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Location Tracking Schemes for Broadband Wireless Networks

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1. Introduction

In order to enable the delivery of last mile wireless broadband access, the IEEE 802.16-2004 standard (IEEE Std 802.16-2004, 2004) for the wireless metropolitan area networks (WMAN) is designed to fulfill various demands for higher capacity, higher data rate, and advanced multimedia services. Furthermore, the IEEE 802.16e standard (IEEE Std 802.16e-2005, 2006) enhances the original IEEE 802.16-2004 specification by addressing the mobility issues for the mobile stations (MSs). Recently, the IEEE 802.16-2009 standard (IEEE Std 802.16-2009, 2009) has been specified as an integrated version of the IEEE 802.16 specification by the IEEE 802.16 maintenance task group. The IEEE 802.16-2009 standard is as known as the revision of IEEE 802.16-2004 and consolidates material from IEEE 802.16e-2005, IEEE 802.16-2004/Cor1-2005, IEEE 802.16f-2005, and IEEE 802.16g-2007. In order to fulfill the requirement of the E911 phase II requirement advanced by Federal Communications Commission, the location-based services (LBSs) (Perusco & Michael, 2007) are considered one of the key functions of the IEEE 802.16-2009 standard. Moreover, for fulfilling the resource management purpose, location update is also essential to other numerous functions such as the paging processes.

Based on the IEEE 802.16 standard, it is required to provide satisfactory location estimation performance under a wide-range of MS's moving speeds. Location tracking is designed as one of the options to provide feasible estimation performance in order to trace the MS's moving behaviors. However, there are several issues required to be considered before enabling the location tracking scheme within IEEE 802.16 system. It is noted that timing information, i.e., the time-difference-of-arrival (TDOA) measurements, from at least four base stations (BSs) is required to perform a two-dimensional location estimation and tracking for an MS. With the stringent synchronization requirement for the IEEE 802.16 OFDMA-based system, the frequent TDOA measurements with other neighbor (a.k.a. non-serving) BSs can be time-consuming and impractical processes for location estimation and tracking. It is a waste of the bandwidth to scan for the neighbor BSs frequently, especially under broadband wireless communication.

In this book chapter, two location tracking schemes are proposed to alleviate the problem that requires frequent connections between the MS and the neighbor BSs. The kinematics-assisted location tracking (KLT) scheme adopts the kinematic relationship to estimate the MS's location at the time instant with unavailable neighbor BSs; while the geometry-assisted location tracking (GLT) algorithm utilizes the geometric constraints for the prediction of MS's position. The two schemes are proposed to interpolate the location of an MS between two direct

location estimations from the MS to the neighbor BSs. It will be shown in the simulations that both proposed schemes can provide feasible performance with significantly reduced communication overhead.

2. TDOA Measurements of IEEE 802.16 Network

To illustrate for the TDOA measurement scheme, the procedures related to the basics of IEEE 802.16 network operations are introduced first. The IEEE 802.16 adopts OFDMA based technique, which implies the MS and the serving BS should synchronize in both time and frequency domain in order to receive the data correctly. Providing that an MS intends to join an IEEE 802.16 network, it conducts initial ranging with the serving BSs to obtain the synchronization parameter. In order to indicate which time slots for the MS to receive and transmit data, the downlink map (DL-MAP) and the uplink map (UL-MAP) are designed respectively. First the MS should listen to the BS's broadcast message to capture the ranging opportunity in the UL-MAP. The MS conducts contention based initial ranging to obtain related parameter and then is granted to join the network. After the MS establishes the link with serving BS, the MS performs periodic ranging in order to maintain the synchronization property while the MS may move to different place or the channel condition may vary at different time. It is noted that the periodic ranging is one of the routine process which is not considered as an overhead in this work. The ranging scheme is conducted by the MS sending assigned CDMA codes to serving BS to measure the distance related parameter, e.g. timing advance value. It is noticed that the timing advance value is the round trip time between the MS and the serving BS. The timing advance information is utilized to reserve the proper timing for the uplink transmission. By performing the ranging scheme, the serving BS measures the timing adjustment according to previously recorded timing advance information to update the distance between MS and serving BS. In order to support for the MS's mobility, the scanning scheme is specified for the MS to perform ranging with neighbor BSs. With the negotiation between serving BS and neighbor BSs, the scanning scheme can directly obtain ranging opportunity without contention. However, the MS is unavailable to serving BS while it performs scanning scheme with the neighbor BSs.

