This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the WCNC 2009 proceedings.

Asynchronous Location Tracking Algorithms for Distributed Power-saving Wireless Sensor Networks

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***Abstract*—In recent years, energy conservation has been considered as an important topic within the wireless sensor networks (WSNs). How to extended the network lifetime with cost-effective management is the primary concern within the design of power-saving mechanisms for WSNs. In this paper, with the consideration of energy conservation, two location tracking algorithms are proposed in the distributed WSNs in order to trace a mobile station that is not synchronized with the corresponding sensor nodes (SNs). The scheduled power-saving tracking (SPT) scheme is first proposed for the SNs to trace the MS's beacon instants and consequently to track its movement in a power-saving manner. Coordinators are selected to manage and collect the information for location estimation and tracking of the MS. The predicted information with respect to the MS's movements is obtained by the coordinator in order to notify specific hearable SNs for receiving the MS's next beacon. Moreover, the geometry-assisted power-saving tracking (GPT) algorithm is proposed to further conserve the energy of the SNs. With the consideration of the geometry dilution of precision effect, only specific three SNs will be selected for the computation of MS's positions. Performance comparison of the proposed schemes are conducted by observing both the power efficiency and tracking accuracy under varied MS's velocities. Compared to the SPT scheme, numerical results show that the proposed GPT algorithm can effectively extend the network lifetime and also achieve comparable tracking accuracy.**

***Index Terms*—wireless sensor networks, power-saving, location tracking, geometry dilution of precision (GDOP).**

I. Introduction

Due to the advancement of processing and wireless transmission techniques, sensors are designed to be small, low-powered, and less complexity devices. Sensors scattered in an interested region are capable of sensing, computing, and communicating with each other to gather target information for specific purposes. Consisting of hundreds of sensor nodes (SNs), a wireless sensor network (WSN) has been widely utilized to collect essential data and provide timely responses in different applications, e.g. in environment monitoring, event detection, health care tracing, and battlefield surveillance. In order to construct seamless, ubiquitous, and low-rate wireless person area networks (LR-WPANs), the IEEE 802.15 task group 4 (TG4) aims at investigating power-efficient and inexpensive solutions [1]. Furthermore, a distributed WSN is consisted by a number of randomly distributed SNs without the existence of centralized coordinators. The SNs within a distributed WSN will have to interact with each other based on their limited resources and processing abilities. Specifically, due to the self-contained manner of the distributed WSN, the power consumption of SN should be reduced since it is in general difficult to recharge the battery of each individual SN. Therefore, how to prolong the lifetime of each SN has been considered an important topic with its limited battery capacity.

On the other hand, location estimation and tracking schemes of the mobile station (MS) are essential prerequisites for location-based services (LBS) within WSNs. It is crucial to provide feasible location tracking algorithms based on the collaboration of SNs while the power efficiency can still be maintained. The location tracking schemes based on Kalman filter [2]–[4] have been proposed to estimate and trace the movement of MS. However, these algorithms are primarily designed for the cellular-based networks where the power consumption of the corresponding base stations is considered insignificant. In order to address the severe energy constraints within a distributed WSN, two power-saving location tracking algorithms are proposed in this paper. In order to provide a feasible network scenario, the location-aware SNs are scattered in a randomly distributed manner and are assumed synchronized with each other but not with the MS.

First of all, a scheduled power-saving tracking (SPT) scheme is proposed to conduct location tracking by resolving the asynchronous issue between the SNs and the MS, where the SNs will be scheduled by extendable active durations. Distributed coordinators will be selected among the SNs to be responsible for a localized group of SNs that are utilized to manage location tracking for the MS. Moreover, based on the moving behavior of MS, the coordinator will predict a potential group of SNs that should be in the active power state in order to provide communication with the MS. On the other hand, in order to minimize the number of active SNs for serving the location tracking of MS, the geometry-assisted power-saving tracking (GPT) algorithm is proposed. The geometry-dilution-of-precision (GDOP) metric [5] is utilized as the criterion for the determination of a feasible set of active SNs. Even though less numbers of SNs are chosen for location

[1]This work was in part funded by the MOE ATU Program 95W803C, NSC 96-2221-E-009-016, MOEA 96-EC-17-A-01-S1-048, the MediaTek research center at National Chiao Tung University, and the Universal Scientific Industrial (USI) Co., Taiwan.

