A Location Estimation Algorithm Combined with TDOA and TOA Considering Repeaters

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Abstract**—** Location Detection Technology (LDT), which accurately estimates the location of a mobile station (MS), is one of core techniques for the modern communication system. Among various LDTs, Time of arrival (TOA) and Time Difference of Arrival (TDOA) are the most commonly employed method, which calculates the location of MS based on at least three signals from base stations (BSs). In the urban environment, many repeaters have been installed for overcoming the radio shadow area problem of a receiver, but they cause the serious errors of the location estimation when we utilize signals passed through repeaters. In order to enhance this problem, in this paper, we introduce the combined location estimation approach with TDOA and TOA considering the repeater, based on signals from two repeaters and one BS.

Keywords— Localization; TDOA; TOA; Repeater; Combined Location Estimation;

I. INTRODUCTION

The importance of Location Based Service (LBS) with a variety of applications from the commercial industry including biohealth to the military industry has been increased, as the modern communication system has been developed. The Location Detection Technology (LDT) is the most important technique of LBS, which accurately estimates locations of users or objects utilizing the communication service [1]. There are various estimation methods in LDT, such as Cell ID, Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), Frequency Difference of Arrival (FDOA), etc. The Cell ID method matches a Cell ID to find out the location of the mobile station (MS), and the AOA technique calculates the MS's position using the direction angle of the received signal. TOA, TDOA, and FDOA estimate the MS's location by measuring the time of arrival radio waves, the arrival time difference of signals transmitted from different BSs, and the Doppler frequency difference of signals, respectively [2][3][4].

The urban environment has a huge number of radio interfering or jamming factors causing the radio shadow area [5]. Although, in order to minimize this problem, as possible as many BSs are required in the urban area, that is inefficient due to their high cost. Since the repeater is one of the excellent solutions for this problem, in general, a huge number of repeaters are installed in the urban area [6]. However, it is not possible to use signals passed through the repeater, because we cannot accurately measure TOA or the transmitted distance from BSs, based on those signals. If signals passed through the repeater are directly utilized for estimating MS's location, the huge estimation errors may be generated.

In order to enhance this issue, in this paper, we propose the combined location estimation technique with TDOA and TOA considering the repeater. First, it calculates the signal arrival time between a repeater and MS employing the modified TDOA formula. From this processing, we obtain two TOAs based on two repeaters and calculate two distances between two repeaters and MS. Finally, we estimate the MS's location based on these two distances and the distance between BS and MS, which can be easily calculated, employing the trilateration method.

II. MODIFIED TDOA CONSIDERING REPEATERS

The conventional TDOA method calculates the time difference between two BSs and MS based on the received signals [7][8]. In this section, we introduce the modified TDOA formula for considering repeaters.

Fig. 1 shows the basic concept of the wireless communication between BS and MS including two repeaters, in the specific situation considered in this paper. In the figure, t_1 is the arrival time from BS to MS which can be easily measured. In addition, t_2 and t_3 are the arrival times from BS to MS passed through repeater1 and repeater2, respectively, defined as

$$t_2 = t_{21} + t_{22}$$
$$t_3 = t_{31} + t_{32} \quad (1)$$

where t_{21} and t_{22} are the transmitted time from BS to repeater1 and from repeater1 to MS, respectively, and t_{31} and t_{32} are the transmitted time from BS to repeater2 and from repeater2 to MS, respectively. Note that we may have the information of t_{21} and t_{31} measured priori when these repeaters are installed in the specific locations. In addition, we assume that t_{21} and t_{31} include all inner processing times required in each repeater. The time differences between time from BS to MS passed through repeater1 and time from BS to MS directly and between time from BS to MS passed through repeater2 and time from BS to MS directly are given by

$$\tau_{2,1} = t_2 - t_1$$
$$\tau_{3,1} = t_3 - t_1 \quad (2)$$

Based on equations (1) and (2), the arrival times from repeater1 to MS and from repeater2 to MS, required for estimating the actual location of MS, can be calculated by

$$\hat{t}_{22} = \hat{\tau}_{2,1} - t_{21} + \hat{t}_1$$
$$\hat{t}_{32} = \hat{\tau}_{3,1} - t_{31} + \hat{t}_1 \quad (3)$$

where $\hat{\tau}_{2,1}$ and $\hat{\tau}_{3,1}$ are the measured values of $\tau_{2,1}$ and $\tau_{3,1}$, respectively, and $\hat{t}_1$ is the measured arrival time from BS to MS. The measured or calculated values, $\hat{t}_1$, $\hat{t}_{22}$, and $\hat{t}_{32}$ are applied to calculating distances from BS or repeaters to MS, for estimating the MS's location based on the trilateration technique.