In the IEEE 802.16-2009 standard, two types of TDOA are specified as the downlink TDOA (D-TDOA) and the uplink TDOA (U-TDOA) where the measurements are performed at the MS and the BS respectively. These two schemes are based on ranging and scanning scheme to obtain time difference between the serving BS and the neighbor BSs. Due to the superior timing resolution obtained from the U-TDOA measurement at the BS (i.e., around 25 to 50 nanoseconds measured at the BS compared to microseconds at the MS), the U-TDOA measurement is chosen in this paper for achieving better location estimation accuracy. Moreover, as described in the standard, the general U-TDOA method is adopted while the frequency reuse factor is not equal to one which is considered as a more general case. Several assumptions are specified as follows: (a) both the serving and neighbor BSs are operating with the same frame size; (b) the frames at both the serving and the neighbor BSs are synchronized; and (c) the MS can communicate with both the serving and the neighbor BSs.

Fig. 1 illustrates the timing diagram of the general U-TDOA measurement in IEEE 802.16-2009. The MS ranges sequentially with the serving BS and neighbor BSs. It is noted that the second frame of the MS is operating on the same frequency with the serving BS and the third is the same with the neighbor BS. The serving BS (i.e., the 1st BS) and the neighbor BS (i.e., the 2nd BS) measure the timing adjustment t_{adj_1} and t_{adj_2} respectively, and the neighbor BS reports t_{adj_2} to the serving BS. The timing advance value t_{adv} remains the same since the MS does

Fig. 1. Timing Diagram of the general U-TDOA measurement proposed in the IEEE 802.16-2009 standard.

not make any timing adjustments while conducting ranging with both the serving and the neighbor BSs. Therefore, serving BS calculates the time difference $t_{21} = (t_{adj_2} - t_{adj_1}) / 2$ and the difference of the MS's distance to the serving BS and neighbor BS is obtained by multiplying this difference by the speed of light.

Fig. 2 illustrates the message exchange sequences for the general U-TDOA measurement. The serving BS requests neighbor BSs to assign a dedicated ranging opportunity for the MS. The MS will first conduct ranging with the serving BS in order to perform the U-TDOA measurement. Through the ranging response (RNG-RSP) message, the serving BS will assign a Rendezvous time, a CDMA code, and a Tx opportunity offset for the MS. It is noted that the Rendezvous time specifies the frame in which the BS transmits an UL-MAP containing the definition of the dedicated ranging region. As the Rendezvous time is expired, the MS will transmit the allocated CDMA code within the regular ranging region. The time-of-arrival (TOA) measurement $t_{1,k}$ performed at the serving BS (BS₁) is obtained as an average value of both the timing adjustment $t_{adj_{1,k}}$ from the measurement and the timing advance t_{adv_k} acquired from the periodic ranging, i.e., $t_{1,k} = (t_{adj_{1,k}} + t_{adv_k}) / 2$ where the subscript denotes the k th time step.

Moreover, the dedicated ranging process is repeated through the neighbor BS (e.g. BS₂) by sending the mobile scanning response (MOB_SCN-RSP) message. The neighbor BS measures $t_{adj_{2,k}}$ and reports the value to the serving BS. The TOA measurement for BS₂ can therefore be acquired as $t_{2,k} = (t_{adj_{2,k}} + t_{adv_k}) / 2$. As a result, the U-TDOA measurement calculated at the serving BS is obtained as $t_{21,k} = (t_{adj_{2,k}} - t_{adj_{1,k}}) / 2$. Similar process can be performed to obtain the timing information from the other neighbor BSs. Nevertheless, with the TDOA measurements, at least four BSs should be involved to perform a 2-D location estimation. There is a significant overhead to perform location tracking scheme as depicted in Fig. 2. In the following section, the proposed location tracking schemes are proposed to alleviate the overhead of frequent ranging with neighbor BSs.

