Scheme for Enhanced Tracking of Mobile Subscribers in a WiMAX Network

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Abstract— **In this paper, the base station identification and timing adjust measurements are used to geolocate mobile subscribers in a WiMAX network. The uplink and downlink subframes of the physical layer and management messages of the medium access control layer are examined to extract the necessary data for geolocation. Using a hidden Markov model [1] based algorithm to estimate the track of the mobile subscriber, we demonstrate that the position error can be further reduced by incorporating timing adjust measurements. Simulation results of the proposed scheme are included to demonstrate the effectiveness of the combined use of base station ID and timing adjust measurements.**

Keywords-Geolocation, WiMAX, IEEE 802.16, Timing Adjust, hidden Markov model, tracking.

I. INTRODUCTION

With the wide spread use of wireless communications, the demand for faster data rates and greater user mobility are increasing. With this increase in user mobility, the need for location based services is becoming ever more popular. These services include locating a place of interest, social networking, or emergency situations. In the case of emergency systems, being able to track the user is extremely important. Using the available data such as the base station identification (BSID) and/or timing adjust can prove useful in geolocating and tracking the user.

Geolocating a mobile user for various reasons has been studied for a variety of cellular networking technologies [1], [2]. The focus of the work here is WiMAX and the IEEE 802.16 standard. Various methods of localization are discussed by Bshara et al. [1]. These methods include received signal strength, time of arrival, time difference of arrival, angle of arrival and BSID [1], [2]. Their approach to the geolocation of a mobile subscriber is based on a hidden Markov model (HMM) filter by using not just the serving base station but all neighboring base stations [1]. In this paper, the tracking algorithm is expanded by including the timing adjust measurements with greater accuracy.

Whitty [3] discusses calculation of the location of a mobile subscriber based on timing adjusts. The methods used for calculation were based on the time of arrival and time difference-of-arrival. By incorporating the timing adjusts, Whitty demonstrates that the position error of the mobile user can be dramatically reduced. In this paper, we will compare the timing adjust position error to the position error obtained using just the BSID to geolocate the mobile user [3].

The objective of this paper is to develop an enhanced tracking scheme to continually geolocate a mobile subscriber in a wireless network based upon the IEEE 802.16e standard (mobile WiMAX). A hidden Markov model developed by Bshara et al. [1] will be used to implement the tracking algorithm. The method of triangulation utilizing the timing adjust measurements is used for geolocating the mobile subscriber. Using timing adjust and BSID measurements, we examine the ability to continuously track a mobile subscriber within an acceptable position error. A MATLAB simulation is created to test the effectiveness of the proposed enhancement.

The organization of this paper is as follows. The physical layer frame formats and the MAC layer messages are discussed in Section II. The proposed scheme that utilizes a hidden Markov model based algorithm and a timing adjust based geolocation method for tracking a mobile user is presented in Section III. Section IV includes the results of simulations.

II. PHYSICAL LAYER FRAME STRUCTURE AND MAC LAYER MESSAGES

In a WiMAX network, to provide and manage connectivity between a base station and a mobile subscriber, a number of iterations in the form of message exchange, such as ranging, handover and scanning, take place. Data critical to implementing the proposed scheme in this paper are contained in these messages, both at the PHY and MAC layers.

The downlink subframe contains the information necessary for frame synchronization and control as shown in Figure 1 [5]. The BSID and timing adjust data can be obtained from the ranging messages [5]. Range response messages from each target base station contain the number of neighboring base stations, the neighboring base station IDs, and timing adjust information [5]. A timing adjust value is used by the mobile subscriber to synchronize with the serving base station and neighboring base stations.

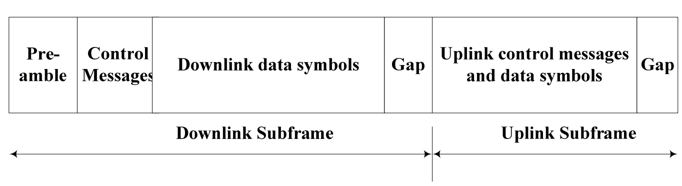

Figure 1. IEEE 802.16 frame structure divided into downlink and uplink subframes [5]

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By using the messages sent during the ranging process, we can geolocate the mobile user through triangulation, a method of determining the precise location of an object by measuring angles from a fixed baseline. In the case of wireless networks, this fixed baseline is represented by the base stations within the area of the mobile subscriber. To triangulate the mobile subscriber, at least three base stations are needed. The base station passes timing adjust to the mobile subscriber during the ranging procedures. By knowing the timing adjust, one can determine the position of the mobile user with fairly high accuracy [3], [5].