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Fig. 1. The superframe format of the IEEE 802.15.4 standard. The beacon frame is issued at the first slot time in the active portion.

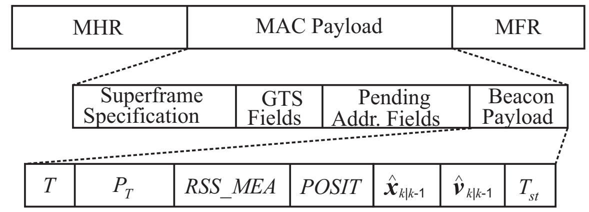

Fig. 2. The beacon frame of the IEEE 802.15.4 MAC standard adopted by the proposed SPT and GPT algorithms.

tracking, smaller estimation errors can still be achieved since a better geometric layout will be selected by adopting the GDOP metric. Performance evaluation and comparison for the proposed SPT and GPT schemes will be conducted by observing the power efficiency and tracking accuracy under different MS's velocities. It will be shown in the numerical results that the proposed algorithms can effectively extend the network lifetime and still achieve comparable tracking accuracy.

The remainder of this paper is organized as follows. Section II briefly reviews the preliminaries applied in this paper. The proposed SPT algorithm is described in Section III; while the proposed GPT scheme is explained in Section IV. The performance evaluations of both the SPT and GPT methods are carried in Section V. Finally, Section VI draws the conclusions.

II. PRELIMINARY

In the following subsections, the adopted superframe and beacon frame are presented in Subsection II-A. The path loss model is summarized in Subsection II-B; while the location estimator and the velocity detector utilized in the SPT and GPT algorithms are briefly described in Subsection II-C. The Kalman filter which provides the predicted information of MS's movements is reviewed in Subsection II-D.

A. Format of Superframe and Beacon Frame

The medium access control (MAC) standard of the IEEE 802.15.4 provides a superframe structure for optional uses. A superframe as shown in Fig. 1 is adopted in this paper, which includes both the active and inactive portions. According to the standard, the active portion is defined by the time duration of T_a which is composed by 16 time slots T_δ. The beacon frame is transmitted at the first time slot. The inactive portion is utilized to conserve the energy by entering into the sleep mode for both the SNs and MS, which will become active until the time slot where the next beacon frame arrives. Furthermore, a MAC layer beacon frame proposed in IEEE 802.15.4 is illustrated in Fig. 2. The MHR and MFR fields represent the MAC header and footer respectively. The proposed SPT and GPT schemes specify seven parameters within the beacon payload area, including the beacon interval T, the transmission power P_T, the received signal strength (RSS) measurement *RSS_MEA*, the position information *POSIT*, the predicted position $\hat{\boldsymbol{x}}_k$, the velocity information $\hat{\boldsymbol{v}}_k$, and the sustaining time T_{st}. The details of these parameters will be explained in next section.

B. Path Loss Model

The RSS measurement can be modeled as a function of the MS's coordinates [6]. The RSS (in dBm) of the ith SN after the reception of MS's kth beacon is given by

$$P_{rss}(d_{i,k}) = P_{T,m} + PL(d_{i,k}), \qquad i = 1, 2, ..., N_k \qquad (1)$$

where $P_{T,m}$ is the MS's transmission power (in dBm) and $PL(d_{i,k})$ (in dB) represents the path loss volume with respect to the distance $d_{i,k}$ that corresponds to the range from the ith SN to the MS which issues the kth beacon. The path loss phenomenon in a object-scattering environment is modeled by a random log-normal distribution [6] as

$$PL(d_{i,k}) = P_{d_{ref}} + 10\, n \log(\frac{d_{i,k}}{d_{ref}}) + X \qquad (2)$$

where $P_{d_{ref}}$ is the power measured at a distance d_{ref} from the MS. The parameter n denotes the path loss exponent, and X is the standard deviation of a zero mean Gaussian distribution which is used to model the random fading effect.

