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A TDoA-based mobile-WiMAX position tracking system to meet E-911 criteria in GPS-shadowed areas

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Abstract: In typical urban wireless channels with large delay spreads, the conventional TDoA (Time Difference of Arrival)-based mobile-WiMAX (Worldwide Interoperability for Microwave Access) positioning systems hardly satisfy the FCC (Federal Communications Commission)'s E-911 (Enhanced-911) detection criteria. In this paper, we propose a simple yet very effective TDoA-based position tracking algorithm for mobile-WiMAX systems when the user moves into GPS (Global Positioning System)-shadowed areas such as indoors or dense urban environments.

Keywords: position tracking, mobile-WiMAX, TDoA, E-911, GPS-shadowed areas

Classification: Wireless communication hardware

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1 Introduction

Highly accurate wireless positioning which is used to determine the location of an MS (Mobile Station), has gained a lot of attention [1, 2]. The exact positioning requirements for the MS arise as a matter of security, in order to track emergency calls made through the United States FCC (Federal Communications Commission)'s E-911 (Enhanced-911) service [3]. Among many kinds of positioning schemes, GPS (Global Positioning System) and TDoA (Time Difference of Arrival)-based schemes utilizing network infrastructures are preferred [4]. Positioning with the GPS, or A-GPS (Assisted-GPS) for more accuracy, is one of the most accurate outdoor positioning technologies which can provide accuracy within 15 m in ideal conditions, and typical accuracy can range up to 50 m [5]. However, it is not suitable for indoors or dense urban areas as the satellite signals may be blocked by building, walls, and ceilings. Hence, when the MS moves from a GPS-enabled area to a GPS-shadowed area, the system typically needs to switch from the GPS mode to a network-based mode such as the TDoA-based positioning for seamless position tracking [5]. The TDoA-based positioning schemes are practical and likely to be widely adopted for wireless networks based on OFDMA (Orthogonal Frequency Division Multiple Access) such as mobile-WiMAX (Worldwide Interoperability for Microwave Access) [4]. However, the conventional TDoA-based schemes create large positioning errors because of NLoS (Non Line of Sight) components of the multipath channels.

In this paper, we propose a simple yet very effective TDoA-based position tracking algorithm for the mobile-WiMAX systems. The proposed algorithm exploits positioning data of the (A-)GPS mode for the initial values of the TDoA-based positioning when the system switches to the network-based positioning mode. It also compares the estimated position of the current state to the previous state information for achieving high reliability. Note that similar positioning approaches were considered in [6]. However, these approaches require high computational complexity to estimate the MS position. The proposed algorithm, however, is extremely simple to implement, while significantly improving the MS detection probability compared to the conventional TDoA-only positioning in channels with large delay spread profiles. The potential improvement using the proposed algorithm can help to satisfy the E-911 requirements by the mobile-WiMAX systems, especially in GPS-shadowed areas.

2 System and signaling models

We consider the network-initiated positioning mode in a downlink mobile-WiMAX system. When the mobile-WiMAX network initiates a positioning

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of the MS, the serving RAS (Radio Access Station) sends the MS information to the neighboring RASs. Then the neighboring RASs send their preamble sequences to the MS. After that, the MS performs the cross-correlation using the received signal with known preambles of the RASs including the serving RAS to select 3 or 4 RASs, which have the highest cross-correlation values. Because all the RASs are synchronized by the GPS, the MS can estimate the received time delay of each incoming preamble sequence and calculate each RD (Relative Delay) with respect to the sequence of the serving RAS. Here, the RD indicates a time delay of a neighboring RAS signal relative to the serving RAS, which can be regarded as the TDoA between the neighboring RAS and the serving RAS. The calculated RD information is sent to the PS (Positioning Server) which is usually located in the serving RAS to estimate the MS position using the TDoA algorithm.

