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ScienceDirect
ICT Express 2 (2016) 28–32
www.elsevier.com/locate/icte

EToA: New 2D geolocation-based handover decision technique☆

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Received 26 September 2015; received in revised form 24 January 2016; accepted 5 February 2016
Available online 2 March 2016

Abstract

Position estimation using Time of Arrival (ToA), Time Difference of Arrival (TDoA), and Angle of Arrival (AoA) measurements are the commonly used location techniques. These techniques, using location parameters received from different sources, are based on intersections of circles, hyperbolas, and lines, respectively. The location is determined using standard complex computation methods that are usually implemented in software and needed relatively long execution time. This paper consists of minimizing and simplifying the computing process in the Mobile Station (MS) during its geo-location phase needed especially for handover. This work considers designing EToA as extended version of ToA, following the same principle but using another aspect for the computational process.

Keywords: Geolocation techniques; AoA; ToA; RSS; Handover

1. Introduction

Recently, mobile location estimation has attracted a significant attention. The network-based location estimation schemes have been widely adopted based on the radio signals between the mobile device and the base stations. Currently, given that many buildings are equipped with WLAN (Wireless Local Area Network) access points (shopping malls, museums, hospitals, airports, etc.), it may become practical to use these access points to determine user location in these indoor environments.

A variety of wireless location techniques have been studied and investigated [1–3]. Network-based location estimation schemes have been widely proposed and employed in wireless communication systems. These schemes locate the position of the MS based on the measured radio signals from its neighborhood BSs. The representative algorithms for the network-based location estimation techniques are the Time-of-Arrival (ToA), the Time Difference-of-Arrival (TDoA), and the Angle-of-Arrival (AoA). The ToA scheme estimates the MS's location by measuring the arrival time of the radio signals coming from different wireless BSs, while the TDoA method measures the time difference between the arriving radio signals. The AoA technique is conducted within the BS by observing the arriving angles of the signals coming from the MS. The equations associated with the network-based location estimation schemes are inherently nonlinear. In this paper, an efficient technique for geometric location estimation based on ToA is proposed to determine the MS position.

The rest of this paper is organized as follows: Section 2 provides the computational details of the proposed geolocation technique (Extended ToA) and conducts its performance evaluation. Finally, Section 3 concludes the paper.

2. Extended time of arrival (EToA): Algorithm and implementation

Location-based service is the most significant characteristic of 3G/4G wireless communication systems which leads to support several new applications. ToA localization technique is the most used for MS position estimation. This technique uses standard methods based on complex computing that are generally implemented with software tools [1,4]. However, the

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Peer review under responsibility of The Korean Institute of Communications Information Sciences.

☆ This paper is part of a special issue entitled "Positioning Techniques and Applications" guest edited by Prof. Sunwoo Kim, Prof. Dong-Soo Han, Prof. Chansu Yu, Dr. Francesco Potorti, Prof. Seung-Hyun Kong and Prof. Shiho Kim.

http://dx.doi.org/10.1016/j.icte.2016.02.007

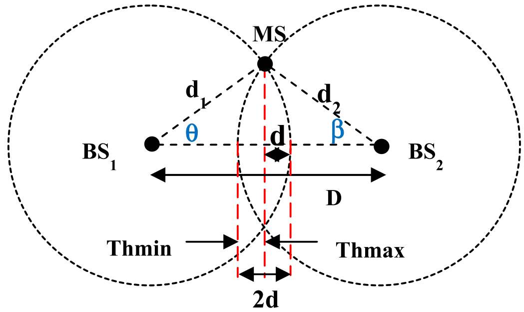

Fig. 1. Basic network architecture for EToA deployment.

main challenge resides on the limited power of the MS that needs to be optimized.

To overcome these limitations, we propose an extended approach of ToA that allows: (a) simplifying intensive and recursive computing of the localization process, and (b) using an implementation environment for acting on the execution time, cost, and therefore power consumption.