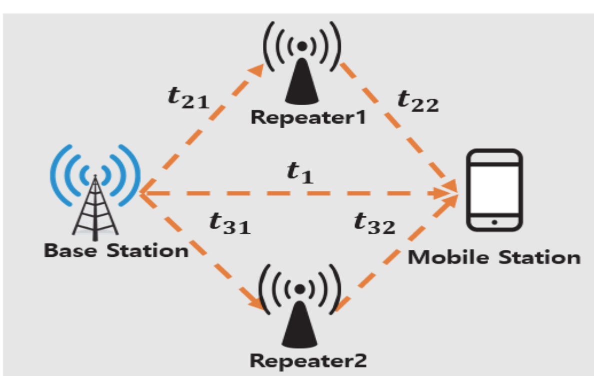

Fig. 1. Concept of wireless communication between BS and MS including two repeaters

III. TOA Trilateration for Estimating MS

The TOA trilateration method is designed to estimate the MS's location based on three circles with each BS's coordinate and radius equal to the distances from BS to MS. It estimates the MS's location to the intersection of these three circles. In this paper, the TOA trilateration estimates the MS's location based on three circles with coordinates of one BS and two repeaters and three radii of distances calculated from $\hat{t}_1$, $\hat{t}_{22}$, and $\hat{t}_{32}$ which are obtained in the previous section, instead of three BSs.

The measured or calculated arrival time, $\hat{t}_1$, $\hat{t}_{22}$, and $\hat{t}_{32}$ are employing to calculate distances as

$$d_1 = c \times \hat{t}_1$$
$$d_2 = c \times \hat{t}_{22} \quad (4)$$
$$d_3 = c \times \hat{t}_{32}$$

where d_1, d_2, and d_3 are distances between BS and MS, between repeater1 and MS, and between repeater2 and MS, c is the speed of propagation. Based on the calculated three distances and coordinates known prior, the TOA trilateration method draws three circles and calculates an intersection point of them as the MS's location. Ideally, since three circles should meet at a point, they have three intersection points. However, they do not meet at a point, and they have six intersection points like an example shown in Fig 2, because the arrival time is estimated by counting the number of time delay or measuring the power of signal.

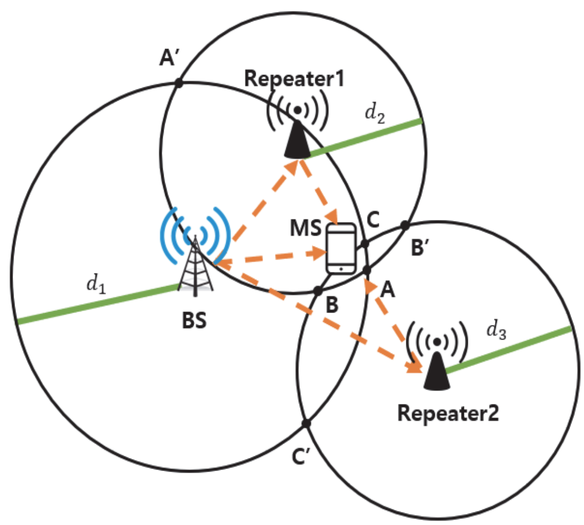

Fig. 2. Example for estimating MS's location based on BS and two repeaters

In order to calculate the MS's coordinate, in this paper, we employ the shortest distance algorithm [9], and the final estimated MS's location is given by

$$\hat{x} = \frac{A_x + B_x + C_x}{3}$$
$$\hat{y} = \frac{A_y + B_y + C_y}{3} \quad (5)$$

where (A_x, A_y), (B_x, B_y), and (C_x, C_y) are coordinates of the inner intersection with two repeaters, the inner intersection of BS and repeater2, and the inner intersection of BS and repeater1, respectively.

The combined location estimation method with TDOA and TOA proposed in this paper, that it calculates TOAs from repeaters to MS employing the modified TDOA and estimates the MS's location based on signals transmitted from BS and passed through BS, is summarized in Fig 3.

