

Location Accuracy of a Ground Station based on RSS in the Rice Channel

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Abstract— The article presents the assessment of the potential accuracy of the location of the terrestrial radio signal source in the Rice channel using the received signal filtering and the non-linear regression function. The basic assumption for the parameterization of the channel was to use a drone with a simple antenna system and Received Signal Strength analysis from multiple measurement points (Multilateration location). Preliminary results under Rice-typical channel conditions indicate position estimation errors of the order of 60 meters for $K=7$, which in the assumed network structure is approximately 10% of the actual average distance. By using properly parameterized filtration systems (Kalman algorithm and Moving Average algorithm set), it is possible to increase this accuracy by one-third of the initial value.

I. INTRODUCTION

THE problem of locating the source of radio radiation is very broad. This task can be viewed as a service to a locator or located user. The method of its implementation varies depending, for example, on the type of services (military or civil), type of system, technical capabilities of devices (e.g. antenna set), conditions in which the task is performed (e.g. type of land cover, user traffic characteristics). In the changing world of technology, one of the recently popular branches of development is the area related to the use of unmanned aerial vehicles [1]-[3]. They are of course used for different purposes and hence can be classified differently.

This study assumes the use of simple, small Unmanned Aerial Vehicles (UAV) with an uncomplicated antenna system (omnidirectional antenna with low gain) and limited computing possibilities (e.g. [4]—[5]). These types of UAVs are relatively cheap and can perform various types of services in a team (e.g. a swarm of UAVs). The article considers the operation of a single UAV, which uses Received Signal Strength (RSS) recorded during the flight and the Multilateration method [6] to locate the radio signal source. Location methods based on RSS measurement belong to the Range Based group and are used relatively easily, realizing location with moderate accuracy, which can be increased by increasing the number of bearing points.

Technical details such as the curvature of the Earth resulting from geodetic corrections are omitted in the study. The results of the analysis shed additional light on the

potential averaged efficiency of using simple, single UAVs in the process of locating the radiation source based on a blind flight over the area of network operation, when the UAV performs other functions simultaneously [7].

Chapter 2 is a reference to the state of knowledge in the analyzed area. The following chapters describe the network structure (Chapter 3), the radio channel model (Chapter 4), the location method and filtering algorithms for the channel response (Chapter 5), and the results of simulation analyzes (Chapter 6).

II. RELATED WORKS

The use of UAVs to locate the source of radio radiation, both indoor and outdoor, is currently the subject of several research and applications. Depending on the goals to be achieved and the technical capabilities of tracking systems and radiation sources, various types of location methods are proposed in [8]—[13]. Others are used in military applications, others in civil applications.

In a situation where advanced technical support from ground nodes cannot be expected, the possibility of using a simple and easy to implement location method based on the measurement of the RSS is often considered (e.g. [14]—[17]). Such algorithms, in connection with the situation when we have a large number of measurement values (the UAV carries out a relatively large number of measurements during the flight while performing other tasks (e.g. securing the network integrity [7], [18]) may offer increased location accuracy, by using the so-called Multilateration algorithms (unlike Trilateration, when the location is based on information from only 3 measurement points [19].

When assessing the possible location accuracy, it should be taken into account that the channel distortions on the Air to Ground connections depend mainly on the type of terrain [20], however, it can be assumed that due to the elevation of the UAV above the ground level, signal fading is not very deep [21] and we often deal with a Rice channel with a coefficient from $K = 7$ to $K = 14$. Nevertheless, increasing the accuracy of the location requires additional filtration operations, the most popular of which are Kalman filtration [22] and the so-called Moving Average.

III. THE NETWORK STRUCTURE

From the point of view of the ground station location algorithm itself, the structure of the network does not matter much. However, to cover the issue in more practical reality,

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it was assumed that the task of the UAV, which performs the network flight and records signals from terrestrial [7] radio sources, is to indicate the location of nodes beyond the network coverage (not connected, Fig. 1) to undertake subsequent actions to connect them with the rest of the network (e.g. by sending retranslation drones). To average the results, tests were carried out for 4 different route cases, differing in the value of the parameter R , which can be interpreted as the turning radius of the UAV.

The following main assumptions were made about such a network:

1. The terrestrial network is relatively stationary
2. Network nodes do not support UAV measurements (they do not have GPS receivers).

