

OPTIMIZATION OF THE INFORMATION COLLECTION MODE USING UAVS ON DISTRIBUTED GROUND NETWORKS OF MEASURING SENSORS

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ABSTRACT

This article is devoted to optimizing the data collection mode using UAVs from ground-based measurement network sensors. The problem of optimizing data collection from clustered ground-based sensors using a UAV swarm is formulated and solved. It is shown that the data collection rate can be maximized when there is a direct linear relationship between the bandwidth of the UAV data reception channel and the intensity of white Gaussian noise in the receiving channel.

KEYWORDS: *measuring sensors, data collection, UAVs, data collection speed*

DOI: [10.36724/2664-066X-2025-11-3-7-12](https://doi.org/10.36724/2664-066X-2025-11-3-7-12)

Received: 15.05.2025

Accepted: 18.07.2025

Citation: Emil M. Akhmedov, "Optimization of the information collection mode using UAVS on distributed ground networks of measuring sensors", *Synchroinfo Journal* **2025**, vol. 11, no. 3, pp. 7-12.

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Introduction

As noted in [1], UAVs are designed to perform a wide range of tasks in areas such as aerial reconnaissance, military applications, target detection, pipeline and power line monitoring, georecognition, agriculture, and goods delivery. One such application is forest fire hazard monitoring [2]. Functionally, in many UAV monitoring applications, the unmanned devices collect information from sensors within a distributed network of measuring transducers located throughout the facility's condition monitoring field. As noted in [3], the number of sensors worldwide is projected to reach hundreds of billions by 2030. Consequently, collecting and processing such a large volume of information requires improvements to data collection and preprocessing systems.

According to [4], the use of UAVs for collecting data for the Internet of Things will provide the following advantages:

- High efficiency and flexibility in data collection: UAVs can significantly reduce data collection time, as the flight trajectory can be optimized [5-7];
- Low power consumption and the ability to supply sensors wirelessly [8, 9];
- Wide field of view. At high UAV flight altitudes, it is possible to cover a large area of objects where sensors are located. [10, 11]

However, the specific arrangement of sensors within an area dictates the need to select a special flight trajectory, as well as increased efficiency in collecting information from ground-based sensors.

A model representation of a network in which a group of UAVs collects and transmits information to a base station is shown in Figure 1.

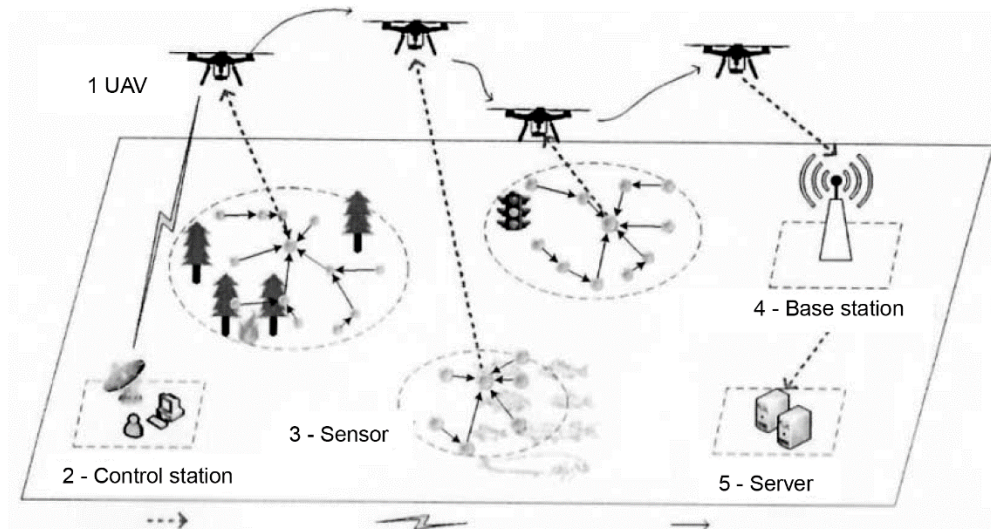


Figure 1. Model representation of information by a group of UAVs from ground sensors and the transmission of information to the base center [4]