C. Location Estimator and Velocity Detector

The two-step least squares (LS) scheme [7] is utilized as the location estimator for the proposed algorithms. The concept of the two-step LS method is to acquire an intermediate location estimate in the first step with the definition of a new variable η_k, which is mathematically related to the MSs position, i.e. $\eta_k = {x_k}^2 + {y_k}^2$. At this stage, the variable η_k is assumed to be uncorrelated to the MS's position. This assumption effectively transforms the nonlinear equations from distance measurements into a set of linear equations, which can be directly solved by the LS method. The variations within the corresponding signal paths are presented in the covariance matrix and are considered in the problem formulation. The second step of the method primarily considers the relationship that the variable η_k is equal to ${x_k}^2 + {y_k}^2$, which was originally assumed to be uncorrelated in the first step. An improved location estimation can be obtained after the adjustment from the second step. The detail algorithm of the two-step LS method for location estimation can be found in [7].

Moreover, the Doppler radar [8] is applied in the proposed algorithms as a velocity detector. As the directional microwave beams are radiated from an SN and are reflected by an MS, the SN can accurately measure the radial velocity of the MS along with the Doppler effect. The radial velocity is the speed on the direction from the MS to the SN and it varies up

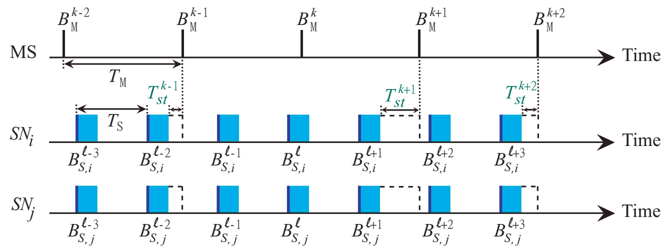

Fig. 3. Timing histories of both the MS and SNs (Blue regions denote the active portions of the superframes).

or down from the SN's operating frequency while the MS moving toward or away from the SN. The detected velocity can therefore be obtained from the radial velocity and the included angle is acquired by intersecting the previously predicted MS's velocity and the connecting line from the SN to the MS's current location estimate.

D. The Kalman Filter

The measurement and state equations of a Kalman filter [9] can be represented as

$$z_k = \mathbf{M}\hat{\boldsymbol{s}}_k + \boldsymbol{m}_k \quad (3)$$
$$\hat{\boldsymbol{s}}_k = \mathbf{F}\hat{\boldsymbol{s}}_{k-1} + \boldsymbol{p}_k \quad (4)$$

where $\hat{\boldsymbol{s}}_k = [\hat{\boldsymbol{x}}_k \ \hat{\boldsymbol{v}}_k \ \hat{\boldsymbol{a}}_k]^T$. The variables $\boldsymbol{m}_k$ and $\boldsymbol{p}_k$ denote the measurement and the process noises associated with the covariance matrices $\mathbf{R}$ and $\mathbf{Q}$ within the Kalman filtering formulation. The vector $z_k = [\hat{\boldsymbol{x}}_{ls,k} \ \hat{\boldsymbol{v}}_{d,k}]^T$ represents the measurement input obtained from the two-step LS estimator and the Doppler radar after the MS's kth beacon. The parameters $\mathbf{M}$ and $\mathbf{F}$ are the measurement and state transition matrices respectively. A Kalman filter consists of two phases, the predicting and updating phases, in one sampling interval. The state obtained in the prediction phase based on the previous estimate is adjusted to a more precise estimate by including the measurement vector z_k. The detail derivations and the associated equations can be referred in [9].

