UAV-Based Target Terminal Search System for Emergency Rescue

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***Abstract*—It is very difficult to obtain accurate location information of a target terminal owned by a man-in-distress. Especially, if a target terminal is a legacy mobile phone or located in a GPS (Global Positioning System)-denied area, it is generally possible to obtain the cell information where a target terminal is located. In this case, search time for a target terminal becomes too long to search a man-in-distress within golden time. To obtain the location, HELPS (Hyper-Enhanced Local Positioning System) was proposed and its performance was evaluated [1]. As cell size increases, the time required to search a target terminal increases with HELPS. In this paper, a novel search system is presented to find the accurate location of a target terminal owned by a man-in-distress. In the proposed system, a UAV (Unmanned Aerial Vehicle) is equipped with SME (Signal Measurement Equipment), which measures the signal transmitted from a target terminal. UAV navigates and changes its direction based on the AoA (Angle of Arrival) of the measured signal. To evaluate the performance of the proposed system, a simulator was built. The simulation results show that accurate location information can be obtained within golden time in most cases.**

***Index Terms*—Emergency Location Service, Localization, UAV, Angle of Arrival.**

I. INTRODUCTION

In case of emergency, it is crucial to find the accurate location information of a man-in-distress. Since most emergency calls are originated from a mobile terminal owned by a man-in-distress, there has been several studies and researches to obtain the accurate location of the mobile terminal [2]–[5].

Traditionally, the emergency location information has been obtained using the measurements on cellular downlinks, WiFi (Wireless Fidelity) and bluetooth signal as well as GPS (Global Positioning System) measurement in a target mobile phone [6], [7]. It is not possible to receive GPS signals indoors. In addition, it is difficult to obtain accurate location information using GPS in environments with big obstacles. WiFi or bluetooth based location has limited service area and accuracy. Furthermore, some legacy phones do not support GPS or WiFi-based location information in emergency environments.

To overcome the accuracy limitation in emergency location services, HELPS (Hyper-enhanced Local Positioning System) has been proposed [1]. HELPS is composed of SME (Signal Measurement Equipment), LCS (Location Calculation Server), a target terminal and a base station which is connected to a target terminal. With HELPS, a serving base station commands a target terminal to transmit a predetermined uplink signal. First responders with portable SME search for a target terminal based on the measurement of SME for the uplink signal transmitted from a target terminal. As SME approaches a target terminal, the received signal strength for a target terminal increases. Therefore, HELPS can provide location information with unlimited accuracy. Furthermore, it is possible to obtain accurate location information for all mobile terminals without modification.

With HELPS, accurate location information can be obtained, as SME moves around the uncertainty range of the location of a target terminal. As the uncertainty range of a target terminal increases, the time required to search a target terminal increases. To overcome the problem of large search time in a large uncertainty condition, in this paper, a novel search system is presented to find the accurate location of a mobile terminal owned by a man-in-distress. The proposed search system is based on a UAV (Unmanned Aerial Vehicle) with SME. The UAV with SME can obtain the AoA (Angle of Arrival) of the signal which a target terminal transmits and navigate to search a target terminal [8]. With the proposed search system based on a UAV, it is possible to search a target terminal in a short time, even in a large cell environment. The performance of the proposed search system is evaluated by simulation.

II. PROPOSED SEARCH SYSTEM

In this paper, a search system is proposed for a target terminal owned by a man-in-distress located within a cell. To search for a target terminal, SME designed for HELPS is installed in a UAV. The UAV with SME is initially located within a cell and navigates to find the accurate location of a target terminal.

Antennas in a uniform circular array are installed in the UAV to enable omnidirectional AoA estimation for signals transmitted from a target terminal [9]. Based on the AoA estimation result, a UAV navigates to the estimated direction searching for a target terminal.

UAV changes direction according to the AoA estimation result, which is obtained using a MUSIC algorithm [10] [11]. The performance of the MUSIC algorithm-based AoA

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estimation is highly dependent on the received SNR at the UAV.

