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모바일 위치추정을 위한 TOA 최단거리 알고리즘

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A TOA Shortest Distance Algorithm for Estimating Mobile Location

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요 약

위치 추정 기술 (LDT, Location Detection Technology)은 자원관리 및 통신 서비스의 품질을 향상시키기 위한 무선통신 분야에서 사용되고 있는 LBS(Location Based Service)의 핵심기술 중 하나이다. 이동국(MS, mobile station)의 위치는 세 개의 기지국(BS, base station)들의 좌표와 이동국과 기지국들 사이의 거리에 상응하는 반지름에 기초한 세 개의 원들에 기반한 도래시간(TOA, Time of Arrival)기법을 사용하여 추정된다. 삼각변 측량법을 이용하여 정확한 이동국의 위치를 추정하기 위해서는 세 개의 원들이 한 점에서 만나야 하는데, 이동국과 기지국의 거리를 추정하기 위한 시간지연 개수와 전송 주파수에 따라 원들의 반지름이 증가하여 세 개의 원들이 한 점에서 만나지 못하는 경우들이 발생한다. 반지름이 증가된 세 개의 원들은 여섯 개의 교점을 가지게 되고 이 교점들 중 세 개의 교점들이 특정 이동국의 좌표에 가까이 위치하게 된다. 본 논문에서는 여섯 개의 전체 교점들 중에서 세 개의 내부 교점들을 선택하는 TOA 삼각변 측량법을 위한 최단 거리 알고리즘을 제안한다. 제안된 방법은 여섯 개의 교점들 중 이동국의 좌표와 가장 가까운 세 개의 교점을 선택하고, 선택된 교점들의 평균 좌표를 특정 이동국의 위치로 결정한다. 제안된 알고리즘의 성능은 컴퓨터 시뮬레이션 예를 통해 확인된다.

ABSTRACT

Location detection technology (LDT) is one of the core techniques for location based service (LBS) in wireless communication for improving resource management and quality of services. The location of a mobile station (MS) is estimated using the time of arrival (TOA) technique based on three circles with centers corresponding to coordinates of three base stations (BSs) and radius corresponding to distances between MS and BSs. For accurately estimating the location of MS, three circles should meet at a point for the trilateration method, but they generally do not meet a point because the radius is increased depending on the number of time delay for estimating the distance between MS and BS and the carrier frequency. The increased three circles intersect at six points and the three intersection points among them should be generally placed close to coordinate of the location for the specific MS. In this paper, we propose the shortest distance algorithm for TOA trilateration method, to select three interior intersection points from entire six points. The proposed approach selects three intersection points with the shortest distances between coordinates of MS and intersection points and determines the averaged coordinate of the selected three points, as the location of the specific MS. We demonstrate the performance of the proposed algorithm using a typical computer simulation example.

키워드

Location Detection Technology, Time of Arrival (TOA), Trilateration Method, Location Based Service (LBS)
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Ⅰ. Introduction

With the rapid development of communication systems, the mobile location detection and estimation technique have generated the great interest in the fields of cellular and wireless local area networks. New technologies and algorithms for the mobile location estimation have found more and more applications in everyday life. Researchers around the world are pushing to get high performance mobile location facilities with low cost, high precision, and high reusability of component.

U.S. Federal Communication (FCC) mandated cellular providers to generate MS location for Enchanced-911 services [1]. It specified that for at least 95% of emergency calls, a resolution of 300m must be achieved in a first instance and that the resolution should be increased to 150m for improved systems. Further 67% of the calls must be located within an error of 100m in the initial stage and 50m in the improved phase. The various approaches of LDT have also been given in [2-6].

Location based services (LBS) involve the ability to find the geographical location of MS and to provide services based on its location information, and it is classified as emergency services, informational services, tracking services, and entertainment services. Emergency services include security alerts and public safety [7-9], and informational services include news, sports, weather, and stocks, etc. Tracking services include asset, fleet, logistic monitoring, and person tracking, and entertainment services include locate a friend, dating, and gaming etc [10, 11].

