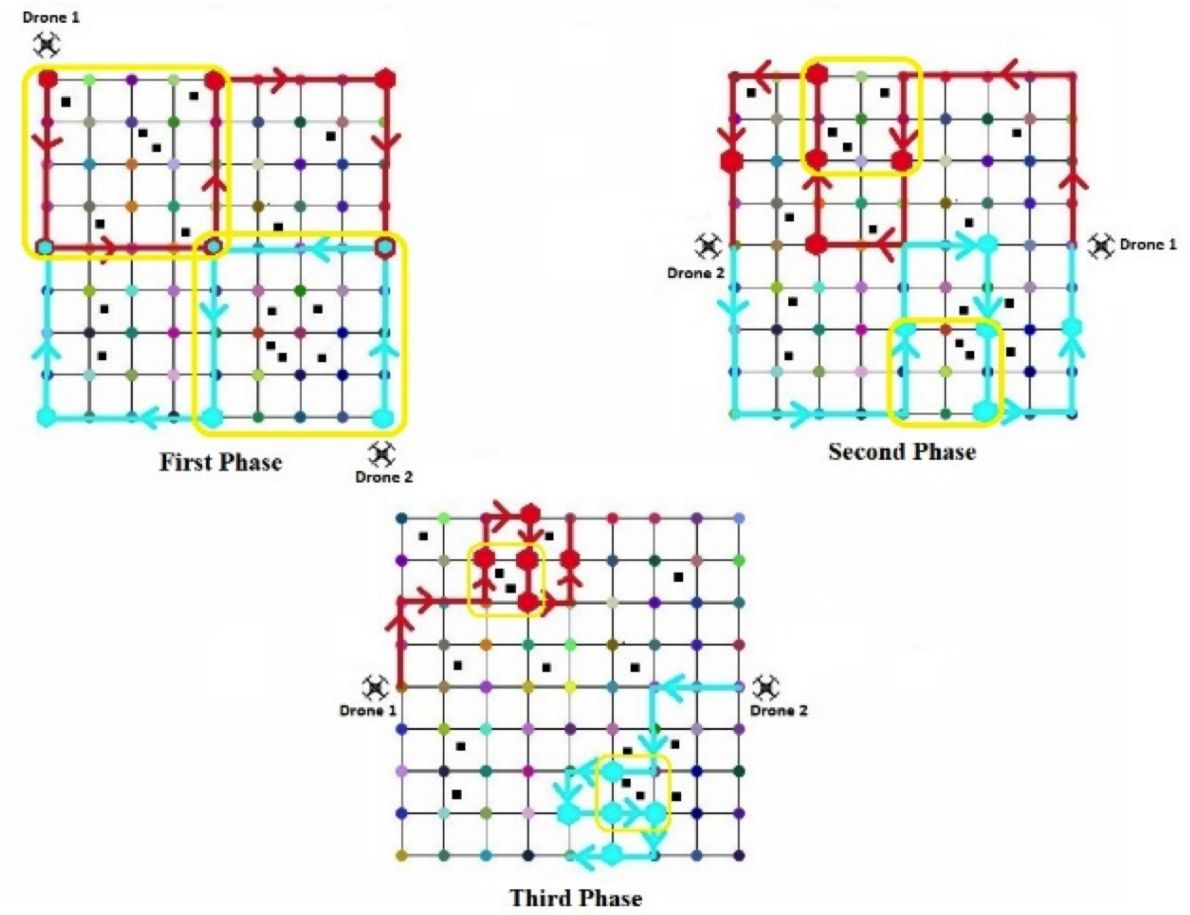

Figure 2: Optimized root in the case of simultaneous use of 2 drones

3. Performance Evaluation

In this section we will evaluate the performance of the flight time optimization and processing algorithm in the case of 1 drone, 2 drones and 4 drones. As already seen in [19] the "Cluster-based Fast Proximity Algorithm" algorithm was applied based on a single drone, in this paper we will apply it to several drones, comparing performance, in terms of time reduction and energy consumption in three different cases.