The signaling time delay model of the preamble sequences from the RASs is depicted in Fig. 1. Here, r_0 is the received signal at the MS from the serving RAS, r_i $(i = 1, \cdots, N)$ is that from the i-th neighboring RAS, N is the number of neighboring RASs, and N_{FFT} is the FFT (Fast Fourier Transform) size in the OFDMA. In addition, T_{sample} is the sampling time which is specified as 100 nsec in the mobile-WiMAX systems.

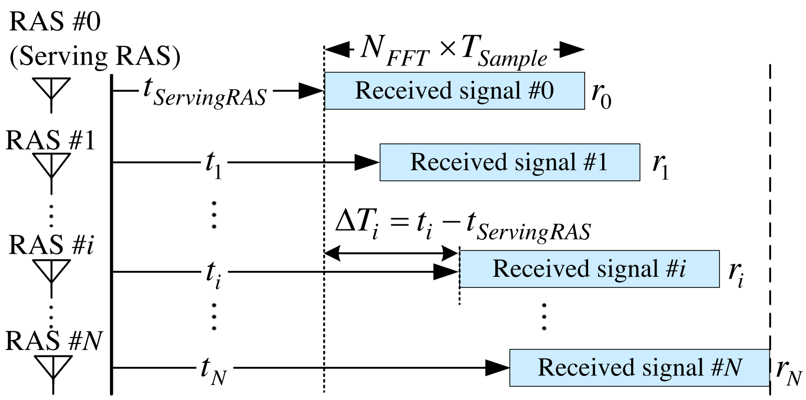

Fig. 1. Signaling model of the preambles from the RASs.

Then, the RD of each neighboring RAS can be expressed as follows.

$$\Delta T_i = t_i - t_{ServingRAS} \quad (i = 1, \cdots, N), \tag{1}$$

where t_i is the signal arrival time between the i-th neighboring RAS and the MS, $t_{ServingRAS} \equiv t_0$ is the signal arrival time at the MS sent from the serving RAS.

To calculate the discrete-time index of the i-th $(i = 0, 1, \cdots, N)$ RAS $\hat{\delta}_i$ that has the maximum correlation value with $i = 0$ denoting the serving RAS, the MS performs the cross-correlation for all the received preamble signals as

$$P_i(n) = \left| \sum_{k=0}^{N_{FFT}-1} x_i^*(k) \cdot r_i(n+k) \right| \quad (i = 0, 1, \cdots, N), \tag{2}$$

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$$\hat{\delta}_i = \arg\max_n \{P_i(n)\} \quad (i = 0, 1, \cdots, N), \tag{3}$$

where n is the discrete-time index and $x_i(n)$ is the preamble signal of the i-th RAS. Note that the NLoS time delay components are included in $\hat{\delta}_i$. After that, the MS compares the maximum correlation values $P_i(\hat{\delta}_i)$ $(i = 0, 1, \cdots, N)$ of the RASs and selects $N_{TDoA} \equiv 3$ or 4 largest RASs. Let us denote the indexes of the selected RASs as $i_\ell \in \{0, 1, \cdots, N\}$ $(\ell = 1, \cdots, N_{TDoA})$. Then, the MS can calculate the estimated RD of the i_ℓ-th RAS $\Delta\hat{T}_i$ as follows.

$$\hat{t}_{i_\ell} = (\hat{\delta}_{i_\ell} - N_{FFT}) \cdot T_{sample} \quad (\ell = 1, \cdots, N_{TDoA}), \tag{4}$$

$$\Delta\hat{T}_{i_\ell} = \hat{t}_{i_\ell} - \hat{t}_{ServingRAS} \quad (\ell = 1, \cdots, N_{TDoA}). \tag{5}$$

3 Proposed TDoA-based position tracking for mobile-WiMAX

In this section, we explain the proposed TDoA-based position tracking algorithm for the mobile-WiMAX systems. The network-based positioning is a very plausible alternative when the GPS signal is weak or blocked in urban areas and indoors [5]. When the network-based mode is enabled, the proposed tracking algorithm uses the several previous position data of the GPS mode as the initial parameters, which can be easily accessed from the PS.