2.1. EToA proposal: Convergence with predefined iteration number

Fig. 1 represents the basic architecture of the network topology considered to apply EToA algorithm. The main parameters needed by EToA algorithm are defined by the coordinates (X_j, Y_j) of the jth BS and the radius d_j $(j = 1, 2)$ of the corresponding area. These parameters are illustrated in a local coordinate system as shown in Fig. 1.

$$(X_1, Y_1) = (0, 0) \qquad (X_2, Y_2) = (D, 0).$$

Consider:

- $\boldsymbol{\theta} = (\widehat{\text{BS1} - \text{MS}, \text{BS1}} - \text{BS2})$
- $\boldsymbol{\beta} = (\widehat{\text{BS2} - \text{MS}, \text{BS2}} - \text{BS1})$
- **D** is the distance between BS_1 and BS_2.
- **d** is the distance between $T_{h\min}$ and $T_{h\max}$.

Using the above data and Fig. 1, the angles θ and β can be defined by:

$$\theta = \cos^{-1}\left(\frac{d_1 - d}{d_1}\right) \qquad \beta = \cos^{-1}\left(\frac{d_2 - d}{d_2}\right).$$

The question now is: How do we calculate the coordinates of the MS from these two angles and the parameters mentioned above?

The proposed technique is based on using two vectors $\vec{V}1$ and $\vec{V}2$ whose origin is located at the position of the base station and the end point exist on the circle ζ_i (BS_i, d_i). The principle of this technique consists of rotating these two vectors $\vec{V}1$ and $\vec{V}2$ until crossing in a focal point coordinated by (x_c, y_c).

First, the initial positions (x_1, y_1) and (x_2, y_2) of the ends of the vectors $\vec{V}1$ and $\vec{V}2$ are $(d_1, 0)$ and $(d_2, 0)$ respectively. The initial and final positions of the first vector $\vec{V}1$ are respectively:

$$\vec{V}_1\begin{pmatrix} x_1 \\ y_1 \end{pmatrix} = \begin{pmatrix} d_1 \\ 0 \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} x_1^n \\ y_1^n \end{pmatrix} = \begin{pmatrix} x1\text{conv} \\ y1\text{conv} \end{pmatrix}.$$

This vector undergoes a global rotation with an angle θ that we propose here to study its complete evolution. Elementary rotations with angles θ_i were performed on the vector $\vec{V}_1$ to reach the final position and therefore calculate the MS position with a given accuracy. To simplify the computing complexity, another question can be asked at this level which is: can we approach an angle θ with an accuracy given in advance by decomposing it into a sum of predetermined angles? In other words, can θ be written as (Eq. (1)):

$$\theta \approx \sum_{k=0}^{n} \delta_k \varepsilon_k, \tag{1}$$

where ε_k is a sequence of distinct predefined angles and δ_k is a coefficient that can take the values -1 and $+1$. More specifically, since it is recommended to reach a certain accuracy, we need to define θ as a combination of angles ε_k according to Eq. (2).

$$\left| \theta - \sum_{k=0}^{n} \delta_k \varepsilon_k \right| \leq \varepsilon_n. \tag{2}$$

If so, it will be necessary to perform $(n + 1)$ steps for approaching θ to ε_n. This can be done by achieving the following steps:

1. First, the sequence $\sum \delta_k \varepsilon_k$ should converge to θ according to Eq. (2), which requires ε_n tending to 0. In other terms, the useful condition requires that ε_n be a sequence of positive real decreasing to 0 (*Condition 1*). In practice, we choose a sequence ε_n where the series $\sum \delta_k \varepsilon_k$ is absolutely convergent.
2. The convergence of the series $\sum \delta_k \varepsilon_k$ to θ is it always possible whatever the real θ? Actually, no. δ_k can take only the values $+1$ or -1, whether $\theta > \Sigma\varepsilon_n$ or $\theta < -\Sigma\varepsilon_n$. As a result, it is not possible to approach the angle θ with the series $\sum \delta_n \varepsilon_n$.

To approach the angle θ close to ε_n, Eq. (3) should be verified:

$$|\theta| \leq \sum \varepsilon_n \quad \text{or} \quad |\theta| \leq \sum_{k=0}^{n} \varepsilon_k \tag{3}$$

Limited to the first $(n + 1)$ terms.

Let us see how can we choose the sequence (δ_n)?