To test the performance of the system, a practical example of a matrix of size $M = 9$ will be considered, i.e. a 9×9 matrix (with a resolution of 2 meters, thus obtaining a monitoring area of 18×18 meters). Using two drones, positioned at opposite edges of the area, it is noted that the number of phases that the algorithm runs is given by (1) and remains unchanged compared to the case of using only one drone, i.e. 3 phases are carried out.

Fig. 1, Fig. 2, and Fig. 3 show the monitoring area divided into 9 rows and 9 columns, the phases of the algorithm and the drone path, respectively, when 1, 2 and 4 drones are employed. The differences concern the number of processing points and the flight segments of each individual drone. In the case only one drone is used, 19 points are processed during the three phases of the algorithm, whereas using two drones they are reduced to 16. As for the flight segments, from the 68 segments obtained with one drone we pass to 56 segments. All this leads to a reduction in the processing and flight times of each individual drone. However, using 4 drones it is possible to observe that the number of phases each drone must complete decreases while maintaining the size of the grid unchanged; this happens because each drone is responsible for scanning a smaller sub area equal to almost half of the original one. This decrease occurs every time 4 drones are used, regardless of the size of the grid. There is also a further decrease in the processing points (equal to 14) and in the flight segments (equal to 28).

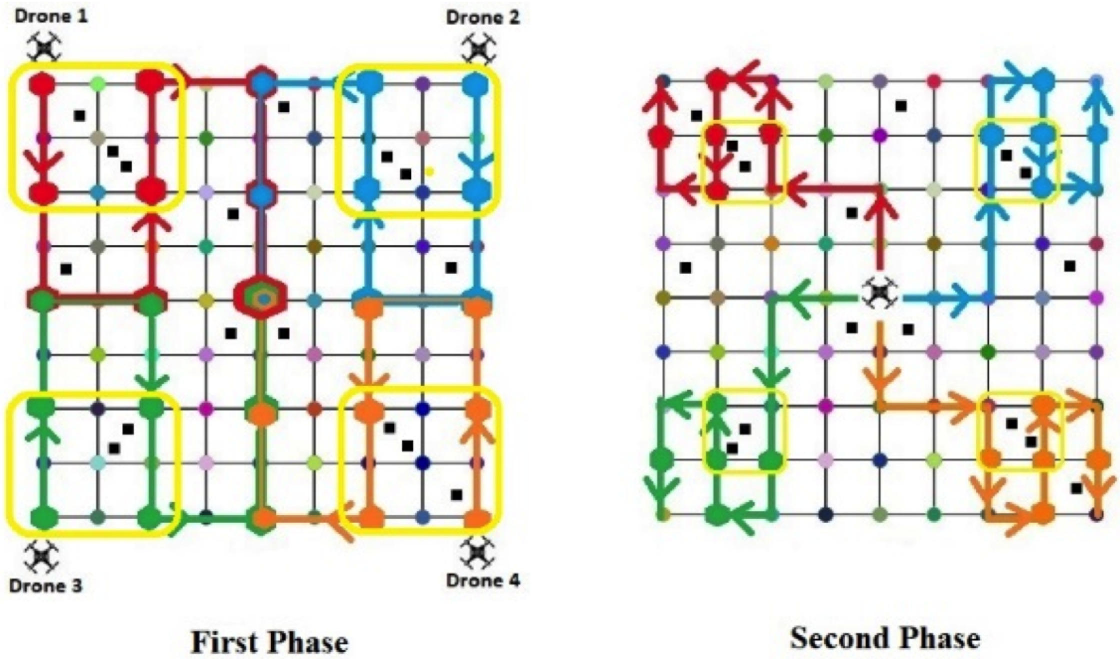

Figure 3: Optimized root in the case of simultaneous use of 4 drones

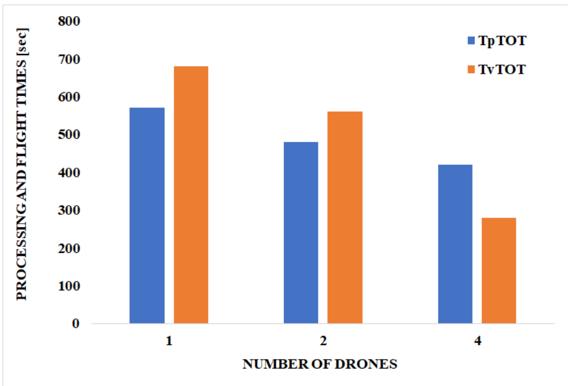

Figure 4: Flight and processing time as the number of drones varies for a 9 × 9 matrix