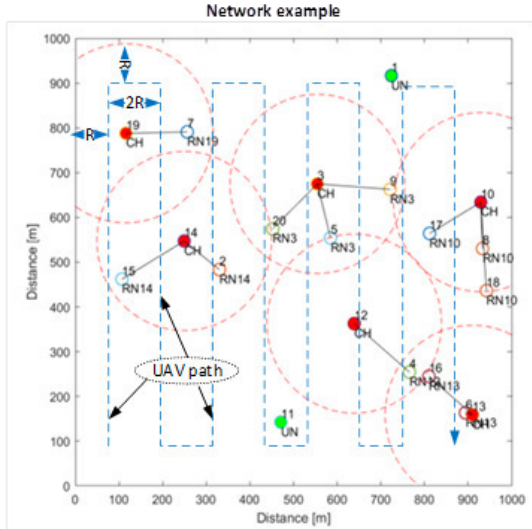


Fig. 1 An example of the location of 20 nodes of a clustered network. RN - Regular Node, CH - Cluster Head (red), UAV - Unmanned Aerial Vehicle (blue line), UN - Unknown Node (green, the disconnected node)

IV. THE RADIO CHANNEL MODEL

The characteristics of the radio channel for the case considered in the material (ground-air link of UAV) mainly depend on the following factors:

1. Drone flight altitudes.
2. UAV flight speed and associated Doppler shift.
3. Land cover (city, suburban area, mountainous area, etc.).
4. Network operating frequencies.
5. Volatility of the above-mentioned factors.

An overview of these types of channels can be found e.g. in [20]. Additional discussion of this type of propagation conditions, e.g. in [18]. The conditions assumed in this study assume an outdoor LOS (Line of Sight) link modelled by the Rice radio channel. According to the guidelines contained in [21], the K factor characterizing the depth of decays ranges from 7 to 14.

We can write down that for the Rice channel:

1. K factor being the ratio of the power of the direct ray to the value of the sum of the powers of the other reflected components

$$K = \frac{\vartheta^2}{2\delta^2}. \quad (1)$$

2. Ω factor as total received power

$$\Omega = \vartheta^2 + 2\delta^2. \quad (2)$$

The amplitude of the received signal is defined as:

$$\vartheta^2 = \frac{K}{1+K} \Omega \text{ and } \delta^2 = \frac{\Omega}{2(1+K)}; \quad (3)$$

and we write the probability density function as:

$$f(x) = \frac{2(K+1)x}{\Omega} \exp\left(-K - \frac{(K+1)x^2}{\Omega}\right) I_0\left(2\sqrt{\frac{K(K+1)}{\Omega}x}\right). \quad (4)$$

Exemplary realizations of the amplitude of the signal received by the UAV for the values of the coefficients $K = 7$ during a single flight over the network (along the selected route) are shown in Fig. 2. The model did not take into account the Doppler shift and antenna characteristics, assuming low UAV speed and omnidirectional characteristics of the antenna with zero gain.

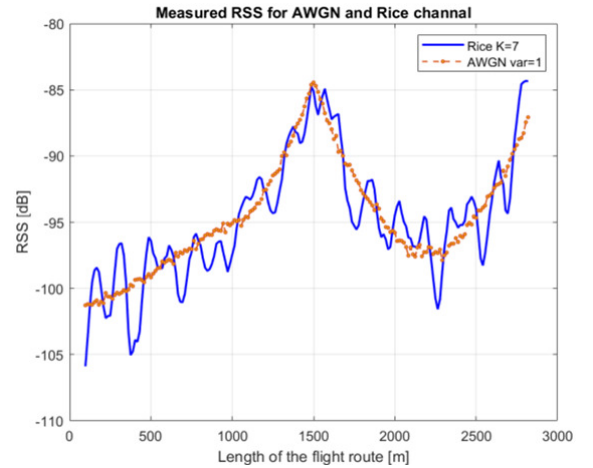


Fig. 2 The amplitude of the signal in the Rice channel for the coefficient $K = 7$

V. DESCRIPTION OF THE LOCATION METHOD

As mentioned in Chapter 2, you can find many literature sources describing different kinds of localization methods. However, if we accept the above-mentioned organizational and technical constraints imposed on network and UAV devices, the problem narrows significantly. In addition, it is worth noting that the assessment of the accuracy of the location in the Rice channel presented in this article is based on the assumption that we have a large set of measurement data, which results in the use of Multilateration algorithms [23], [6], Fig. 3.

Having the bearings from many points, we can save the estimated distance from the localized point in the form:

$$d_i^2 = (x_i - x)^2 + (y_i - y)^2, \quad (i = 1, 2, \dots, n), \quad (5)$$

where:

d – estimated distance from the localized point,
 x_i – coordinate x of DF no. i ,
 y_i – coordinate y of DF no. i .