III. MOBILE SUBSCRIBER TRACKING

As a mobile subscriber moves through the network as illustrated in Figure 2, the mobile device is receiving constant updates about the available base stations. By using these BSID measurements, we can track the mobile subscriber through the network. When timing adjust measurements are available, we are then able to geolocate the mobile subscriber to a more precise position. The area of interest is divided into smaller regions called tiles as shown in Figure 2, and the measurements are collected in these tiles.

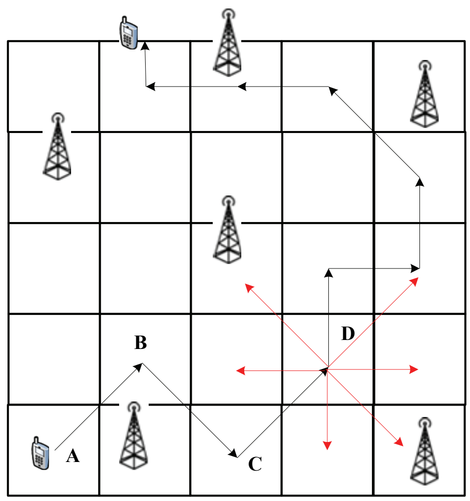

Figure 2. Tracking a mobile subscriber through a wireless network. The area of interest is divided into tiles.

The proposed scheme uses a tracking algorithm based on the hidden Markov model reported in [1]. Let X_k be the $N_T \times 1$ hidden Markov state vector, representing the relative position of a user, at time k where N_T is the number of states. Denoting the probability transition matrix as T, the estimate of the subscriber position at time $k+1$ is [1]

$$X_{k+1|k} = E\left[X_{k+1} \middle| X_k\right] = T^T X_k \tag{2}$$

where the components of T are defined as

$$\left[T\right]_{i,j} \triangleq P\left(X_{k+1} = e_j \middle| X_k = e_i\right) \tag{3}$$

and e_j is a unit vector.

In wireless networks, the user location can be determined using the knowledge of the signals from adjacent base stations that are received at that location and time. Let S_k be the $N_{BSID} \times 1$ data collection vector at time k where N_{NBSID} is the number of base stations (sources) in the area of interest.

The data collection vector S_k and the state vector X_k are assumed to be related by [1]

$$E\left[S_k \middle| X_k\right] = MX_k \tag{4}$$

where components of the measurement matrix M are given by [1]

$$\left[M\right]_{i,j} = P\left(\left[S_k\right]_i = 1 \middle| X_k = e_j\right). \tag{5}$$

The position estimate given by

$$\hat{X}_{k|k} = E\left[X_k \middle| S_{0:k}\right] \tag{6}$$

where $S_{0:k}$ represents all the data collected from time instant 0 to k. The hidden Markov algorithm is summarized as [1]:

1. Initialization:	$\hat{X}_{0\|0} = \bar{X};\ \ set\ k = 1$
2. Position Prediction:	$\hat{X}_{k\|k-1} = T^T \hat{X}_{k-1\|k-1}$
3. Position Estimate:	$\hat{X}_{k\|k} = \dfrac{\Lambda_{S_k} \odot \hat{X}_{k\|k-1}}{\sum_{i=1}^{N_T}\left[\Lambda_{S_k} \odot \hat{X}_{k\|k-1}\right]}$
4. Position Selection:	$\tilde{X}_{k\|k} = \arg\max\left[\hat{X}_{k\|k}\right]_i$
5. If S_{k+1} exists, set $k = k+1$, else stop	

The schematic diagram of the proposed scheme using a hidden Markov model for tracking a mobile subscriber that utilizes the timing adjust measurements as they are available is shown in Figure 3. Once the measurements are collected, we are able to run the algorithm to start building the track the mobile subscriber is following. If enough timing adjusts are provided, the algorithm refines the position to a more accurate estimate. If not enough timing adjusts are collected, then the algorithm gives the location to be centered in a tile which the algorithm has calculated.

Once the updated position estimate $\widetilde{X}_{k|k}$ is selected, the tracking scheme then utilizes the timing adjust data to improve the accuracy of the position estimate. This updated position using timing adjusts replaces the position found with the BSID and corrects the track accordingly. For the WiMAX system, the range per timing adjust is calculated from

$$R_r = \frac{c}{2F_s} \tag{7}$$

where c is the speed of light and F_s is the sampling frequency, given by [5]

$$F_s = \left\lfloor n \frac{B}{8000} \right\rfloor 8000 \tag{8}$$

where B is the system bandwidth and n is a scaling factor.