The main idea of the proposed position tracking algorithm is that if the distances between the estimated position of the current state and the positions of the previous states are over the threshold, then the system decides that the estimated position is an error in the current state. A detailed description of the proposed tracking algorithm to improve the detection probability is in order.

(a) The algorithm is started when the MS moves from a GPS-enabled area to a mobile-WiMAX network-controlled area (i.e., GPS-shadowed area) at time t. Note that the position of the MS is estimated by the GPS at times $(t-2)$ and $(t-1)$.

(b) Initialize $flag(t-1) = 0$. This is the flag for error checking of the estimated MS position.

(c) The PS performs the TDoA algorithm to estimate the position of the MS at current time t.

(d) Calculate $dist(t-2, t)$ and $dist(t-1, t)$. Here, $dist(t_a, t_b)$ is the distance of the estimated position between t_a and t_b.

(e) If $dist(t-2, t) > d_{th}$ and $dist(t-1, t) < d_{th}$, then the PS checks $flag(t-1)$. Here, d_{th} is the error decision threshold.
   - If the flag is set to 0, then the position of the MS at current time $\{x(t), y(t)\}$ is determined as the position of previous state $\{x(t-1), y(t-1)\}$. And, set $flag(t) = 1$.
   - If the flag is set to 1, then $\{x(t), y(t)\}$ is determined as the new position $\{\hat{x}(t), \hat{y}(t)\}$, which is estimated by the PS in current time. And, set $flag(t) = 0$.

(f) If $dist(t-2, t) < d_{th}$ or $dist(t-1, t) < d_{th}$, then the PS sets $flag(t)$ to 0, and let $\{x(t), y(t)\}$ be $\{\hat{x}(t), \hat{y}(t)\}$.

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(g) Set $t \leftarrow t+1$ and go to (d) for the next period.

4 Simulation results

The considered mobile-WiMAX cell layout for the simulation was 19 macro-cells in a 2-tier environment around the serving RAS in the center. We assumed that the cell radius to a vertex was 1 km. The considered fading channel was Pedestrian-B model of ITU-R (International Telecommunication Union-Radio sector) M.1225 [7]. Note that we regarded this channel model as a high delay spread urban environment with mobility of 3 km/h. We also considered a distance-dependent path loss L given by (6), and shadowing effect modeled by a log-normal distribution with the standard deviation of 10 dB [7].

$$L = 40\log_2 R + 30\log_2 f + 49 \text{ [dB]}, \tag{6}$$

where R is the distance between the RAS and the MS in kilometers, and f is the carrier frequency in MHz. The main simulation parameters for the mobile-WiMAX systems are described in Table I. Because we focused on the satisfaction of the E-911 requirements which considered error distance criteria of 100 m and 300 m, we set the error decision thresholds between 100 m and 300 m. We also considered an initial GPS position error of 50 m, which is the typical worst accuracy of the A-GPS.

Table I. Main simulation parameters of mobile-WiMAX systems.

Parameter	Value
Center frequency / bandwidth	2.3 GHz / 10 MHz
FFT size / cyclic prefix points	1,024 / 128
Frame / sample duration	5 msec / 100 nsec
RAS transmit power / antenna gain	46 dBm / 17 dBi
Penetration loss / MS noise figure	10 dB / 7 dB
Thermal noise power spectral density	-174 dBm/Hz
Estimation period	10 sec
Error decision threshold, d_{th}	100 m ~ 300 m
Initial GPS position error	50 m