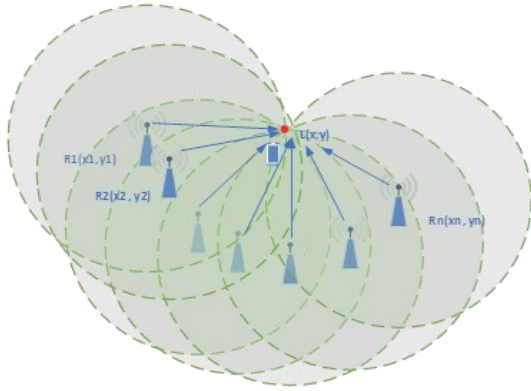


Fig. 3 An example of a directional finding using the Multilateration method with the use of n Directional Finders (DF). $L(x, y)$ - position of the localized station

The position of the signal source can be expressed, for example, in a general form as a solution to the algebraic equation [24]:

$$\begin{bmatrix} 1 & -2x_1 & -2y_1 & -2z_1 \\ 1 & -2x_2 & -2y_2 & -2z_2 \\ 1 & -2x_3 & -2y_3 & -2z_3 \\ \vdots & \vdots & \vdots & \vdots \\ 1 & -2x_n & -2y_n & -2z_n \end{bmatrix} \begin{bmatrix} x^2 + y^2 + z^2 \\ x \\ y \\ z \end{bmatrix} = \begin{bmatrix} d_1^2 - x_1^2 - y_1^2 - z_1^2 \\ d_2^2 - x_2^2 - y_2^2 - z_2^2 \\ d_3^2 - x_3^2 - y_3^2 - z_3^2 \\ \vdots \\ d_n^2 - x_n^2 - y_n^2 - z_n^2 \end{bmatrix}, \quad (6)$$

where z - coordinate z (in a spatial case).

Here, to determine the estimate of the radio signal source location, the MATLAB nonlinear regression function was used, giving the model function in the form $\text{modelfun} = @(b, X) (\text{abs}(b(1) - X(:, 1)).^2 + \text{abs}(b(2) - X(:, 2)).^2).^(1/2)$ and the starting point of searching for the optimal solution (position of the target station) in the center of the monitored plane.

To increase the accuracy of the location, the measured signal was pre-filtered. For comparison, Kalman filtering and 7 different Moving Average algorithms were used (Fig. 4).

In addition, before performing the proper location calculation, taking into account the fact that the filtered signal is subject to a time shift (delay), a corresponding correcting time shift and averaging window for the Moving Average methods were made individually for each filter result.

This action was aimed at minimizing the vector distance between the distorted original signal and the filtered signal according to the relationship:

$$\text{MinDistance} = \min \left| \sum_{i=1}^n \sqrt{R_i^2 + Y_i^2} - \sqrt{R_i^2 + Yf_i^2} \right|, \quad (7)$$

where:

- R_i – i -th point of the UAV route,
- Y_i - i -th RSS level of measured signal,
- Yf_i - i -th RSS level of filtered signal.

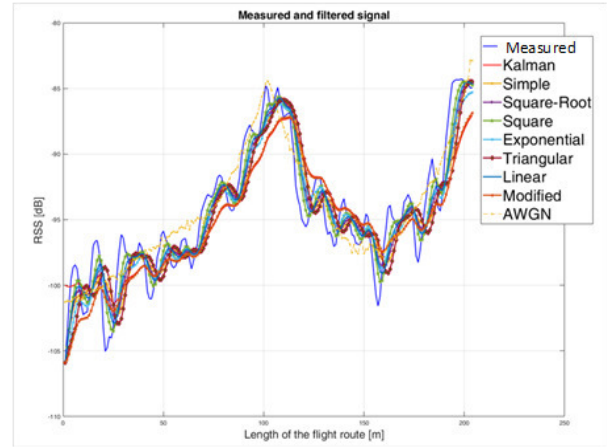


Fig. 4 The effect of applying filtration using various algorithms

This action resulted in a significant reduction in tracking errors.

VI. SIMULATION RESULTS

I. System parametrization

The simulations were carried out in the MATLAB R2021b simulation environment (9.11.0.1769968) using the parameters presented in Table . 30 channel conditions randomization was performed for each set value of the R and K parameters.