III. Proposed Scheduled Power-saving Tracking (SPT) Algorithm

The proposed SPT algorithm mainly comprises of three aspects to fulfill the goals of power-saving and tracking in a distributed WSN. In Subsection III-A, the initialization process of the SPT scheme is described. The adaptive adjustment of active duration is explained in Subsection III-B. The selection of distributed coordinators is presented in Subsection III-C; while Subsection III-D addresses the calculation of power consumed in the tracking processes.

A. Initialization

As shown in Fig. 3, the SNs are considered synchronized with a common beacon interval T_S; while the MS exploits a different beacon interval T_M comparing with the SNs. According to their beacon intervals, the MS and SNs will respectively emit beacon frames B_M^k and B_S^ℓ at the MS's kth and the SNs ℓth beacon instants. Since the scenario that the MS does not synchronize with the SNs is adopted in this paper, the acquisition method [10] that applies a training preamble or stacked sequences is utilized to recover the initial MS's beacon instant. Each MS's beacon frame B_M consists of the beacon interval T_M and the transmission power $P_{T,m}$ in its beacon payload area as in Fig. 2. The ith SN SN_i^ℓ which receives B_M^k from the MS's kth beacon within the SN's ℓth beacon interval belongs to the kth working group (WG) and will broadcast its beacon frame which comprises both the RSS measurement $RSS\_MEA_i^k$ and its own position $POSIT_i$ as shown in Fig. 2. For convenience, the superscript $k = 1$ is denoted as the occasion while the first B_M is acquired. Initially, as the SNs receive B_M^1, they will construct the first WG and broadcast their beacon frames. These SNs will mutually compare their *RSS_MEA* values and the SN with the smallest *RSS_MEA* value will be elected as the coordinator $\mathbf{C}_1$ at the initial step. Since the moving information of the MS is not obtainable at the initial stage, the decision for choosing $\mathbf{C}_1$ is primarily based on its shortest distance toward the MS. This selection can avoid potential prediction mismatch of the MS's movement. Once the coordinator $\mathbf{C}_1$ has been determined among the SNs, all the other active SNs within the first WG can enter into the sleep mode.

At the next step, the coordinator $\mathbf{C}_1$ will conduct location and velocity estimations by adopting the Kalman filtering technique in order to predict the MS's position $\hat{\boldsymbol{x}}_{2|1}$, velocity $\hat{\boldsymbol{v}}_{2|1}$ and acceleration $\hat{\boldsymbol{a}}_{2|1}$. Afterwards, $\mathbf{C}_1$ will directionally broadcast a beacon frame as shown in Fig. 4 toward the direction of $\hat{\boldsymbol{v}}_{2|1}$ with the maximum transmission range equal to $R_{CM,1}+R_M$. It is noted that $R_{CM,1}$ represents the distance between $\mathbf{C}_1$ and the predicted MS's position $\hat{\boldsymbol{x}}_{2|1}$; while R_M is the MS's transmission range which can be obtained from the MS's transmission power $P_{T,m}$ and the path loss model.

B. Adaptive Adjustment of Active Duration

After the initial acquisition stage, the SNs that receive the beacon frame issued by the coordinator $\mathbf{C}_1$ will be notified with a sustaining time (T_{st}) to the next MS's beacon instant and consequently form a scheduling group (SG). The number of time slots between the occurrence of B_M^k and B_S^ℓ beacons are donated by $N_D^{\ell,k} = \lceil (k\cdot T_M - \ell\cdot T_S)/T_\delta \rceil$, where the ceiling function $\lceil x \rceil$ denotes the function whose value is the nearest integer not less than x.