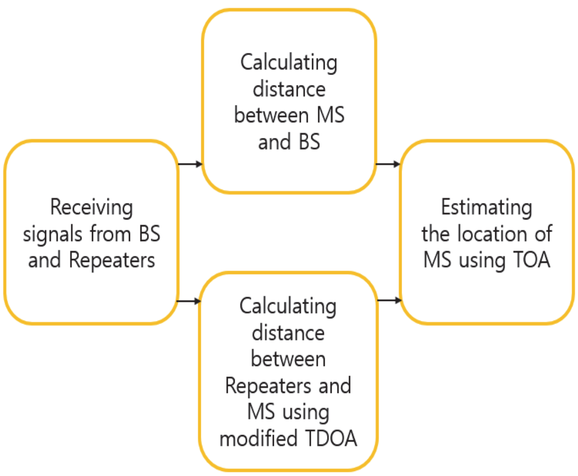

Fig. 3. Block diagram of the combined location estimation method with TDOA and TOA considering repeaters

IV. Computer Simulation

In this section, we provide the computer simulation examples for illustrating the performance of the proposed location estimation approach based on the combined TDOA and TOA technique considering repeaters. For simulations, we consider two scenarios:

1. Scenario1

   BS: (-3000, 700), two repeaters: (-1000, 2500), (-500, -2000)

2. Scenario2

   BS: (2000, 1000), two repeaters: (500, 700), (700, -2500)

In Scenario1 and Scenario2, the given values in the bracket are coordinates of BS and repeaters, and the unit is meter (m). In addition, the MS's locations in Scenario1 and Scenrio2 are arbitrarily chosen in ranges of (0~500, 0~500) and (-200~200, -200~200), respectively. Fig. 4 and Fig. 5 show layouts of BS, repeaters, and MS, for Scenario1 with the MS coordinate of (250, 250) and for Scenario2 with the MS coordinate of (0, 0), respectively.

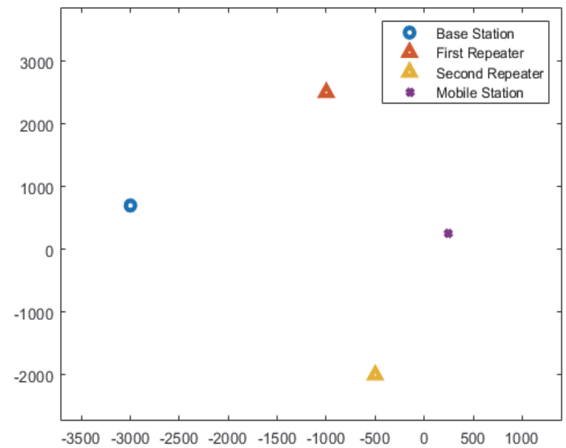

Fig. 4. Layouts for Scenario1

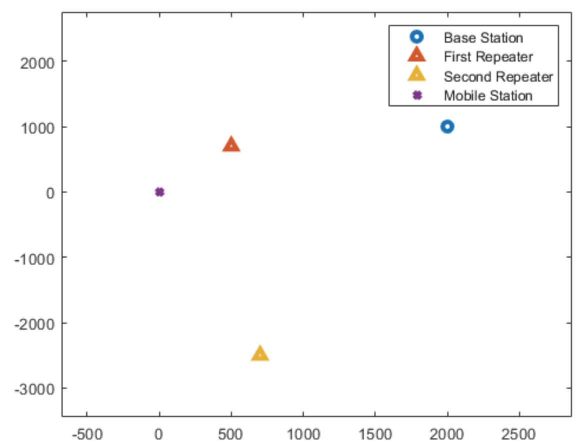

Fig. 5. Layouts for Scenario2

In order to present the performance of the proposed location estimation technique and compare it to the conventional one, we consider Root Mean Square Error (RMSE) defined as

$$RMSE = \sqrt{\frac{E\left[(x-\hat{x})^2\right] + E\left[(y-\hat{y})^2\right]}{2}} \quad (6)$$

where (x, y) is the actual coordinates of MS. Fig. 6 and Fig. 7 show RMSE curves for the proposed estimation techniques and the TOA trilateration algorithm as a conventional method, for Scenario1 and Scenario2, respectively, versus various carrier frequencies (100MHz, 500MHz, 1GHz, 5GHz and 10GHz). Since the general TOA trilateration technique does not consider the repeater, we assume that two BS coordinates for the general TOA trilateration are the same as two coordinates of repeaters in each scenario. In addition, each RMSE value is calculated by repeating 10,000 times for each frequency. Although the proposed location estimation technique considers repeaters unlike the conventional TOA trilateration, from figures, we observe that both methods have the similar estimation performances (RMSEs) in both scenarios.