Consider $s_i = \sum_{k=0}^{i-1} \delta_k \varepsilon_k$ and build the sequence δ_n as follows:

- If $\theta \geq 0$ then $s_1 = \varepsilon_0$ (approaching to θ starting from ε_0, i.e. $\delta_0 = +1$). If not, $s_1 = -\varepsilon_0$ (approaching to θ starting from $-\varepsilon_0$, i.e. $\delta_0 = -1$).
- If $\theta - \delta_0\varepsilon_0 \geq 0$, then $s_2 = \varepsilon_0 + \varepsilon_1$ (approaching to θ by adding ε_1, i.e. $\delta_1 = +1$). If not, $s_2 = \varepsilon_0 - \varepsilon_1$ (approaching to θ by subtracting ε_1, i.e. $\delta_1 = -1$).

More generally:

- If s_k is greater than θ, so $s_{k+1} = s_k - \varepsilon_k$ therefore $\delta_k = -1$.
- If s_k is less than θ, so $s_{k+1} = s_k + \varepsilon_k$ therefore $\delta_k = +1$.

Finally,

$$\delta_k = \text{sign}\,(\theta - s_k)\,. \tag{4}$$

Now, it is useful to consider whether the inequality ($\left|\theta - \sum_{k=0}^{n}\delta_k\varepsilon_k\right| \le \varepsilon_n$ — Eq. (2)) implies a certain condition on the sequence (δ_n). Assuming that inequality is true for the integer n, we try to find what condition should verify ε_{n+1}, so that it remains true for the integer $n+1$.

At the order $n+1$, we have: $\left|\theta - \sum_{k=0}^{n}\delta_k\varepsilon_k\right| = \left|\theta - \sum_{k=0}^{n}\delta_k\varepsilon_k - \delta_{n+1}\varepsilon_{n+1}\right|$.

If $\theta - \sum_{k=0}^{n}\delta_k\varepsilon_k \ge 0$, so the inequality (Eq. (2)) can be written at the order n as:

$$0 \le \theta - \sum_{k=0}^{n}\delta_k\varepsilon_k \le \varepsilon_n.$$

Moreover, $\delta_{n+1} = \text{sign}\,(\theta - s_{n+1}) = +1$.

Then, $-\varepsilon_{n+1} \le \theta - \sum_{k=0}^{n}\delta_k\varepsilon_k - \varepsilon_{n+1} \le \varepsilon_n - \varepsilon_{n+1}$.

So, $\left|\theta - \sum_{k=0}^{n}\delta_k\varepsilon_k\right| \le \max(\varepsilon_{n+1}\varepsilon_n - \varepsilon_{n+1})$.

We want to obtain $\left|\theta - \sum_{k=0}^{n+1}\delta_k\varepsilon_k\right| \le \varepsilon_{n+1}$ which is equivalent to $\varepsilon_n - \varepsilon_{n+1} \le \varepsilon_{n+1}$.

Finally, $\varepsilon_{n+1} \ge \frac{1}{2}\varepsilon_n$

if $\theta - \sum_{k=0}^{n}\delta_k\varepsilon_k \le 0$, we can verify in the same way finding the same condition for ε_{n+1}. Finally, the inequality (Eq. (2)) is true for every $n \epsilon N$ only when the sequence ε_n meets the necessary and sufficient condition (Eq. (5)):

$$\frac{1}{2}\varepsilon_n \le \varepsilon_{n+1} \le \varepsilon_n \quad \text{for every } n\epsilon N. \tag{5}$$

Under this condition, we can demonstrate by recurrence that (Eq. (2)) is true for every natural integer, providing that θ respects the initial condition $|\theta - \delta_0\varepsilon_0| \le \varepsilon_0$.

Now, it is possible to answer our question:

Under the condition 1 and Eq. (5), it is possible to approach the angle θ close to ε_n by adding or subtracting certain times a predefined angle ε_k.

The principle of this algorithm consists of applying elementary rotations (where their sum is equal to θ) on a vector coordinated by $\vec{V}_1\binom{x_0}{y_0} = \binom{d_1}{0}$. At the convergence (x_c, y_c), we obtain $\binom{x_0^n}{y_0^n} = \binom{x0\text{conv}}{y0\text{conv}}$, where the quotient $\frac{x0\text{conv}}{y0\text{conv}}$ can be approximated to tang(θ) based on its definition.