Fig. 2 (a) shows the performance comparison of the detection probability according to the error distance with various error decision thresholds, when the estimation period is 10 sec. As shown in the results, the proposed positioning algorithm outperforms the TDoA-only scheme for all considered error decision thresholds. Note that the TDoA-only scheme cannot satisfy the E-911 requirements even when the system utilizes 4 RASs. However, the proposed positioning algorithm can improve the detection probability enough to satisfy the E-911 criterion when utilizing 4 RASs. Moreover, the proposed algorithm utilizing 3 RASs can satisfy the E-911 requirements when the error decision threshold is set to 200 m. The distribution of the estimated tracking positions when the estimation time is 10 sec and 4 RASs are utilized, is shown in Fig. 2 (b). As shown in the figure, the conventional TDoA-only positioning

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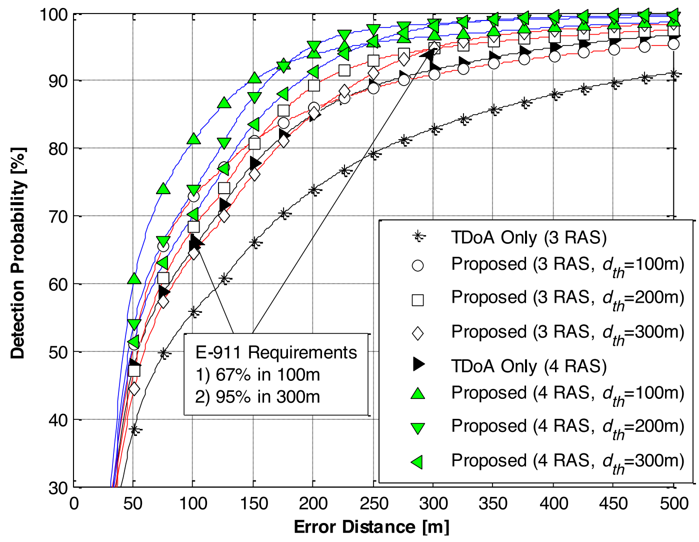
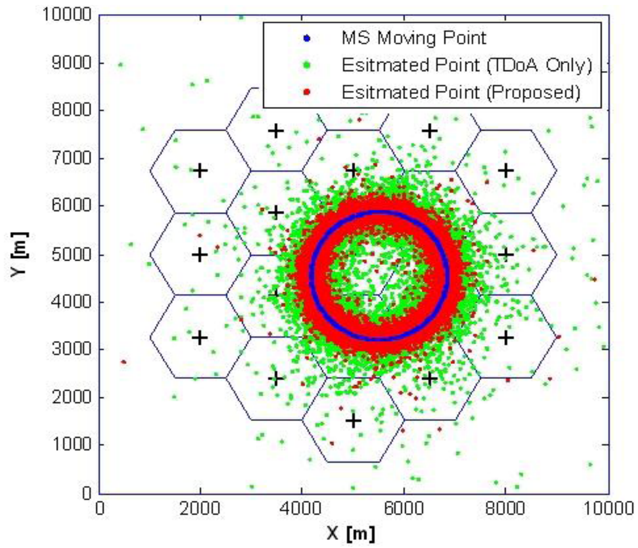


(a)



(b)

Fig. 2. MS positioning performance of the proposed scheme (estimation period of 10 sec): (a) MS detection probability according to the error distance, (b) distribution of the estimated MS positions.

scheme has a large distance error. On the other hand, the proposed algorithm can compensate for these large distance errors in the case of practical MS moving paths.

5 Conclusion

In this paper, we have proposed a simple yet very effective TDoA-based position tracking algorithm for mobile-WiMAX systems for the MS moving into the GPS shadowed area. As shown in the simulation results, the proposed algorithm can improve the detection probability of MS positions by just applying additional simple functionalities. The proposed algorithm may

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be considered as one of the simplest schemes to improve positioning performance, and this work shows the potential that such TDoA-based algorithms can satisfy the E-911 criteria using currently-deployed mobile-WiMAX systems. Here, we expect that a modified algorithm such as one jointly applying successive TDoA measurements, can achieve even better positioning performance at the price of increased complexity. We also expect that the proposed algorithm can be applied not only to the TDoA-based scheme, but also to other positioning schemes using various network-based systems.

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