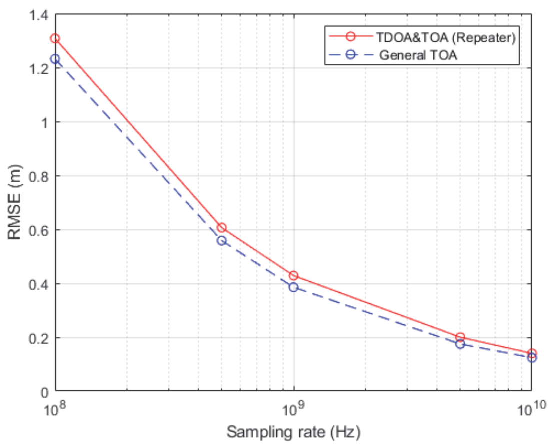

Fig. 6. RMSE curves for the proposed location estimation technique and the conventional TOA trilateration technique for Scenario1

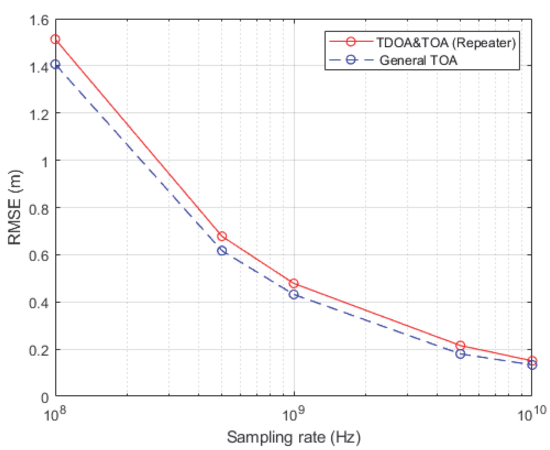

Fig. 7. RMSE curves for the proposed location estimation technique and the conventional TOA trilateration technique for Scenario2

V. Conclusion

A huge number of repeaters installed in urban area for compensating the radio shadow area problem, may cause the serious errors for estimating the MS's location. In order to enhance this problem and use repeaters more efficiently, in this paper, we proposed the combined location estimation technique with TDOA and TOA, for considering signals passed through repeaters. After it calculates time of arrival from repeaters to MS, employing the modified TDOA, it estimates the MS's location using three circles based on three distances calculated by the modified TDOA. The proposed combined technique does not only consider signals passed through repeaters, but it also has the similar estimation performance to the conventional TOA trilateration method.

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References

[1] S. Hwang, J. Yi, S. Yoon and Y. Kwon, "APPARATUS AND METHOD FOR POSITIONING IN WIRELESS COMMUNICATION SYSTEM," Korea Patent no. 10-1048444, Nov. 2011.

[2] D. Kim, J. Park, M. Lee, Y. Park and H. Kim, "Analysis on the Minimum Required Time of TDOA/FDOA Extraction for Target Performance Based on Communication Signals," Proc. of Symposium of the Korean Institute of communications and Information Sciences, 2015, pp. 250-251.

[3] S. Kwon, D. Kim, S. Moon, J. Lee, S. Bae, H. Kim, Y. Lim, D. Kim, C. Kim and I. Hwang, "3D Localization for a Launch Vehicle using Virtual TOA, AOA, and TDOA," J. Institute of Electronics and Information Engineers, vol. 55, no. 1, 2018, pp. 3-14.

[4] I. Guvenc and C. Chong, "A survey on TOA based wireless localization and NLOS mitigation techniques," IEEE Communications Surveys Tutorials, vol. 11, no. 3, 2009, pp. 107-124.

[5] S. Kim, H. Choi, Y. Park, G. Han and C. Cho, "Repeater Effect Suppression Method for TDOA algorithm in CDMA system,"2007 4th Workshop on Positioning, Navigation and Communication, 2007, pp. 171-175.

[6] D. Cho, K. Kim, S. Lee, M. Kim, K. Kim, B. Park and H. Ko, "The Design of Smart Antenna Structures for RF Repeater," Journal of the Institute of Convergence Signal processing, vol. 14, no. 2, 2013, pp. 110-116.

[7] B. Jin, X. Xu and T. Zhang "Robust Time-Difference-of-Arrival(TDOA) Localization Using Weighted Least Squares with Cone Tangent Plane Constraint," Senors, vol. 18, no. 3, Mar. 2018, p.778.

[8] Z. Su, G. Shao and H. Liu, "Synchronization-Free Model with Signal Repeater for Timing-Based Localization,"IEEE 84th Vehicular Technology Conference, 2016, pp.1-5.

[9] S. Pradhan and S. Hwang, "A TOA Shortest Distance Algorithm for Estimating Mobile Location," J. of the Korea institute of electronic communication sciences, vol. 8, no. 12, Dec. 2013, pp. 1883 -1890