Consider $0 \le \theta \le \frac{\pi}{2}$ and several ε_i where $\theta = \sum_{i=0}^{n}\varepsilon_i$ with $\varepsilon_n \le \varepsilon_{n-1} \le \cdots \le \varepsilon_1 \le \varepsilon_0$.

Assuming M_0 coordinated with (X_0Y_0), M_1 image of M_0 by the rotation around O with an angle ε_0, will have coordinates (X_1, Y_1) satisfying:

$$X_1 = X_0 * \cos\varepsilon_0 - Y_0 * \sin\varepsilon_0$$
$$Y_1 = X_0 * \sin\varepsilon_0 + Y_0 * \cos\varepsilon_0.$$

This can be written in matrix form as $\binom{X_1}{Y_1} = \begin{pmatrix}\cos\varepsilon_0 & -\sin\varepsilon_0\\ \sin\varepsilon_0 & \cos\varepsilon_0\end{pmatrix}\binom{X_0}{Y_0}$, where $\begin{pmatrix}\cos\varepsilon_0 & -\sin\varepsilon_0\\ \sin\varepsilon_0 & \cos\varepsilon_0\end{pmatrix}$ is the matrix which represents the rotation around the center O (origin of the local coordinate) with an angle ε_0. Similarly, enforcing a rotation with an angle ε_1 to the point $M_1(x_1y_1)$ leads to obtain the point M_2 coordinated by (x_2y_2) and defined according to the transformation $\binom{X_2}{Y_2} = \begin{pmatrix}\cos\varepsilon_1 & -\sin\varepsilon_1\\ \sin\varepsilon_1 & \cos\varepsilon_1\end{pmatrix}\binom{X_1}{Y_1}$.

Transforming M_0 to M_2 can be deduced by the matrix product $\begin{pmatrix}\cos\varepsilon_1 & -\sin\varepsilon_1\\ \sin\varepsilon_1 & \cos\varepsilon_1\end{pmatrix} * \begin{pmatrix}\cos\varepsilon_0 & -\sin\varepsilon_0\\ \sin\varepsilon_0 & \cos\varepsilon_0\end{pmatrix}$ governing the elementary transformations of M_0 to M_1 and then M_1 to M_2. As result:

$$\begin{pmatrix}X_2\\ Y_2\end{pmatrix} = \begin{pmatrix}\cos(\varepsilon_0+\varepsilon_1) & -\sin(\varepsilon_0+\varepsilon_1)\\ \sin(\varepsilon_0+\varepsilon_1) & \cos(\varepsilon_0+\varepsilon_1)\end{pmatrix} * \begin{pmatrix}X_0\\ Y_0\end{pmatrix}. \tag{6}$$

In general case, n successive rotations with angle θ_i correspond to n transformations allowing to determine the coordinates of the points $M_1, M_2, M_3, \ldots, M_{n-1}$ and M_n where M_n is very close to the position of the MS.

In Eq. (6), if $(\varepsilon_0 + \varepsilon_1)$ is an approximation of θ, so $\binom{X_2}{Y_2}$ represents an approximation of the MS position in the local coordinates beside BS_1. This allows writing:

$$\begin{pmatrix}X_n\\ Y_n\end{pmatrix} = \begin{pmatrix}\cos\varepsilon_0 & -\sin\varepsilon_0\\ \sin\varepsilon_0 & \cos\varepsilon_0\end{pmatrix} * \begin{pmatrix}\cos\varepsilon_1 & -\sin\varepsilon_1\\ \sin\varepsilon_1 & \cos\varepsilon_1\end{pmatrix} * \cdots * \begin{pmatrix}\cos\varepsilon_{n-1} & -\sin\varepsilon_{n-1}\\ \sin\varepsilon_{n-1} & \cos\varepsilon_{n-1}\end{pmatrix} * \begin{pmatrix}X_0\\ Y_0\end{pmatrix}.$$