TABLE I.
SIMULATION PARAMETERS

Parameter	Value
Channel models	AWGN, Rice
K factor of Rice channel	7 to 14
Noise Variance	1
Number of UAV	1
The number of random repetitions of each case	30
Number of measures	In the range from 144 to 362 depending on the UAV route.
R [m]	100, 150, 200, 250

II. Results

The results of the simulation tests are shown in Fig.5 and Fig.6. It can be initially concluded that each of the filtration methods increases the efficiency of localization to a similar degree. The final error, in the analyzed cases, is the smaller the smaller the value of the K coefficient (channel with deeper fades), and for $K = 7$ it is about one-third smaller than the original value (Fig. 5).

The highest potential in the discussed distortion filtration process, in the range of small K values, is shown by Kalman filtration and the Simple Moving Average.

VII. CONCLUSION

The article assesses the accuracy of the location of the radio ground station in the Rice Channel based on RSS level measurements by the UAV flying around the entire network deployment area. As a result of the application of the Multilateration method and the nonlinear regression function

supported by the filtering algorithms of the measured signal, the location accuracy was improved by several to several dozen meters depending on the depth of the decays (the greater the effect, the deeper the value of the decays). The further direction of work will be related to research using other types of channels and verification of the obtained results in real channel conditions.

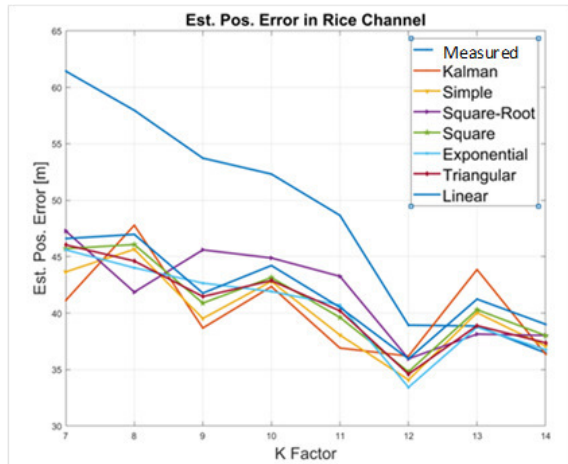


Fig. 5 Mean position error for Rice channels and various measurement signal filtering methods

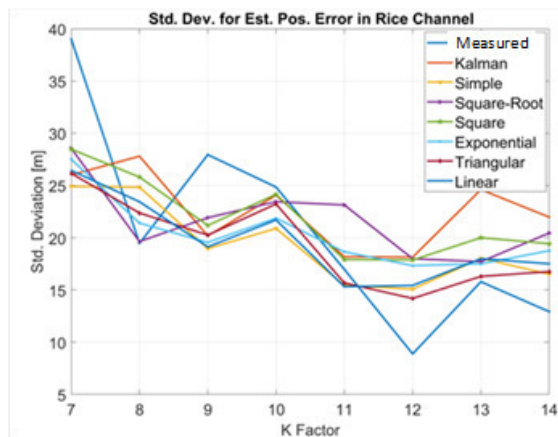


Fig. 6 The standard deviation for the mean position error in the Rice channels and different filtration methods