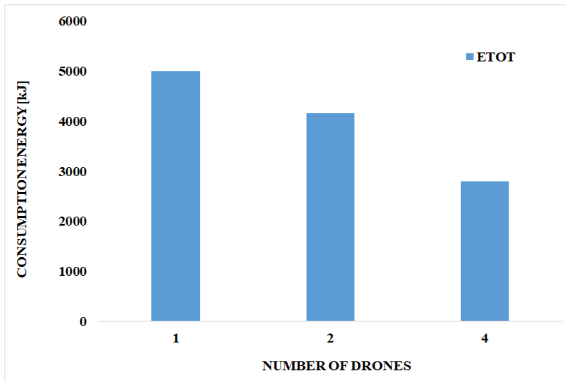

Figure 5: Energy consumed by a single drone as the number of drones varies for a 9 × 9 matrix

Fig. 4 shows the flight and processing time trends of a matrix M = 9, as the number of drones used varies. As for the processing time, it can be observed that it significantly decreases using 4 drones, going from 570 seconds (9.5 minutes) with one drone to 420 seconds (7 minutes) with 4 drones. Using two drones, however, the processing time drops to 480 seconds (8 minutes). While, the total flight time varies from 680 seconds (11.33 minutes) using one drone, to 560 seconds (9.33 minutes) with 2 drones, decreasing up to 280 seconds (4.67 minutes) using 4 drones. In this case we can see that the maximum decrease is obtained by passing from 2 to 4 drones, with the flight time being halved.

Regarding the energy, represented in Fig. 5, a net decrease is obtained, passing from the use of 2 drones (total energy equal to 50.44Wh) to 4 drones (33.95 Wh). With one drone, on the other hand, there is an energy consumption of 60.62 Wh.

To generalize the considerations made, additional graphs were obtained as the size of the matrix on which the localization algorithm is applied varies. Fig. 6, Fig. 7 and Fig. 8 represent, respectively, the trend of the curves

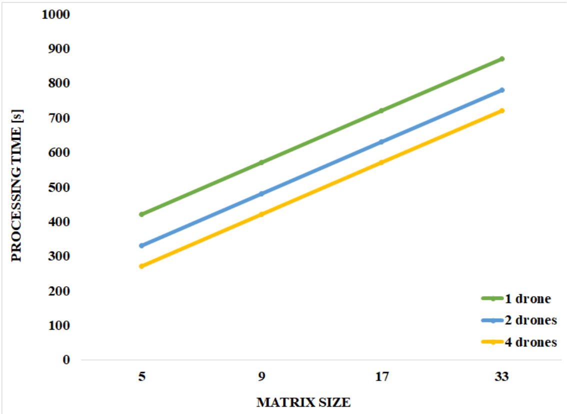

Figure 6: Processing time of a single drone as the size of the matrix and the number of drones vary.

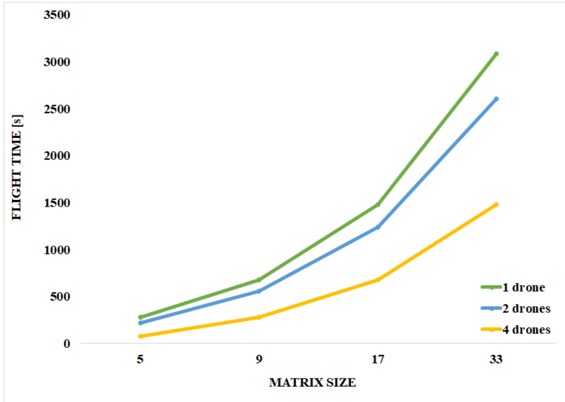

Figure 8: Flight time of a single drone as the size of the matrix and the number of drones vary.