The time duration corresponding to $N_D^{\ell,k}$ is depicted as $T_D^{\ell,k} = N_D^{\ell,k} \times T_\delta$ and it is used to adjust the sustaining time while the tracking tasks proceed. Without loss of generality, $T_D^{\ell,k}$ can be considered within the range of $[0, T_S]$. The kth sustaining time T_{st}^k given by the coordinator is utilized to extend the duration of active portion and is defined as

$$T_{st}^k = \begin{cases} T_D^{\ell,k} - T_a, & \text{for} \quad T_a \le T_D^{\ell,k} \le T_S \\ T_D^{\ell,k}, & \text{for} \quad 0 \ \le T_D^{\ell,k} < T_a \end{cases} \quad (5)$$

For example as shown in Fig. 3, both SN_i and SN_j will be informed by the previous coordinator that the next MS's beacon instant will happen at the end of the additional time

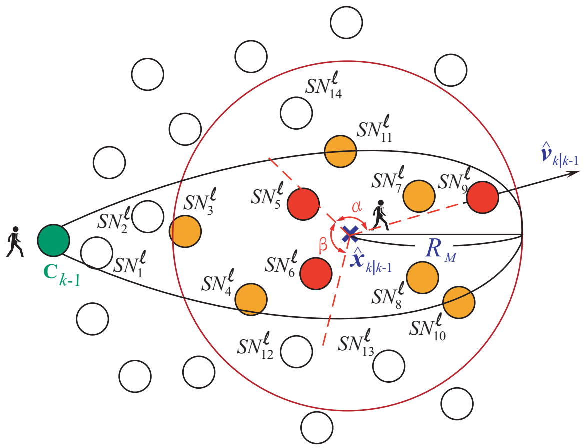

Fig. 4. The schematic diagram of the tracking process in the SPT and GPT algorithms. The SNs that colored with orange and red are selected in the SPT scheme; while only the ones with red color are chosen in the GPT algorithm. The two included angles α and β are designed and determined only in the GPT algorithm.

duration T_{st}^{k-1} after the $(\ell-2)$th T_a. Therefore, the active portions of these two SNs are extended to the time instant that the MS sends out a beacon frame, and these SNs can receive the MS's beacon if they lie within the MS's transmission range. If any of these two SNs locates outside the MS's transmission range, the false-informed SN will enter into the sleep mode after the MS's beacon instant. Similar situations for the SNs' $(\ell+1)$th and $(\ell+3)$th beacon instants can also be observed in Fig. 3. In the case that the MS emits a beacon within the SNs active portion (e.g. within the SNs' ℓth beacon interval in Fig. 3), the T_{st}^{k} will be assigned to $T_D^{\ell,k}$ as in (5). After certain SNs have obtained the MS's beacon, they will form a WG and broadcast beacons based on the frame format in Fig. 2 along with the information of their own *RSS_MEA* and *POSIT*. Afterwards, the coordinator selection process will be restarted.

C. Selection of Distributed Coordinators

The coordinator selection method is explored in the SPT algorithm after the MS's movement has been predicted from the initial step. As presented in Fig. 4, before the MS's oncoming kth beacon instant ($k \geq 2$), the kth SG is organized via the directional broadcast that is delivered by the previous coordinator $\mathbf{C}_{k-1}$. The SNs SN_i^{ℓ} for $i = 1$ to 11 will form the kth SG and are scheduled to synchronize with the MS by extending their active portions with a specific duration T_{st}^{k}. The MS's beacon frame will be received by the SNs SN_j^{ℓ} for $j = 3$ to 11, which compose of the kth WG. The SNs SN_1^{ℓ} and SN_2^{ℓ} will enter into the sleep mode after the MS's beaconing since they are not located within the MS transmission range. The SNs SN_j^{ℓ} with $j = 12$ to 14 can not receive the MS's beacon frame since they are not notified to extend their active portions in order to wait for the upcoming MS's beacon instant. The SNs are able to receive the MS's beacon frame only when they are in the active mode and the MS emits a beacon concurrently.