REFERENCES

- [1] H. Wang, H. Zhao, J. Zhang, D. Ma, J. Li, J. Wei, „Survey on Unmanned Aerial Vehicle Networks: A Cyber Physical System Perspective,” *IEEE Communications Surveys & Tutorials*, pp. 1027-170, vol.22, No.2, 2020
<http://dx.doi.org/10.1109/COMST.2019.2962207>.
- [2] T. D. Chuyen, H. V. Huy, T. L. Nguyen, „Control design of an UAV-Q based on feedback linearization and optimum modulus methods,” w *Proceedings of the Sixth International Conference on Research in Intelligent and Computing*, 2021, <http://dx.doi.org/10.15439/2021R20>.
- [3] T. Adam, F. Babič, „UAV Mission Definition and Implementation for Visual Inspection,” w *Proceedings of the 16th Conference on Computer Science and Intelligence Systems*, 2021, <http://dx.doi.org/10.15439/2021F24>.
- [4] N. Boonyathanming, S. Gongmenee, P. Kayunyeam, P. Wutticho, S. Prongnuch, „Design and Implementation of Mini-UAV for Indoor Surveillance,” *International Electrical Engineering Congress*, 10-12 March 2021, <http://dx.doi.org/10.1109/IEECON51072.2021.9440350>.
- [5] S. Gupte, P.I.T. Mohondas, J.M. Conred, „A Survey of Quadrotor Unmanned Aerial Vehicles,” *IEEE Xplore*, 2012, <http://dx.doi.org/10.1109/SECOn.2012.6196930>.
- [6] C.D. Morales, D. Guevara, M.A. Truvol, „Using Terrestrial Radio Links to Multilateration Techniques,” *IEEE COLCOM*, 2016, <http://dx.doi.org/10.1109/ColComCon.2016.7516389>.
- [7] J. Michalak, „Efficiency of selected drone flight algorithms in increasing the level of ad-hoc network connectivity without knowing the location of disconnected nodes,” *37th International Business Information Management Conference (IBIMA)*, May 2021.
- [8] S. Goswami, *Indoor Location Techniques*, Milpitas: Springer, 2013, <http://dx.doi.org/10.1007/978-1-4614-1377-6>.
- [9] Ed. H.A. Karimi, *Advanced Locatin-Based Technologies and Services*, London: CRC Press, 2013.
- [10] Ed. S.A.Zekavat, R.M. Buehrer, *Handbook of Position Location*, Hoboken: Wiley, 2012.
- [11] Y. Liu, Z. Yang, *Locatin, Localization and Localizability*, London: Springer, 2011, <http://dx.doi.org/10.1007/978-1-4419-7371-9>.
- [12] R.A. Poisel, *Electronic Warfare Target Location Methods*, Boston, London: Artech House, 2012.
- [13] F. Zafari, A. Gkelias, K.K. Leung, „A Survey of Indoor Localization Systems and Technologies,” *IEEE Communications Surveys & Tutorials*, 2019, <http://dx.doi.org/10.1109/COMST.2019.2911558>.
- [14] S. Uluscan, T. Filik, „A Survey on the Fundamentals of RSS based Localization,” 2016, <http://dx.doi.org/10.1109/SIU.2016.7496069>.
- [15] N. Saeed , H. Nam, T. Y. Al-Naffouri , M. S. Alouini, „A State-of-the-Art Survey on Multidimensional Scaling-Based Localization Techniques,” *IEEE Communications Surveys & Tutorials*, Vol.21 2019, <http://dx.doi.org/10.1109/COMST.2019.2921972>.
- [16] S. Bohidar, S. Behera, C. R. Tripathy, „A Comparative View on Received Signal Strength (RSS) Based location Estimation in WSN,” *IEEE International Conference on Engineering and Technology (ICETECH)*, March\ 2015, <http://dx.doi.org/10.1109/ICETECH.2015.7275032>.
- [17] Q.Duy, P.De, „A Survey of Fingerprint-Based Outdoor Localization,” *IEEE Communications Surveys & Tutorials*, 2016, <http://dx.doi.org/10.1109/COMST.2015.2448632>.
- [18] J. Michalak, „Location accuracy of a radio ground station in the Rice channel by the multilateration method with the use of non-linear regression function,” *39th International Business Information Management Conference (IBIMA)*, April 2022.
- [19] O.S. Oguejiofor, A.N. Aniedu, H.C., Ejiofor, A.U. Okolibe, „Trilateration Based localization Algorithm for Wireless Sensor Network,” *International Journal of Science and Modern Engineering*, Vol.1, Issue 10 September 2013.
- [20] W. Khawaya, I. Guvenc, D.W. Matolak, U.C. Fiebig, N. Schneckenburger, „A Survey of Air-to-Ground Propagation Channel Modeling for Unmanned Aerial Vehicles,” *IEEE Communicaitons Surveys & Tutorials*, Vol.21, No.3 2019, <http://dx.doi.org/10.1109/COMST.2019.2915069>.
- [21] Y.Diang, Y. Xiao, J. Xie, T. Zhang, „A Time-varying Transition Channel Model for Air-Ground Communication,” *IEEE Xplore*, 2017, <http://dx.doi.org/10.1109/DASC.2017.8102055>.
- [22] M.S. Grewal, A.P. Andrews, „Kalman Filtering, Theory and Practice Using MATLAB,” by *John Wiley & Sons, Inc.*, 2015.
- [23] M.N. Rahman, I.A.T. Hanuranto, R. Mayasari, „Trilateration and Iterative Multilateration Algorithm for Localization Schemes on Wireless Sensor Network,” *International Conference on Control, Electronics, Renewable Energy and Communications*, 2017, <http://dx.doi.org/10.1109/ICCEREC.2017.8226710>.
- [24] A. Norrdine, „An Algebraic Solution to the Multilateration Problem,” *International Conference on Indoor Positioning and Indoor Navigation*, 13-15 November 2012.