This form can be simplified by taking $\cos\varepsilon_k$ as common factor for all matrices. As a result, $\tan\varepsilon_k$ appears as given in the following equation.

$$\begin{pmatrix}X_n\\ Y_n\end{pmatrix} = \prod_{k=0}^{n-1}\cos\varepsilon_k \begin{pmatrix}1 & -\tan\varepsilon_k\\ \tan\varepsilon_k & 1\end{pmatrix} * \begin{pmatrix}X_0\\ Y_0\end{pmatrix}.$$

In another form, $\varepsilon_k = \arctan\,(2^{-k})$ and $\delta_k = \text{sign}\,(\theta - (\delta_0\varepsilon_0 + \delta_1\varepsilon_1 + \cdots + \delta_{k-1}\varepsilon_{k-1}))$. These forms allow re-writing the previous result as:

$$\begin{pmatrix}X_n\\ Y_n\end{pmatrix} = \prod_{k=0}^{n-1}\cos\varepsilon_k \begin{pmatrix}1 & -\delta_k 2^{-k}\\ \delta_k 2^{-k} & 1\end{pmatrix} * \begin{pmatrix}X_0\\ Y_0\end{pmatrix}.$$

Given the choice of the sequences (ε_n) and (δ_n), we can obtain $\theta = \lim_{n\to+\infty}\sum_{k=0}^{n+1}\delta_k\varepsilon_k$, provided that θ respects the condition in Eq. (3). i.e. consider $\theta \le \sum \arctan\,(2^{-k}) \approx 1.7$. But, since the sine and cosine functions are 2π periodic, we can limit our study to $|\theta| \le \pi/2$.

Thus, calling K the real $\prod_{k=0}^{n-1}\cos(\arctan\,(2^{-k}))$ defined as constant value ≈0.60725, the last equation becomes:

$$\begin{pmatrix}\cos\theta\\ \sin\theta\end{pmatrix} = K\prod_{k=0}^{n-1}\begin{pmatrix}1 & -\delta_k 2^{-k}\\ \delta_k 2^{-k} & 1\end{pmatrix} * \begin{pmatrix}1\\ 0\end{pmatrix}$$
$$= \prod_{k=0}^{n-1}\cos\theta_k \begin{pmatrix}1 & -\delta_k 2^{-k}\\ \delta_k 2^{-k} & 1\end{pmatrix} * \begin{pmatrix}K\\ 0\end{pmatrix}.$$

This preliminary study allows deducing the forms of the sequences (X_n) and (Y_n) which converge to $\cos\theta$ and $\sin\theta$. These sequences constitute the key elements of our EToA localization technique.

7 bits							.	9 bits								
b_6	b_5	b_4	b_3	b_2	b_1	b_0	.	b_{-1}	b_{-2}	b_{-3}	b_{-4}	b_{-5}	b_{-6}	b_{-7}	b_{-8}	b_{-9}
2^6	2^5	2^4	2^3	2^2	2^1	2^0	.	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}	2^{-9}

$$\mathrm{Value} = -\mathrm{b}_6.\,2^6 + \sum_{i=-9}^{5}(\mathrm{b}_i 2^i)$$

Fig. 2. 16-bit words format used for computational process.

$$\begin{cases} X_0 = K; \\ Y_0 = 0; \\ S_0 = \theta; \\ \delta_k = \mathrm{sign}\ (S_k); \\ X_{k+1} = X_k - \delta_k Y_k 2^{-k}; \qquad \text{(a)} \\ Y_{k+1} = Y_k + \delta_k X_k 2^{-k}; \qquad \text{(b)} \\ S_{k+1} = S_k - \delta_k \varepsilon_k; \qquad \text{(c)} \\ \text{where } \varepsilon_k = \arctan\ (2^{-k}) \end{cases} \tag{7}$$

Two main originalities are provided in this work. First, EToA represents a new proposal for geo-localization of mobile devices based on the basic principle of ToA. It constitutes an efficient method to calculate the coordinates of MSs based on the fundamental vectorial functions (shift, addition and rotation). EToA calculates the approximate position of MSs in a 2D space. Second, a hardware implementation of this algorithm has been considered as second contribution in order to reduce the cost where the most positioning systems are suffering.