Fig. 2. The message exchange sequences of the general U-TDOA measurement method proposed in the IEEE 802.16-2009 standard.

3. Proposed Location Tracking Schemes

3.1 Mathematical Modeling of Signal Measurements

In this subsection, the mathematical models for both the TOA and the TDOA measurements are presented to facilitate the location estimation of the two-dimensional coordinates for the MS. The measured relative distance ($r_{i,k}$) between the MS and the i th BS (obtained at the k th time step) can be represented as

$$r_{i,k} = c \cdot t_{i,k} = \zeta_{i,k} + m_{i,k} + n_{i,k} + s_{i,k} \tag{1}$$

where $t_{i,k}$ denotes the TOA measurement obtained from the i th BS at the k th time step, and c is the speed of light. $r_{i,k}$ is contaminated with the TOA measurement noise $m_{i,k}$ due to the imprecision of the measuring device. The non-line-of-sight (NLOS) error $n_{i,k}$ is assumed to be existent in the considered environments, which is inherently a parameter with positive value. $s_{i,k}$ denotes the unknown asynchronous clock time offset between the MS and the BS. The noiseless relative distance $\zeta_{i,k}$ between the MS and the i th BS can be obtained as

$$\zeta_{i,k} = [(x_k^\circ - x_{i,k})^2 + (y_k^\circ - y_{i,k})^2]^{\frac{1}{2}} \tag{2}$$

where $\mathbf{x}_k^o = [x_k^o \ y_k^o]^T$ represents the MS's true position at the k th time step, and $\mathbf{x}_{i,k} = [x_{i,k} \ y_{i,k}]^T$ is the location of the i th BS. On the other hand, the relative distance $r_{ij,k}$ from the TDOA measurement $t_{ij,k}$ can be obtained by computing the time difference between the MS w.r.t. the i th and the j th BSs as

$$\begin{aligned} r_{ij,k} &= (r_{i,k} - r_{j,k}) = c \cdot (t_{i,k} - t_{j,k}) = c \cdot t_{ij,k} \\ &= (\zeta_{i,k} - \zeta_{j,k}) + (m_{i,k} - m_{j,k}) + (n_{i,k} - n_{j,k}) \end{aligned} \quad (3)$$

It is noted that in IEEE 802.16-2009 standard each BS equips a GPS in order to achieve time synchronization. Therefore, the relationship $s_{i,k} - s_{j,k} = 0$ is true since the frames at the serving and the neighbor BS are synchronized. As depicted in the previous section for the general U-TDOA method, the TOA measurement (in (1)) is acquired for the purposed of obtaining the TDOA measurement (in (3)).

3.2 Location Estimation and Tracking Algorithms

The main concept for the proposed schemes is to maintain the accuracy for location estimation with a reduced number of dedicated ranging (i.e., the general U-TDOA measurement in Figs. 1 and 2) between the MS and the BSs. The increased number of dedicated ranging with the neighbor BSs can result in unsatisfactory communication performance between the MS and its serving BS, e.g. with degraded scheduling performance for realtime applications. It is noted that the dedicated ranging state indicates the state for the MS to conduct the general U-TDOA method with the serving and the neighbor BSs as shown in Fig. 2. Without communications between the MS and the BSs, on the other hand, the non-dedicated ranging state (i.e., the general U-TDOA measurement is not available) is defined as the state in which the MS's location information is estimated and predicted by the proposed KLT and GLT schemes, which will be explained in the next two subsections.

Fig. 3. The timing diagram for the relationship between the dedicated and non-dedicated ranging states.