As noted in [4], the system uses a LoS (line-of-sight) communication channel. The probability of successful data transmission over such a communication line is calculated using the formula

$$P_{\text{LOS}}(S_{m,U}) = \frac{1}{1 + a \exp[-b (A(S_{m,U}) - a)]} \quad (1)$$

where $A(S_{m,U})$ is the angle between the sensors S_m and m , $m \in M$, a and b are environmental parameters that primarily depend on the density of buildings in the area, as well as the height of the buildings.

The data transfer rate from the UAV sensor S_m is determined as [18]

$$R(S_m, U) = B \cdot \log_2 \left(\frac{1 + |h(S_m, U)|^2 P_m}{N_0} \right) \quad (2)$$

where B is the channel bandwidth;
 $h(S_m, U)$ is the channel gain between the UAV and the sensor;
 P_m is the power of the transmitted signal from the sensor to the UAV;
 N_0 is the additive Gaussian noise power.

The objective of this study is to analyze the possibility of increasing R by optimizing the UAV operating mode.

Materials and methods

Let us assume that the data collection and transmission system shown in Figure 1 is clustered and brought into the form shown in Figure 2.

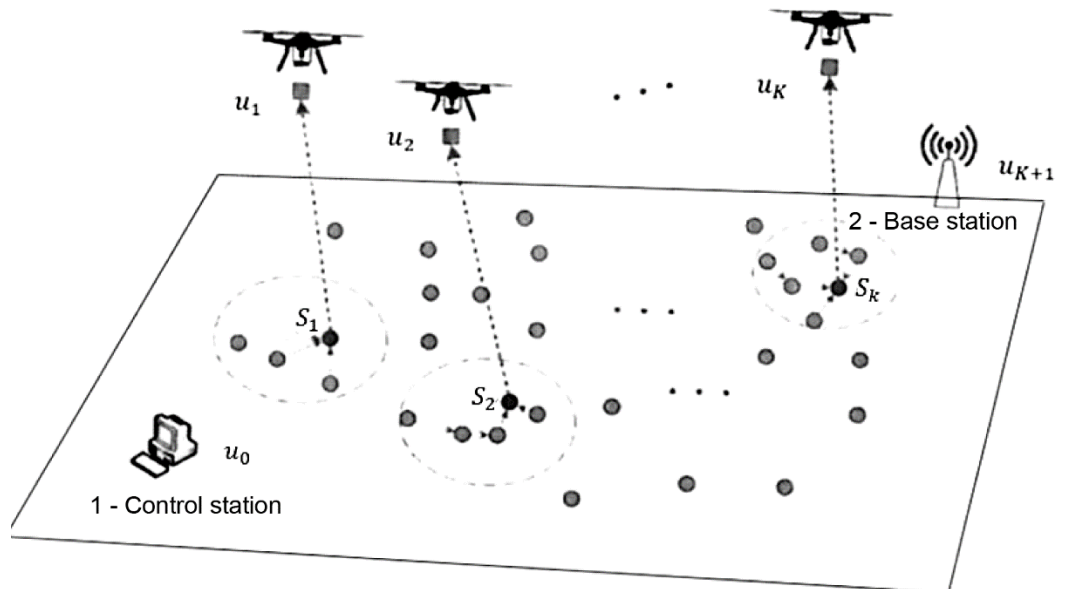


Figure 2. A system for collecting and transmitting data from clustered sensors using UAVs [4]

Let's assume that the communication channel of the i -th UAV contains white noise with intensity N_{0i} . Moreover, $i = \overline{1, n}$.