The SN within the kth WG will broadcast its beacon frame, including $RSS\_MEA_i^k$ and $POSIT_i$, after receiving the MS's beacon frame. Based on the distributed manner, the SN belonging to the kth WG will collect the emitted information from other SNs in order to determine if it will be served as the kth coordinator $\mathbf{C}_k$. It is noted that the selection of the kth coordinator is dominated by both the direction of predicted MS's movement and the MS transmission range R_M. The kth coordinator will be chosen along the direction of the predicted MS's velocity $\hat{\boldsymbol{v}}_{k|k-1}$ with minimum angle dispersion. If there are more than one SN satisfies the above criterion, a reference distance metric is applied. The reference velocity $\mathbf{V}_{ref}$ is defined as R_M/T_M, and the kth reference distance $R_{r,k}$ is given by

$$R_{r,k} = R_M \exp\left(\frac{-\mathbf{V}_{ref}}{\hat{\boldsymbol{v}}_{k|k-1}}\right), \quad k \geq 2 \tag{6}$$

If $\hat{\boldsymbol{v}}_{k|k-1} > \mathbf{V}_{ref}$, it denotes that the MS will be out of its current transmission range before the next MS beacon instant. Therefore, a longer $R_{r,k}$ will become more feasible to be chosen. The kth coordinator will be selected from the kth WG based on the following: (a) by minimizing the angle dispersion away from the direction $\hat{\boldsymbol{v}}_{k|k-1}$ and (b) by minimizing the difference of $R_{r,k}$ and the distance between $\hat{\boldsymbol{x}}_{k|k-1}$ and those hearable SNs. Consequently, the selected coordinator $\mathbf{C}_k$ will estimate and predict the MS's position and velocity; while the processes described in Subsections III-B and III-C will be repeated.

D. Energy Consumption

The energy consumed in the positioning and tracking processes can be characterized into two different cases:

$$E = [E_n + (T_D^{\ell,k} - T_\delta)P_A]N_w + P_{T,c}T_\delta \tag{7}$$

where $E_n = (P_{T,b} + P_R + P_{T,s}) \times T_\delta$ denotes the energy required for the SN to conduct message delivery, including the required power for periodic beacon $P_{T,b}$, the power for receiving MS's beacon P_R, and the power for broadcasting its measurement and position $P_{T,s}$. P_A represents the power required for maintaining the active mode. N_w indicates the number of SNs within the WG set. Moreover, the power $P_{T,c}$ is utilized by the coordinator to directionally broadcast the predicted MS's movement information. Considering that the receiving sensitivity for each SN is given, the power $P_{T,c}$ for the kth tracking task can be determined by the path loss model (1) and (2) with maximum range less than $R_{CM,k} + R_M$. The power consumed in the inactive portion, i.e. the sleep mode, is considered insignificant in (7).

IV. Proposed Geometry-assisted Power-saving Tracking (GPT) Algorithm

In order to provide better energy conservation, the proposed GPT algorithm enhances the SPT scheme by incorporating the geometric information between the MS and the SNs. The GPT algorithm will be implemented in the case that the difference between the previously predicted MS's position and

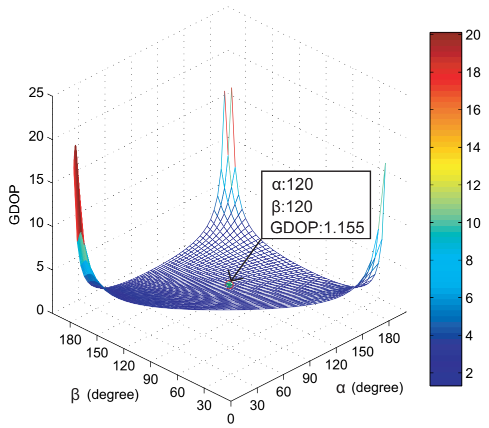

Fig. 5. The relationship between α, β and the GDOP value in arbitrary triangular network topologies.