Fig. 3 illustrates the relationship between the dedicated and the non-dedicated ranging states. The location estimation period (T_E) is defined as the time duration between two ded-

icated ranging states. On the other hand, the location information period (T_I) is designed as $T_I = T_E/m$ with $m \geq 1$, which represents the time interval either between two non-dedicated ranging states or between a dedicated and a non-dedicated states. In other words, T_I is defined as the interleaved period where the MS's location information becomes available, either obtained from the general U-TDOA method of the proposed KLT/GLT scheme. In other word, the U-TDOA method is utilized at the dedicated ranging state; while the KLT/GLT scheme interpolates the position information at the non-dedicated ranging state. Moreover, the sampling time Δt is denoted as the time interval between the k th and the $(k - 1)$ th time steps as in (1) to (3) It is selected the same as the location information period, i.e. $\Delta t = T_I$.

Fig. 4. The schematic diagram of the proposed KLT and GLT algorithms.

Fig. 4 illustrates the schematic diagram of the proposed KLT and GLT algorithms. Either the dedicated or the non-dedicated ranging can happen for obtaining the MS's estimated position $\hat{\mathbf{x}}_k = [\hat{x}_k \hat{y}_k]^T$. For the dedicated ranging case, the cascaded location tracking (CLT) scheme as proposed in (Chen & Feng, 2005) is exploited. The CLT algorithm is cascaded by two functional components, i.e. the two-step least square (LS) method for location estimation and the Kalman filtering technique for location tracking. The two-step LS method obtains the initial location estimation $\hat{\mathbf{x}}_k^{LS} = [\hat{x}_k^{LS} \hat{y}_k^{LS}]^T$ from the TDOA measurement input $t_{ij,k}$ (in (3)) within two computing iterations. Furthermore, the Kalman filter is utilized to smooth out and trace the estimation errors and finally acquires the MS's estimated location $\hat{\mathbf{x}}_k = [\hat{x}_k \hat{y}_k]^T$. On the other hand, since the TDOA measurements are not available during the non-dedicated ranging state, two schemes are proposed to substitute the functionality of the two-step LS method as follows.

3.2.1 Kinematics-Assisted Location Tracking (KLT) Scheme

With the unavailability of the TDOA measurements during the non-dedicated state, the KLT scheme is utilized to adopt the predicted information from the output of the Kalman filter. Considering a three-states linear model, the MS's position, velocity, and acceleration can be estimated via the Kalman filter as $\hat{\mathbf{z}}_k = [\hat{\mathbf{x}}_k \hat{\mathbf{v}}_k \hat{\mathbf{a}}_k]^T$, where $\hat{\mathbf{x}}_k = [\hat{x}_k \hat{y}_k]^T$, $\hat{\mathbf{v}}_k = [\hat{v}_{x,k} \hat{v}_{y,k}]^T$, and $\hat{\mathbf{a}}_k = [\hat{a}_{x,k} \hat{a}_{y,k}]^T$. Assuming that the state vector $\hat{\mathbf{z}}_k$ is available either via the dedicated or non-dedicated ranging, the next non-dedicated states $\hat{\mathbf{z}}_{k+1}$ at the $(k + 1)$ th time instant can be acquired by utilizing the feedback information from the output of the Kalman filter at time k .

By adopting the updates from the kinematic relationship, the MS's predicted position $\hat{\mathbf{x}}_{k+1}$ at the $(k + 1)$ th time step can be acquired as

$$\hat{\mathbf{x}}_{k+1}^{KLT} = \hat{\mathbf{x}}_k + \hat{\mathbf{v}}_k \cdot \Delta t + \frac{1}{2} \cdot \hat{\mathbf{a}}_k \cdot \Delta t^2$$

(4)

where Δt is the sampling interval as $\Delta t = T_I$. The location estimation and tracking at the non-dedicated ranging state can therefore be performed.

3.2.2 Geometry-Assisted Location Tracking (GLT) Scheme

Fig. 5. The message exchange sequences of propose GLT schemes.

Similar to the KLT algorithm as described in the previous subsection, the proposed GLT scheme is utilized to provide location estimation during the non-dedicated ranging state. The concept of the GLT algorithm is to utilize the frequent periodic ranging between the MS and the serving BS. Based on the periodic ranging, the relative distance $r_{1,k}$ between the serving BS and the MS can be obtained from the corresponding TOA measurements $t_{1,k}$. Fig. 5 depicts the message exchange sequences of the proposed GLT schemes within the IEEE 802.16-2009 network. It is noticed that the flowchart is the same as the general U-TDOA scheme as in Figs. 1 and 2 at the dedicated ranging state. However, at the non-dedicated ranging state, the TOA measurement is obtained through periodic ranging scheme as shown in Fig. 5.