For AoA estimation based on a MUSIC algorithm, SME computes the spatial spectrum value for a received signal over a fixed time interval. To obtain a more reliable AoA estimation, SME non-coherently accumulates the spectrum values measured in different time. The non-coherent accumulation can be expressed as

$$P_{acc}(\theta) = \sum_{k=1}^{K} P_{MUSIC,k}(\theta), \qquad (1)$$

where $P_{MUSIC,k}(\theta)$ is the spatial spectrum value computed during the k-th time internal and K is the number of non-coherent accumulations. After accumulation, the AoA is determined as the angle corresponding to the maximum of $P_{acc}(\theta)$ [12] [13].

Depending on the received SNR, the cell is divided into three different regions, which are low SNR, medium SNR, and high SNR regions. The low SNR region is the area where the received SNR is lower than a threshold T_1. The high SNR region, on the other hand, is the area where the received SNR exceeds another threshold T_2. The medium SNR region is where the received SNR is between T_1 and T_2. If the UAV is located in the lower SNR region, the accuracy of the AoA estimation becomes lower. Therefore, considering the AoA accuracy depending on the received SNR, different number of accumulations is performed in each region.

TABLE I
SEARCH PARAMETERS OF THREE SNR REGIONS

Region	Moving distance between direction changes (m)	Time spent in each movement (sec)
Low SNR	500	20
Medium SNR	100	5
High SNR	20	2

Table I shows an example of the search parameters of three SNR regions. The UAV changes direction after moving 500 m, 100 m and 20 m in a low, medium and high SNR regions, respectively. As the UAV is located in lower SNR regions, SME accumulates more times instant spatial spectrum values to obtain a more reliable AoA estimation.

III. SIMULATION RESULTS

The performance of the proposed search system was evaluated using a simulator. The simulator is composed of a UAV with SME, a target terminal, and a wireless channel model. For the estimation of AoA based on a MUSIC algorithm, 8 antennas are installed in the UAV.

Search tasks for a target terminal were simulated for rural channel with an elevation angle of 10°. The probability of LoS (Line-of-Sight) was set for each channel considering the elevation angle [14]. SME computes a spatial spectrum value for a measurement time interval of 1 ms. All measurement time intervals are separated by 100 ms, which is the period of signals transmitted from a target terminal for HELPS operation. Therefore, all short-term fadings which the transmitted signals experience become independent of each other. Since the UAV navigates more than 20 meters after a direction change, the AoA estimation is assumed to be obtained for an independent shadowing and LoS probability.

The received power at the SME P_{RX} can be expressed as

$$P_{RX} = P_{TX} + P_0 - CL - 10n \cdot \log_{10} d + N + \psi, \qquad (2)$$

where P_{TX} is the transmission power of a target terminal, P_0 is the received signal power at a distance of 1 meter from the target terminal of which transmission power is 0 dBm, CL is clutter loss, n is a path loss exponent, d is the distance between the SME and the target terminal, N is the spectral density of a thermal noise, and ψ is a shadowing component.

Simulations are performed in a cell, of which center a base station is located. The radius of a cell is assumed to be 5, 10 or 20 km. For each search task, the location of a target terminal is uniformly located within a cell. The UAV is assumed to start a search task from the center of the cell. If the distance between the target terminal and the UAV is less than 20 meters, the search task is finished.

TABLE II
SIMULATION RESULT (RURAL)

Cell radius (km)	Average number of direction changes			Average search time (sec)
	Low SNR region	Medium SNR region	High SNR region	
5	3.1	15.2	6.9	151.8
10	10.1	16.0	7.0	296.0
20	23.0	16.0	7.0	554.0

Table II show the simulation results obtained from 300 search tasks for the proposed search system. The results are obtained for rural channel. The simulation results include the average number of UAV direction changes in each SNR region and the average search time spent for a search task. As the cell radius increases, the average search time increases from 151.8 seconds to 554.5 seconds, and the average number of UAV direction changes in a low SNR region increases from 3.1 to 23.0. The average number of UAV direction changes does not change significantly in medium or high SNR region.