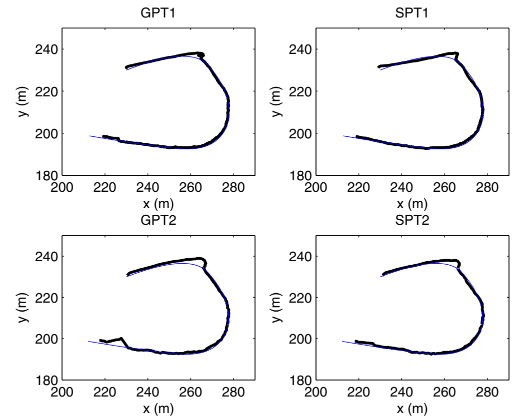

Fig. 6. The comparison of tracking performance by adopting the proposed SPT and GPT algorithms. The blue line indicates the MS's true trajectory; while the black line represents the predicted MS's movement.

the present location estimation is smaller than a prespecified threshold. The major reason is primarily attributed to the situation that the GDOP information will become feasible only with tolerable estimation errors. The distributed coordinator is responsible for determining the operating state and pre-informs specific three SNs with the concern of geometric effect between the MS and the SNs.

The GDOP metric is originally adopted in the satellite-based systems to verify whether the geometry relationship of the satellites is good or not for positioning tasks. It has also been applied recently in both the cellular-based and wireless sensor networks. A GDOP value derived from a network topology can be considered as a performance measure for position estimation based on the geometric layout. A poor network layout will lead to a larger GDOP value and cause the degradation of positioning performance. Based on the definition of GDOP, only the azimuth rather than any other parameter is included in the computation of the GDOP value. As shown in Fig. 4, α and β are designed to be the two adjustable angles starting from the direction of $\hat{\boldsymbol{\nu}}_{k|k-1}$. The minimum achievable GDOP value in arbitrary triangles is $2/\sqrt{3}$ which can be obtained while both α and β are 120^o [11], as can be verified in Fig. 5.

As shown in Fig. 4, considering the case that tolerable estimation error has been observed by the $(k-1)$th coordinator $\mathbf{C}_{k-1}$, the GPT scheme will be exploited to reduce additional energy consumption. Based on the GDOP metric, only three SNs with included angles are equal to or around 120^o will be selected by the $\mathbf{C}_{k-1}$. For example as in Fig, 4, the SNs SN_j^ℓ for $j = 5$, 6 and 9, are chosen to cooperate at the next MS's beacon instant. The adjustment of the active duration will be the same as that described in subsection III-B. The next coordinator will be selected as SN_9^ℓ, which is closest to the MS's moving direction, in order to be responsible for the estimation and prediction of MS's movement. The power consumption in the GPT scheme can be computed similar to (7) with the case that $N_w = 3$.

V. Performance Evaluation

Simulations are conducted in a 500×300 m^2 network topology with 150 randomly deployed SNs. The antenna receiving sensitivity is set to be -98 dBm which is referred from the MAC specification of IEEE 802.15.4 standard [1]. The transmission power of MS is -11.44 dBm which can sustain a radio range of around 30 meters. On the other hand, a SN broadcasts its periodic beacons and measurements with the power of -1.17 dBm, which covers a range with radius of 60 meters. The velocity of the MS is varied from -5 to 5 m/s to represent general human movements. It is noticed that each time slot is selected as $T_\delta = 0.96$ ms, and hence the duration of active portion $T_a = 15.36$ ms. The beacon intervals $T_S = 30$ ms and two T_Ms, one is 50 ms and the other with 100 ms, are applied in the simulations for a total of 60 seconds. The parameters of path loss model and power benchmark referred from [12] and [13] are listed as below.

TABLE 1 : SIMULATION PARAMETERS

Parameter	Value
$P_{d_{ref}}$	60 dB
d_{ref}	5 m
n	4.7 dB
$P_{T,m}$	7.18×10^{-2} mW
$P_{T,b}$	7.63×10^{-1} mW
$P_{T,s}$	7.63×10^{-1} mW
P_R	7.03×10^{-1} mW
P_A	3.2×10^{-1} mW