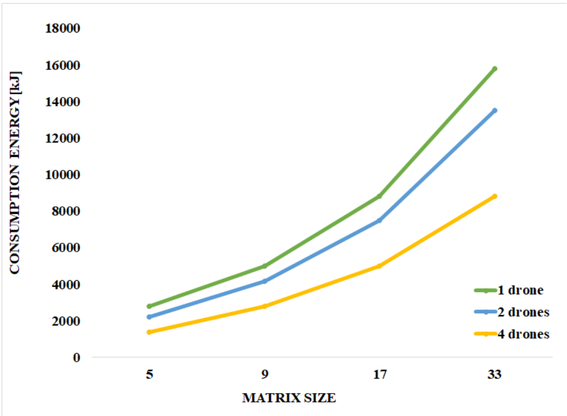

Figure 7: Energy consumed by a single drone as the size of the matrix and the number of drones vary.

Table 1
Evaluation of flight times, processing times and energy, as the size of the monitoring area varies using two drones

M	$T^{o}_{P\text{-tot}}$ [min]	$T^{o}_{V\text{-tot}}$ [min]	E^{o}_{TOT} [MJ]
5	5.5	3.66	2.2
9	8	9.33	4.16
17	10.5	20.66	7.48
33	13	43.33	13.52

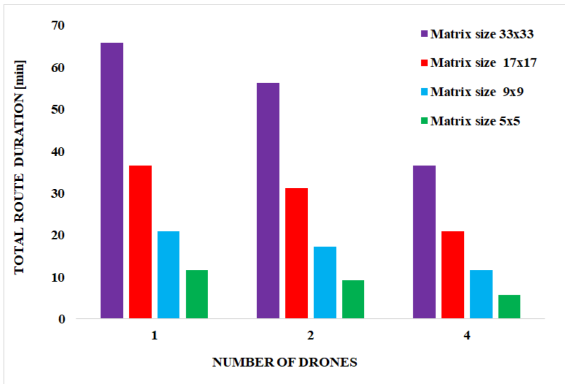

Figure 9: Total duration of the journey of a single drone as the number of drones and the size of the matrix vary.

relating to processing time, flight and energy consumption, based on the use of 1, 2 or 4 drones. These figures confirm what has been said for a 9 × 9 matrix. In fact, as regards the processing time, the greatest reduction is obtained by passing from 1 to 4 drones.

In terms of flight time and energy, there is a sharper decrease from 2 to 4 drones. Once the number of drones has been fixed, processing times, flight times and energy increase hand in hand with the increase in the size of the matrix, but with a different trend. The processing time increases linearly, while the flight time and energy grow according to an exponential trend.

For example, having set the use of drones equal to 2, the flight, processing and energy consumption times were obtained as the size of the matrix changed. The data is represented in Table 1.

Another interesting graph that has been obtained concerns the total duration of the journey of each drone, given by the sum of the processing and flight times. As shown in Fig. 9, once the size of the matrix is fixed the total duration of the journey is considerably reduced, almost halving going from 2 to 4 drones.

Considering that during a search and rescue operation of missing persons time is a determining factor, being able to locate terminals in the shortest possible timeframe is a major advantage.

4. Conclusion

In this paper, a study was presented concerning the combined use of drones and femtocells. In particular, the paper analyses the cases UAV-femtocell systems are used to create ad hoc emergency networks during disaster scenarios or to facilitate search and rescue operations for civilians missing in post-earthquake scenarios. Using a real simulation scenario, the following were considered:

- the number of drones required with respect to different parameters (duration of the intervention, user coverage, flight height of the drone, level of service provided to the user);
- reduction of processing and flight times of each individual drone;
- optimization of battery life (if, for example, a single drone has a discharged or low battery to cover the entire monitoring area, there are other drones to support it to cover the areas it cannot);
- possibility to replace a drone in case any of them is damaged;
- localization of more terminals, through the selection of a greater number of sub-areas, where greater quantities of terminals with greater power are detected.

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