Fig. 6. The schematic diagram of the geometric constraints for the proposed GLT scheme.

As shown in Fig. 6, the circular region can be formed according to the center point $x_{1,k} = [x_{1,k} \ y_{1,k}]^T$ with radius of $r_{1,k}$. Meanwhile, two additional linear equations can be acquired from the feedback of the Kalman filter at the k th time instant, i.e. $x = \hat{x}_k$, $y = \hat{y}_k$. As a result, the two linear and one circular equations can be utilized to provide the geometric constraints for obtaining the MS's position estimation. Based on the constrained region, the LS method is employed to minimize the sum of the square errors for the MS's position. Therefore, the MS's estimated position by adopting the GLT scheme is acquired as

$$\hat{x}_{k+1}^{GLT} = \mathbf{G} \cdot (\mathbf{H}^T \mathbf{H})^{-1} \mathbf{H}^T \mathbf{J} \quad (5)$$

where

$$\mathbf{G} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \quad (6)$$

$$\mathbf{H} = \begin{bmatrix} -2x_{1,k} & -2y_{1,k} & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \quad (7)$$

$$\mathbf{J} = \begin{bmatrix} r_{1,k}^2 - x_{1,k}^2 - y_{1,k}^2 \\ \hat{x}_k \\ \hat{y}_k \end{bmatrix} \quad (8)$$

4. Performance Evaluation

Simulations are performed to show the effectiveness of the proposed KLT and the GLT schemes. Different noise models (Greenstein et al., 1997) are considered in the simulations in order to represent various environments, including the urban, the suburban, and the rural cases. In the cellular-based network, an exponential distribution is assumed for the NLOS model with the distribution of $p_{n_{i,k}}(v)$ as

$$p_{n_{i,k}}(v) = \begin{cases} \frac{1}{v_{i,k}} e^{\frac{-v}{v_{i,k}}} & v > 0 \\ 0 & v \leq 0 \end{cases} \quad (9)$$

where $v_{i,k} = c \cdot \tau_{i,k} = c \cdot \tau_m \zeta_{i,k}^\varepsilon \omega$ is the RMS delay spread between the i th BS to the MS at the k th time step; τ_m is the median value of $\tau_{i,k}$ whose value depends on various environments, i.e. $\tau_m = 0.4, 0.3$, and 0.1 for urban, suburban, and rural respectively. ε is the path loss exponent which is assumed to be 0.5 . The shadow fading factor ω is a lognormal random variable with zero mean and standard deviation σ_ω chosen as 4 dB in the simulations. Moreover, the measurement noises (i.e. $m_{i,k}$ in (1)) is considered Gaussian-distributed as $\mathcal{N} \sim (0, \sigma_m^2)$ with $\sigma_m = 10$ m. The asynchronous offset (i.e. $s_{i,k}$ in (1)) between the MS and the BS clock time is also assumed to be Gaussian-distributed with $\sigma_s = 7.5$ m.

Fig. 7. The geometric layout of the simulation (Green Line: MS's True Trajectory; Red Empty Circles: the Position of the BSs)).

Fig. 7 illustrates the MS's trajectory with the Manhattan street scenario in the simulation. The MS's true trajectory is illustrated via the green lines; while the locations of the BSs are represented by the red empty circles as in Fig. 7. The acceleration is designed to vary at time $t = 21, 26, 31, 47, 63, 76$, and 89 sec from $\mathbf{a}_k = (a_{x,k}, a_{y,k}) = (0, -1), (4, 0), (-4, 0), (0, 2), (0, -2), (-3, 0)$ to $(3, 0)$ m/sec². The corresponding MS's velocity lies between $(0, 70)$ km/hr.