The comparison of the tracking performance by adopting the proposed SPT and GPT schemes are shown in Fig. 6. It is noted that the cases with GPT1 and SPT1 are simulated with $T_M = 50$ ms; while GPT2 and SPT2 with $T_M = 100$ ms. Comparing with SPT2 and GPT2, better trajectory tracking performance can be achieved by SPT1 and GPT1 since more measurements are acquired. Fig. 7 shows the comparison of location estimation error of the proposed SPT and GPT algorithms. The estimation error is defined as the difference

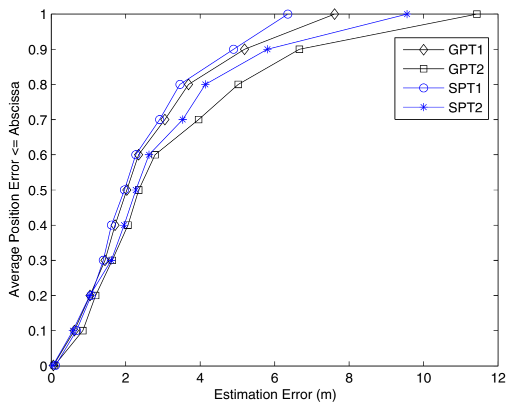

Fig. 7. Performance comparison of the estimation error between the SPT and GPT algorithms.

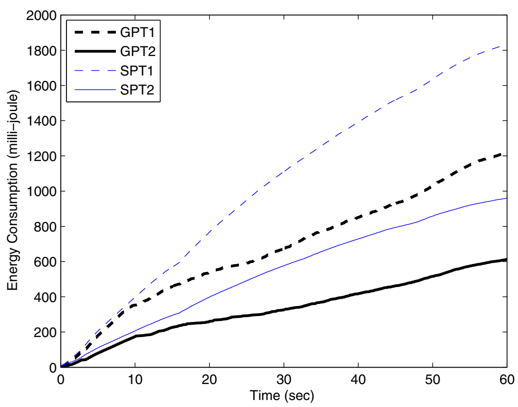

Fig. 8. The performance comparison of energy consumption between the SPT and GPT algorithms.

between the location estimate obtained from the Kalman filter and the true MS's position. As presented in Fig. 7, the estimation error inherits the same result as shown in Fig. 6. In other words, the estimation errors of the SPT scheme is smaller than that of the GPT algorithm under specific beacon interval. Moreover, since the cases with SPT1 and GPT1 track the MS's movements more frequently than that from the SPT2 and GPT2 cases, better performance can be achieved for location estimation and tracking of the MS.

The energy consumed in the positioning and tracking processes by exploiting the proposed schemes are compared in Fig. 8. It is observed that the cases with SPT1 and GPT1, which utilize twice of beacon frames for better tracking performance, approximately consume two times of power comparing with that obtained from the case with SPT2 and GPT2. On the other hand, although the tracking performance of the GPT algorithm is slightly worse compared to that of the SPT method (as in Fig. 7), more energy can be conserved by adopting the GPT scheme as illustrated in Fig. 8. The difference of energy consumption between GPT1 and SPT1 after 1200 tracking trials (i.e. $1200 \cdot 50$ ms $= 60$ seconds) is about 614 milli-joules. Considering that averagely 1.53 milli-joules are consumed in a tracking trial by adopting the SPT1 (i.e. $(1835/1200) = 1.53$), additional 401 times of tracking process can be implemented by adopting the GPT1 case. Therefore, it can be observed that the GPT algorithm can provide better energy-conserving capability comparing with the SPT method.

VI. Conclusion

In this paper, the power-saving and location tracking mechanisms are investigated under the wireless sensor networks, where the mobile station is considered not synchronized with the sensor nodes (SNs). The scheduled power-saving tracking (SPT) scheme is proposed to conserve energy by pre-informing specific SNs to be in the ready state for the reception of next MS's beacon. Furthermore, the geometry-assisted power-saving tracking (GPT) algorithm is proposed to reduce the power consumption by considering only three SNs in each tracking task according to the geometric-dilution-of -precision metric. Comparing to the SPT scheme, the results reveal that the GPT algorithm can effectively conserve more power with slightly sacrificing the tracking precision.

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