In this paper, the location of MS is found out by an intersection of three circles with center being BS's location and radius being the distance between MS and each BS. Since the distance between them is estimated counting the number of time delay, three circles might be increased and they do usually not intersect at a single point to give the location of MS. Instead of that they meet at a point, there generally exist six intersection points from three circles. This problem should cause the performance degradation for accurately estimating the location of MS. In order to solve this problem, we propose the shortest distance algorithm based on the selection of three interior intersection points among entire intersection points. The proposed approach determine the averaged coordinate of three selected intersection coordinates as a location coordinate of the specific MS.

The rest of the paper is organized as follow: Section Ⅱ describe the proposed mobile location estimation algorithm so called shortest distance algorithm. The performance of the proposed algorithm is discussed by simulation design and results in Section Ⅲ. Finally, conclusions are presented in Section Ⅳ.

Ⅱ. Shortest Distance Algorithm for Accurately Estimating MS Location

In this section, we present the shortest distance algorithm to solve the problem for the MS location estimation, caused by the unmatched intersection point of three circles based on center coordinates of three BSs and radius corresponding distances between MS and each BS.

2.1 Shortest Distance Algorithm

There are two fundamental principles such as the triangulation and trilateration, used in traditional localization algorithm for MS.

While the triangulation method determines the location of MS based on measuring angle of the received signal from BSs, the trilateration method estimates the location of the specific MS using at least three quadratic equations based on three circles with center point corresponding to the coordinates of BS and the radius corresponding to

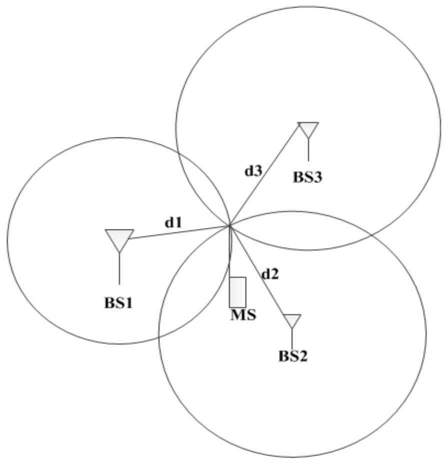

Fig. 1 Trilateration method for estimating the location of MS

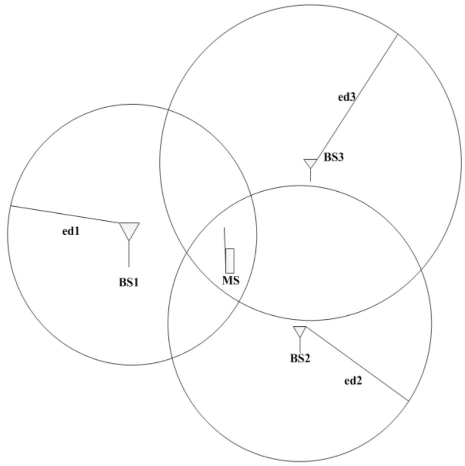

Fig. 2 Three circles based on increased distances between MS and BSs

the distance between MS and each BS. In order to estimate the location of MS using the trilateration method, three circles must intersect at a single point shown in Fig. 1. In Fig.1, $d_1, d_{2,}$ and d_3 denote the distances between MS and BS1, BS2, and BS3, respectively. The trilateration method is based on TOA or the received signal strength (RSS) measurements whereas triangulation is based on the angle of arrival (AOA) measurements [12-15]. In this paper, we focus on the location estimation approach based on the trilateration and TOA methods.

The distance between MS and the ith BS, denoted by d_i, is given by

$$d_i = \sqrt{(x-x_i)^2+(y-y_i)^2},\ i=1,2,3. \quad (1)$$

where (x,y) is the true position of MS and (x_i, y_i) is the coordinates of the ith BS.