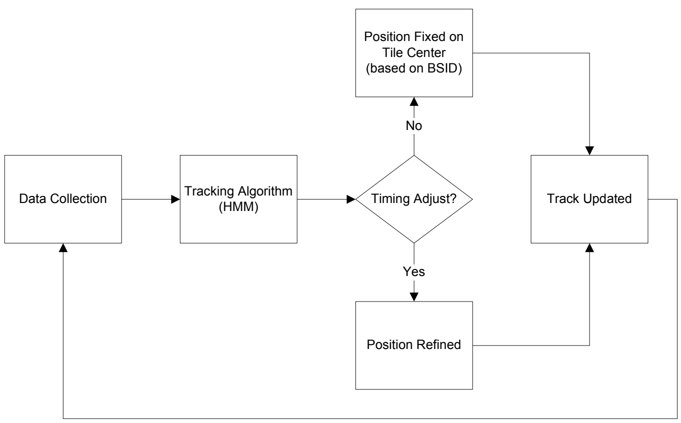

Figure 3. Proposed enhanced tracking scheme.

IV. SIMULATION RESULTS

In order to simulate the tracking scheme, an area of interest of 10×10 square kilometer centered over San Jose, California was considered for its heavy concentration of base stations from the Clearwire wireless network [6]. From Clearwire's coverage map, approximately 46 base stations were located within the area of interest [7]. For simulation purposes, each base station covers 360 degrees with a maximum separation distance of approximately 1,700 meters, corresponding to a single timing adjust of 13.4 meters. Also, we are ignoring the antenna sectoring at the base station. A bandwidth of 10 MHz and a scaling factor of 28/25 are used to obtain the range of each timing ring. A maximum of 127 rings per base station were used. The position error of the location estimate provided by the tracking scheme utilizing the timing adjust data is assumed to be ± 23 meters based on the results reported in [3].

The area of interest was subdivided into a 12 × 12 grid of tiles. Each tile is 1 square kilometer in size. Given the tile size, the position error of the location estimate given by the HMM algorithm is ± 500 meters. The area of interest and the base stations as mapped into the MATLAB are shown in Figure 4 [6]. The roads are represented by solid black lines with hollow circles, and the 46 base stations are indicated by the blue dots. The mobile subscriber has the ability to move in both the cardinal and ordinal directions out of the tile while adhering to the road system as stated. Figure 4 illustrates the reference track taken by the mobile subscriber through the network [6]. The mobile subscriber starts at point A and travels a northerly route to point B.

For this simulation, the mobile subscriber is moving at a rate of approximately 105 km/h or 29 m/s. The simulated measurement collection rate is every three seconds, which translates to the mobile subscriber moving approximately 87 meters per collection. There are a total of 157 data collection points in this simulation.

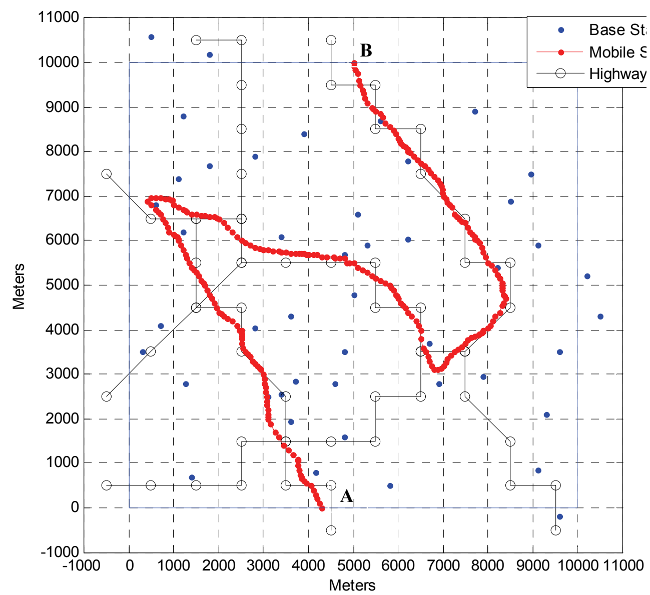

Figure 4. The reference track of the mobile subscriber through the network.

The track constructed from the position estimates provided by the scheme using BSID measurements only is illustrated by Figure 5. The numbered arrows describe the route the mobile subscriber traveled. The areas in which the algorithm shows the estimated track deviated from the actual path but was corrected as data collection continued errors were at the road junctions, i.e., points 2, 4, 7, 9, 11, and 14. Overall, the results are positive in tracking the mobile subscriber by comparing to the reference track in Figure 4; note that the estimation accuracy of the track using only BSID data is ± 500 meters in this simulation.