Fig. 8 shows the performance comparison between the proposed KLT and GLT schemes under the urban environment (with $T_I = 1$ sec and $T_E = 1, 2$, and 4 sec). It is noted that the position error is defined as $P_e = \|\hat{\mathbf{x}}_k - \mathbf{x}_k^o\|$. The case with $T_I = T_E = 1$ sec indicates that the non-dedicated ranging does not exist, which is served as the lower bound of the estimation errors. As shown in the figure, comparably inferior performance is observed with larger values of T_E , which indicates that the dedicated ranging with the TDOA measurement is not frequently available. Moreover, the proposed GLT algorithm outperforms the KLT scheme for each specific case, e.g. around 50 m less of the position error under the case of $T_E = 4$ sec with 67% of position errors.

Fig. 8. Performance comparison between the proposed KLT and GLT schemes under the urban environment ($T_I = 1$ sec).

Fig. 9 shows the performance comparison with 67% of position errors between the proposed KLT and GLT schemes under the different noise environment. It is noticed that the KLT scheme performs similar to GLT scheme at the smaller NLOS environment, e.g. $\tau_m = 0.1$ (rural environment). However, the performance of KLT is comparably worse than the performance of GLT scheme under the excessive NLOS errors. The effectiveness of adopting the periodic ranging in GLT scheme can be observed in the case.

In order to evaluate the overhead of the frequent location tracking, serving BS unavailable time (i.e. T_U) is defined for the percentage of the frame communicating between the MS and the neighbor BSs. In the dedicating ranging period, the MS should synchronize with other BSs and therefore the ongoing transmission should be buffered in serving BS. Although the more frequent the dedicating ranging performed brings higher location estimation accuracy, the total usage in the serving BS's point of view would decrease. In the Fig. 2, the MS needs to synchronize to the neighbor BSs first and then performs the ranging process. The following parameter is defined to perform a dedicated ranging with the other BSs:

- T_{syn} : average time to synchronize with the new BS
- T_{rng} : average time to perform range process with a BS

The values for T_{syn} and T_{rng} are chosen as 20 millisecond (msec) and 30 msec in average as reported in (Jiao et al., 2007). As the dedicated ranging specified for the LBS, the time of T_{rng} might be shorter. In terms of the T_{syn} and T_{rng} , the serving BS unavailable time counts in percentage is:

$$T_U = \frac{3 * (T_{syn} + T_{rng})}{T_E}$$

(10)

Fig. 9. Performance comparison between the proposed KLT and GLT schemes under different NLOS noise ($T_l = 1$ sec).

Fig. 10. Serving BS unavailable time via the average time to perform range process.

It is noted that at least three neighbor BSs participate a dedicated ranging. Fig. 10 shows the percentage of the BS unavailable time via the T_{rng} from 5 to 40 msec. As the curves shows that the KLT/GLT scheme with $T_E = 2sec$ has half unavailable time than $T_E = 1sec$. While the overhead of the serving BS is considered as the important factor, comparing to the performance of location estimation in Fig. 9, the KLT/GLT scheme with $T_E = 2sec$ is a better solution with a tradeoff.

5. Conclusion

Two assisted location tracking schemes are proposed in this paper. The schemes are capable of estimating the position, velocity, and acceleration of the MS during the dedicated ranging state. With the non-dedicating ranging state, the assisted methods utilizing the tracking information and the periodic ranging information are proposed. It is shown in the simulation results that the proposed location tracking schemes provide consistent performance and reduces the overhead of the serving BS.

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In the last decades the restless evolution of information and communication technologies (ICT) brought to a deep transformation of our habits. The growth of the Internet and the advances in hardware and software implementations modified our way to communicate and to share information. In this book, an overview of the major issues faced today by researchers in the field of radio communications is given through 35 high quality chapters written by specialists working in universities and research centers all over the world. Various aspects will be deeply discussed: channel modeling, beamforming, multiple antennas, cooperative networks, opportunistic scheduling, advanced admission control, handover management, systems performance assessment, routing issues in mobility conditions, localization, web security. Advanced techniques for the radio resource management will be discussed both in single and multiple radio technologies; either in infrastructure, mesh or ad hoc networks.

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