Let's adopt the following model N_{0i}

$$N_{0i} = N_{0i-1} + \Delta N_0$$

Where $\Delta N_0 = const$

$$N_{0,0} = 0. \quad (3)$$

Note that condition (3) implies the existence of an ordered set.

$$N_0 = \{N_{0i}\} \quad (4)$$

We also adopt the following model of the multiplier B

$$B_j = B_{j-1} + \Delta B \quad \text{where} \quad \Delta B = const$$

at $B_0 = 0; j = \overline{1, n}$.

The existence of an ordered set is also assumed.

$$B = \{B_j\} \quad (5)$$

Next, we introduce the following possible connection function for consideration.

$$N_i = \varphi(B_j) \quad (6)$$

Taking into account (2), (5), and (6), we construct the following discrete sum.

$$R_\Sigma = \sum_{j=1}^n B_j \cdot \log_2 \left(\frac{1 + |h(S_{m,U})|^2 \cdot P_m}{\varphi(B_j)} \right) \quad (7)$$

We write the discrete functional (7) in a conventional analog form.

$$R_\Sigma = \int_0^{B_{\max}} B \cdot \log_2 \left[\frac{1 + |h(S_{m,U})|^2 \cdot P_m}{\varphi(B)} \right] dB \quad (8)$$

To find the optimal form the function $\varphi(B)$, we impose the following constraint on this function.

$$\int_0^{B_{\max}} \varphi(B) dB = C; \quad C = const \quad (9)$$

Taking into account expressions (8) and (9), we construct the objective optimization functional F .

$$F = \int_0^{B_{\max}} B \cdot \log_2 \left[\frac{1 + |h(S_{m,U})|^2 \cdot P_m}{\varphi(B)} \right] dB + \lambda \left[\int_0^{B_{\max}} \varphi(B) dB - C \right] \quad (10)$$

where λ is the Lagrange multiplier.

The solution to optimization problem (10) according to the Euler-Lagrange method satisfies the condition

$$d \left\{ B \cdot \log_2 \left[\frac{1 + |h(S_{m,U})|^2 \cdot P_m}{\varphi(B)} \right] dB + \lambda \cdot \varphi(B) \right\} = 0 \quad (11)$$

From condition (11), we obtain

$$-\frac{B}{\varphi(B)} + \lambda = 0 \quad (12)$$

From expression (12), we find

$$\varphi(B) = \frac{B}{\lambda} \quad (13)$$

Let's calculate the Lagrange multiplier. To do this, using expressions (9) and (13), we obtain

$$\int_0^{B_{\max}} \frac{B}{\lambda} dB = C \quad (14)$$

From expression (14), we find

$$\lambda = \frac{B_{\max}^2}{2C} \quad (15)$$

Taking into account expressions (13) and (15), we obtain

$$\varphi(B) = \frac{2BC}{B_{\max}^2} \quad (16)$$

We will show that when solving (13), R_{Σ} reaches a maximum, i.e., the data transmission rate from the sensors to the UAV reaches a maximum. To do this, according to the Lagrange criterion, it is sufficient to calculate the second derivative of the integrand in (14) and verify that it is always negative.

Discussion

Thus, the problem of optimizing data collection from clustered ground sensors using a UAV swarm has been formulated and solved. An assumption has been made regarding the existence of a dependence between the intensity of Gaussian white noise in the UAV receiving channel and the bandwidth of the same channel. An integral constraint is applied to this dependence, significantly limiting the choice of the optimal function from the space of continuous and twice-differentiable functions.

An objective functional for optimizing the data collection system has been constructed. Application of the unconstrained variational optimization method and Euler's method to solve the optimization problem enabled the optimal form of the desired function to be obtained, for which the selected objective functional reaches its maximum.

Conclusion

The optimization of data collection using UAVs from clustered ground-based sensors is considered. It is shown that the data collection rate can be maximized when there is a direct linear relationship between the UAV data reception channel bandwidth and the intensity of white Gaussian noise in the receiving channel.

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