Eq. (7)(a)–(c) allow calculating, from an initial angle (θ), the real coordinates (X_n, Y_n) of the MS. First, it is useful to initialize the variables X_0, Y_0 and S_0 at K, 0 and $\theta(\theta = \cos^{-1}\left(\frac{d1-d}{d1}\right))$ respectively. The accumulator S_k rotates until it reaches 0. The resulting values (X_n, Y_n) express the MS position coordinated by the angle θ. A testing phase at each iteration of the elementary angle ε_k is considered to determine the sign of δ_k.

The useful condition resulting to the algorithm convergence consists of stopping the calculation process when the difference between the current angle and the desired angle exceeds some configurable and known error. To simplify the development, we suggest stopping the process after 8 iterations (i.e. a precision of $2^{-8} = 0.1^0$). It allows setting the size of the data which will be considered in the calculation. Moreover, setting the iteration number allows knowing in advance the size of manipulated words and simplifying the coding development. In this context, 16-bit words are used where 7 bits represent the integer part and 9 bits define the fractional part as shown in Fig. 2.

2.2. Geolocation usage in mobile networks: Handovers managements

Many multipoint routing protocols have been enriched by new geo-casting techniques [5–7] based on location information. In Ad-Hoc networks, the positions of terminals can also be used to facilitate data packets routing between mobile devices [8]. In cellular networks, handover performance has been enhanced based on position location of the mobile terminals.

Our idea is based on the use of the mobile device position as metric improving level 2 handovers occurring in Wi-Fi and IPv6 networks. A mobility controller, integrated in the MS, allows selecting the future access points based on their geographical distance from the MS. In other terms, EToA technique calculates the coordinates (x, y) of the mobile terminal which can directly authenticate and associate with the nearest BS. Thus, the scan phase is replaced by a quick localization mechanism that can be done within a number of iterations fixed in advance. In this case, *MinChannelTime* and *MaxChannelTime* parameters are not used.

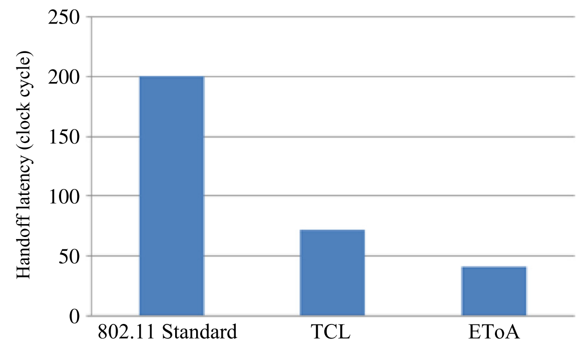

Fig. 3. Comparative study of the handover latency.

For performance evaluation, a sequencer has been employed to initiate and finish the computational cycle as well as activate the transitions between states. The sequencer also allows calculating the number of cycles needed for the whole process achievement. As result, the handoff latency (Fig. 3) is deducted from the number of cycles based on a hardware simulation approach.

The hardware implementations of TCL (Triangular Convergence Localization [9]) and EToA at the MS are considered to reduce the handover latency and provide transparent communication during intercellular transitions, especially compared to IEEE 802.11 standard. These techniques can perform level 2 handovers during a reduced number of clock cycles. TCL and EToA require 70 and 40 clock cycles respectively to find a new path for an established communication. However, 200 cycles are required to perform a handover within IEEE 801.11 standard [10]. This gain in time is mainly due to the optimization of the discovery phase, where the mobile station calculates its position, identify its closest BS and immediately passes to the authentication phase.

3. Conclusion

In this paper, we presented EToA as geolocation technique to estimate the location of a MS for handover management. Performance evaluation is considered to demonstrate its efficiency during intercellular transitions, especially compared to IEEE 802.11 standard. As result, the proposed technique is sharply convergent within a reduced number of iterations ($k < 10$). Moreover, the implementation simplicity and low computational overhead constitute their major advantages. In perspective, the MS position accuracy will be considered as major future evaluation metric.

Acknowledgment

This work is supported by the research center of the College of Computer and Information Sciences, KSU.

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