Since the signal from a BS is transmitted with a particular carrier frequency, we calculate the travel time of the transmitted signal from BS to MS, counting the number of time delays in case of the TOA method. The number of delay samples in terms of the particular frequency is calculated as

$$nt_i = ceil\left(\frac{d_i}{c} \times f\right) \quad (2)$$

where, nt_i denotes the number of delay for the i th BS, c is the velocity of light, f is the carrier frequency, and $"ceil"$ is a function of round up. The reason of using the round function is to make $(d_i/c)\times f$ to a natural number because nt_i should be a natural number. Based on counting the number of delay samples, nt_i, the estimated distance between MS and the ith BS is given by

$$ed_i = nt_i \times c \times \left(\frac{1}{f}\right) \quad (3)$$

The estimated distance in (3) is increased from original distance depending on the carrier frequency, because the original distance is generally not a natural number, but nt_i is a natural number. This increased distance results in the increased circles, and three circles do not intersect at a point shown in Fig. 2 unlike Fig. 1. In Fig. 2, $ed1$, $ed2$, and $ed3$ are the increased distances corresponding BS1, BS2, BS3, respectively.

Due to the incremental distance between BS and MS, three circles based on three available BSs do not meet at a single point and there exist six intersection points of three circles. In order to estimate the location of MS from unmatched three circles, we select three interior intersection points among six points. For the ith BS, we calculate two distances between the coordinate of the ith BS and two intersection points of two circles based on other BSs and we compare two calculated distances. In this approach, the intersection point corresponding the shorter distance between two distances is determined to one of three interior. In order to select other two interior intersection points, we repeat this step for other two BSs. Fig. 3 shows an example of this method. For the BS3, we assume that the estimated distance between MS and BS1 ($ed1$) is smaller than the estimated distance between MS and BS2 ($ed2$) in this figure. The difference of coordinates for BS1 and BS2 is defined as

$$\triangle x = x_2 - x_1,\ \triangle y = y_2 - y_1 \tag{4}$$

and the center distance of BS1 and BS2 is calculated by

$$\triangle = \sqrt{\triangle x^2 + \triangle y^2} \tag{5}$$

The distance from BS1's center coordinate to line joining points of intersection is calculated by

$$k = \frac{(\triangle^2 + ed1^2 - ed2^2)}{2\triangle} \tag{6}$$

Using k in (6), coordinates of intersection points based on BS1 and BS2, $I(Ix, Iy)$ and $I'(Ix', Iy')$ calculated as

$$Ix = x_1 + (\triangle x \times k/\triangle) - \left((\triangle y/\triangle) \times \left(\sqrt{ed1^2 - k^2}\right)\right) \tag{7}$$
$$Iy = y_1 + (\triangle y \times k/\triangle) + \left((\triangle x/\triangle) \times \left(\sqrt{ed1^2 - k^2}\right)\right)$$

$$Ix' = x_1 + (\triangle x \times k/\triangle) + \left((\triangle y/\triangle) \times \left(\sqrt{ed1^2 - k^2}\right)\right)$$
$$Iy' = y_1 + (\triangle y \times k/\triangle) - \left((\triangle x/\triangle) \times \left(\sqrt{ed1^2 - k^2}\right)\right)$$

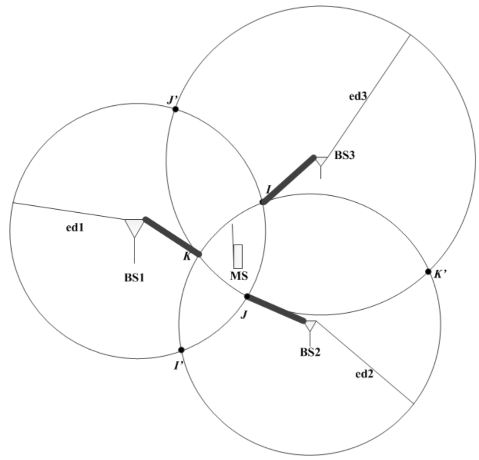

Fig. 7 The shortest distance between intersections of circles

After we calculate distances between the coordinate of BS3 and I and I', we compare two distances. Finally, we select an intersection point with the shorter distance between two distances to one of three interior intersection points. This step is repeated for BS1 and BS2 for selecting three intersection points among six points.