The timing adjust measurements are then used to geolocate the position of the mobile subscriber within an average of ± 23 meters of the actual position [2], [3]. When enough timing adjusts are available, the tracking algorithm updates the track with position of the intersecting timing adjust rings. In order to geolocate the mobile subscriber using the timing adjust data, we need timing adjusts from three or more base stations collected during that time instance. If less than three timing adjusts are collected, then the track is centered on the tile in which the tracking algorithm determines the position to be.

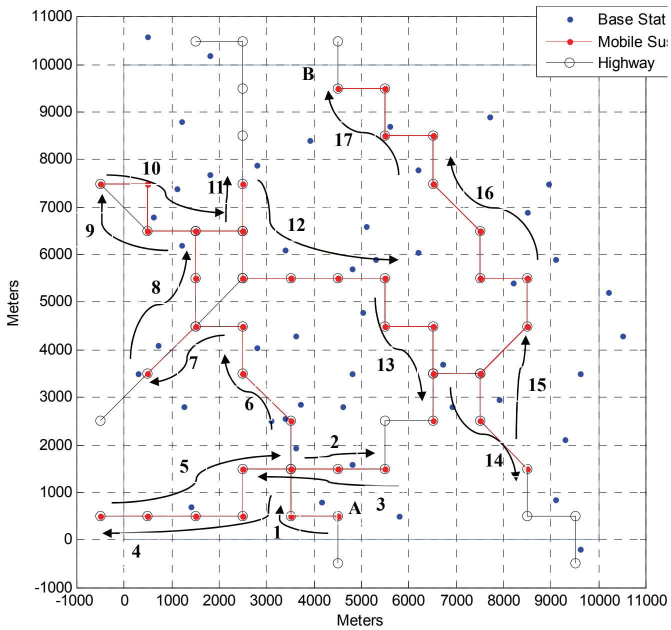

Figure 5. Estimated track using BSID data only.

Figure 6 shows the estimated track obtained using both BSID and timing adjust measurements. Once the timing adjust measurements are added to the tracking scheme, tracking errors at points 2 and 3, 4 and 5 were corrected. At points 7 and 8, 9 and 10, and points 14 and 15, where the track deviated from the actual track, the error is not corrected. This is due to the lack of availability of enough timing adjust data in areas 1 and 2.

V. Conclusion

In this paper, we explored the use of base station IDs and timing adjusts to track a mobile subscriber through a WiMAX cellular network. A hidden Markov model based algorithm developed by Bshara [1] was used to estimate tracks for the case when only BSID measurements were available. The incorporation of timing adjust measurements into the tracking algorithm significantly enhanced the geolocation accuracy of the mobile subscriber. A MATLAB simulation was developed to demonstrate the effectiveness of the proposed addition of timing adjust measurements to locate a mobile subscriber with increased accuracy. The results indicate that obtaining enough timing adjust measurements to triangulate the mobile subscriber position may not always be possible. Having the BSID data when there are gaps in timing adjust measurements is valuable to successfully continue tracking the mobile subscriber.

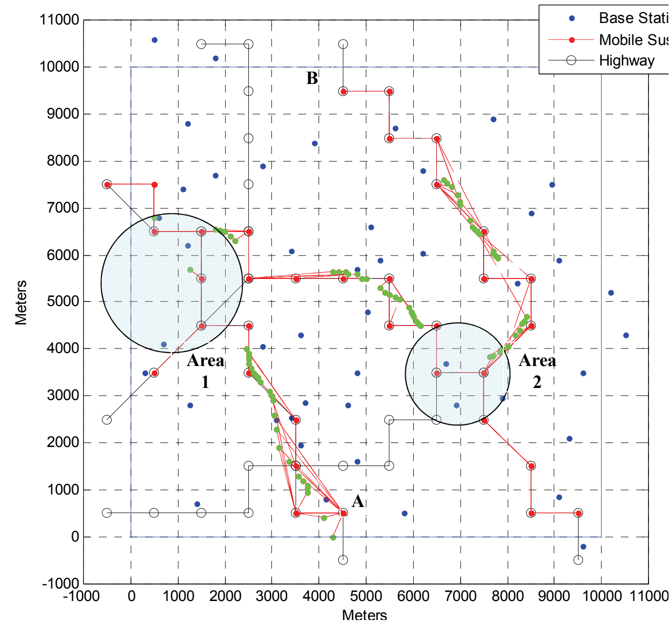

Figure 6. Estimated track using both BSID and timing adjust measurements. The green dots represent the refined position based on timing adjust measurements.

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