From the results, it can be observed that the average search time increases as the cell radius increases. As the cell radius increases, it can be observed that the number of direction changes increases in low SNR region but does not change significantly in medium and high SNR regions.

IV. CONCLUSION

In this paper, a UAV-based search system is proposed to search the target terminal owned by a man-in-distress using HELPS. The performance of the search system is evaluated via simulation in rural channel. The simulation results show that the search time increases as cell radius becomes larger. With the proposed search system, it is possible to search a target terminal in a reasonable time even in a large cell environment.

REFERENCES

[1] H. Moon, H. Park and J. Seo, "HELPS for emergency location service: Hyper-enhanced local positioning system," *IEEE Wirel. Commun.*, vol. 31, no. 4, pp. 276–282, Aug. 2024.

[2] A. Albanese, V. Sciancalepore and X. Costa-Pérez, "SARDO: An automated search-and-rescue drone-based solution for victims localization," *IEEE Trans. Mobile Comput.*, vol. 21, no. 9, pp. 3312-3325, Sep. 2022.

[3] M. Atif, R. Ahmad, W. Ahmad, L. Zhao and J. J. P. C. Rodrigues, "UAV-assisted wireless localization for search and rescue," *IEEE Syst. J.*, vol. 15, no. 3, pp. 3261-3272, Sep. 2021.

[4] C. Kyrkou and T. Theocharides, "EmergencyNet: Efficient aerial image classification for drone-based emergency monitoring using atrous convolutional feature fusion," *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 13, pp. 1687-1699, Mar. 2020.

[5] E. T. Alotaibi, S. S. Alqefari and A. Koubaa, "LSAR: Multi-UAV collaboration for search and rescue missions," *IEEE Access*, vol. 7, pp. 55817-55832, Apr. 2019.

[6] X. Zhu, W. Qu, T. Qiu, L. Zhao, M. Atiquzzaman and D. O. Wu, "Indoor intelligent fingerprint-based localization: principles, approaches and challenges," *IEEE Commun. Surv. and Tutor.*, vol. 22, no. 4, pp. 2634-2657, 4th Quart., 2020.

[7] F. Zafari, A. Gkelias and K. K. Leung, "A survey of indoor localization systems and technologies," *IEEE Commun. Surv. and Tutor.*, vol. 21, no. 3, pp. 2568-2599, 3rd Quart., 2019.

[8] F. Zhou, W. Zhang, B. Zhang, X. Ji and X. Li, "DOA estimation algorithm based on spread spectrum sequence in low signal-to-noise ratio," *EURASIP J. Wirel. Commun. Netw.*, vol. 2022, p. 60, Jul. 2022.

[9] M. Amine and B. Seddik, "2-D DOA estimation using MUSIC algorithm with uniform circular array," in *Proc. 2016 4th IEEE Int. Colloq. on Inf. Sci. and Technol.*, pp. 850-853, Oct. 2016.

[10] Y. Gao, W. Chang, Z. Pei and Z. Wu, "An improved music algorithm for doa estimation of coherent signals," *Sensors and Transducers*, vol. 175, no. 7, pp. 75–82, 2014.

[11] M. M. Gunjal and A. B. Raj, "Improved direction of arrival estimation using modified MUSIC algorithm," *IEEE Inter. Conf. Commun. Electron. Syst. (ICCES)*, Jun. 2020, pp. 1-6.

[12] Z. Wang, T. Zhao and Z. Wang, "A MUSIC like DOA estimation method for signals with low SNR," *IEEE Global Symp. on Millimeter Waves*, pp. 321-324, Apr. 2008.

[13] L. Zhou, Y.-J. Zhao and H. Cui, "High resolution wideband DOA estimation based on modified MUSIC algorithm," in *Proc. Int. Conf. Inf. Autom.*, Jun. 2008, pp. 20-22.

[14] 3GPP TR38.811, *Study on New Radio to support non-terrestrial networks*, v.15.4.0, Oct. 2020.