2.1 Determining Location of MS

In this section, we estimate the location of MS using the selected three interior intersection points among six intersection points of three circles in the previous section. The location of MS is estimated using the average of the coordinates of the selected three interior intersection points. The example of the estimated location of MS in Fig. 3, $(\hat{x}, \hat{y})$ is given by

$$\hat{x} = \frac{I_x + J_x + K_x}{3},\ \hat{y} = \frac{I_y + J_y + K_y}{3} \tag{8}$$

The proposed entire algorithm for estimating MS based on the TOA trilateration method is summarized in Table 1 and Fig. 4 shows the flow chart of the proposed approach.

Table 1. Algorithm for Estimation of MS Location

Step 1 :	Initialize the circles c1, c2, and c3 of BSs with radius equal to estimated distances $ed1$, $ed2$, and $ed3$, and coordinates of the considered BSs.
Step 2 :	Find all six intersection points formed by three circles of BSs.
Step 3 :	Calculate distances between center of circle c1 (x_i, y_i) and each intersection point (x_j, y_j) formed by other circles of BSs (c2 and c3). For example i=1 and j=2, and 3. $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$, $j = 1,2,3,4,5,6$ $i = 1,2,3$
Step 4 :	Select intersection point corresponding to the shorter distance from step 3.
Step 5 :	Repeat step 3 and step 4 for center of circles c2 and c3 of BSs.
Step 6 :	Decide position of MS by taking average of selected three interior intersection points.

III. Computer Simulations

In this section, we provide computer simulation results to verify the location estimation performance of the proposed algorithm. For the simulation, the location error between the original and estimated MS based on Euclidean distance is defined as

$$Error_{Position} = \sqrt{(x - \hat{x})^2 + (y - \hat{y})^2} \tag{9}$$

and the mean square error of the MS location is can be given by

$$MSE_{Position} = E\left[Error^2_{Position}\right] \tag{10}$$

Similarly, the distance error between the true distance and the estimated distance is given by

$$Error_{distance} = \sqrt{(d_i - ed_i)^2}, i = 1,2,3 \tag{11}$$

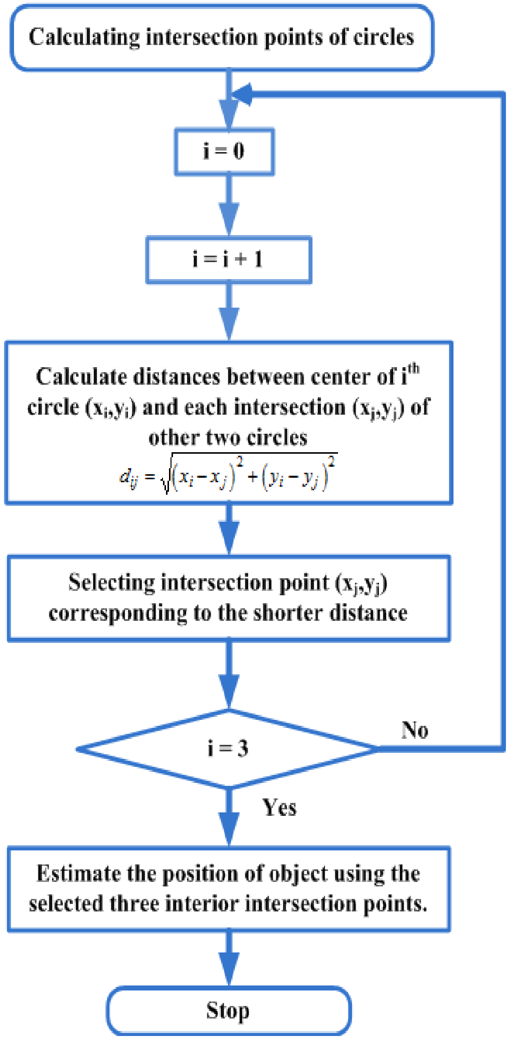

Fig. 4 Flow chart for the proposed location estimation algorithm

and the mean square error of distance is defined as

$$MSE_{distance} = E\left[Error^2_{distance}\right] \tag{12}$$

In the scenario of the simulation, we assume that there are three available base stations with fixed coordinates as follows: (−1000, 5000), (6000, −3000), (−7000, 600). For the coordinates in this section, the unit of them is meter (m). The different carrier frequencies f has been selected as 10MHz, 50MHz, 100MHz, 500MHz, 1GHz, 5GHz, and 10GHz. In other to calculate MSE, the simulation results are performed 1000,000 times. and the coordinate of MS location is randomly chosen with ranges of -100m ~ 100m and -500m ~ 500m, for the first and second cases, respectively.

The simulation results of MSE verses carrier frequencies for the estimated distance are shown in Fig. 5 and 6, for the first and second cases, respectively. From the figures, we observe that MSE for the estimated distance is decreased, as the carrier frequencies is increased. That means the MSE for the estimated location of MS will be decreased, as the carrier frequency is increased. Fig. 7 and 8 show simulation results of MSE verses carrier frequencies for the estimated location of MS using the proposed shortest distance algorithm in the first and second cases, respectively. From the figures, we observe that MSE for the estimated location of MS is decreased, as the carrier frequency is increased. That means the performance of the location estimation for MS based on the high carrier frequency is better than it based on the low carrier frequency.

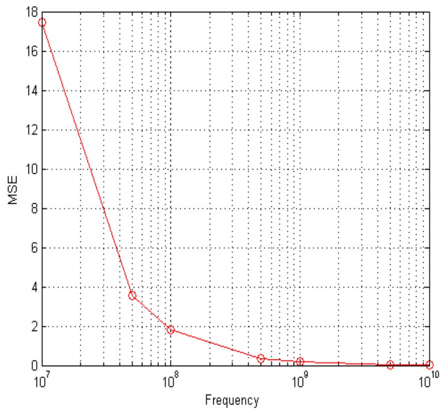

Fig. 9 MSE for the estimated location of MS for the first case

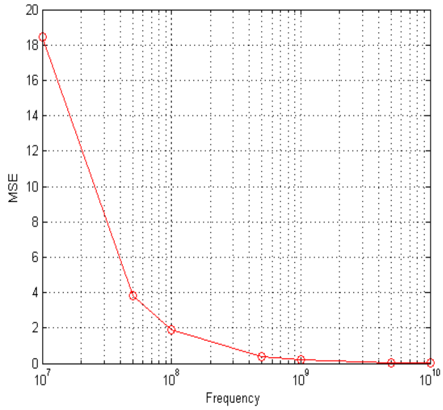

Fig. 10 MSE for the estimated location for the second case

IV. Conclusion

The location of MS is determined from the intersection point of three circles based on coordinates of three BSs and distances between MS and three BSs, for the TOA trailateration method. Since the distance between MS and BS is estimated counting the number of time delay, it might be increased comparing with the original distance. The increased distance corresponding to the radius of the circle results in the error of the estimated location of MS, because three circles do not meet at a single point in this case. In this paper, we proposed the shortest distance algorithm to reduce the location estimation error of MS for the TOA trilateration method. The proposed approach selects three interior intersection points among six entire intersection points by three circles. Finally, it determines the averaged coo-rdinate of selected three interior intersection points to the estimated location of MS. The performance of the location estimation performance based on the proposed algorithm was illustrated using computer simulation results.

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