Entry-Exit Based Target Tracking using Non-Overlapping Sensor Deployment

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***Abstract*—Target localization and tracking are one of the important applications of sensor networks. Majority of localization and tracking techniques developed for wireless systems rely on expensive infrastructure of specialized sensors and overlapping deployment. In this paper, we propose a novel technique to track the target using binary detection and sparse non-overlapping deployment. Our technique tracks target on the basis of time it spends inside and outside the vicinity of the sensor. On the basis of time interval and estimated speed, distance traveled by target is computed on the basis of which we formulate a mathematical model to track the target. The approach computes a band in which target lies. We simulate the tracking scenario in NS2 and evaluate the proposed algorithms.**

I. Introduction

Continuous improvement in wireless sensor network (WSN) technology makes it feasible to use WSN in variety of scenarios. One such scenario is target tracking which involves identifying an object by its signature and tracking it. Target tracking is used in domains such as border infiltration, enemy tracking, battlefield etc. [1], [2]. The need of high accuracy in estimating the target location is met by use of sophisticated sensor technology and support of overlapping sensor deployment [7]. This results in an increased infrastructure expense. In this paper, we propose a novel approach to track target in which even a sparse deployment of sensors with non-overlapping sensing region is sufficient. Further, the sensors are not required to have any sophisticated hardware on it. They are required to detect only entry-exit time of the target within their vicinity.

The time of entry and exit of the target within the vicinity of the sensors is collated at the central server. The central server then estimates the distance traveled by the target in the circular vicinities of sensors on the basis of the speed estimated by a small number of border sensors that have minimally extra capabilities. The proposed method computes a region or a band in which the trajectory of target lies on the basis of inter-sensor distance traveled by target and optimize it using intra-sensor distance traveled. We have evaluated the proposed method on various scenarios of target motion with simulations on NS2. Experimentation shows high accuracy of our model even with low infrastructure cost.

We present related work in Section II. We give detailed description of problem in Section III followed by the proposed approach, Band method, in Section IV. We then present experimental results in Section V and finally conclude and discuss open issues in Section VI.

II. Related Work

Tracking mobile targets in large scale sensor networks has gained extensive attention recently. Widely used approach of tracking involves localizing using principle of triangulation law (Figure 1a) which requires at least three sensors to measure distance to the target at any given time [7]. Thus it requires overlapping deployments and sophisticated mechanisms of sensors to measure distance, resulting in increased cost of infrastructure.

A small class of literature focuses on localization of target using binary detection of sensors [3], [4], [5]. In [3] authors make use of a weighted average of time spent by target in the vicinity of sensor. In [5], the authors mark the region of arc from which the target is assumed to have entered and take the middle point of arc as the location of the target. These approaches use simple sensors for binary detection. They still require deployment of sensors with overlapping sensing regions. A simple method to track target with non-overlapping sparse deployment is to just report the sensor in whose vicinity the target is detected. The infrastructure and

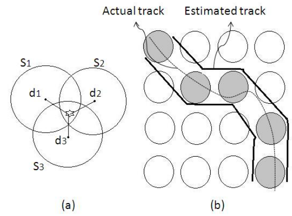

Fig. 1. (a) Localization using triangulation (b) A simple method.

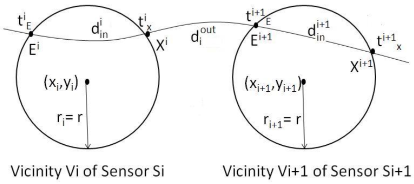

Fig. 2. Target's entry and exit from vicinity of a sensor.

computation cost of this approach is low. However, the tracking accuracy is low as well. This method estimates the track in the form of a band or a region in which target trajectory lies. The size or the width of the resulting band is $2 * r$, where r is the radius of the sensing region of the sensor. This is shown in Figure 1b.

In this paper, we propose a technique, Band method to track a target. This approach requires sensors to only detect time of entry and exit of the target.

III. Problem Definition

In this section, we define various terms used in this paper with a detailed description of problem.

Let the sensor s_i be located at (x_i, y_i) with circular sensing region or vicinity, V_i of radius r_i. Let the time of entry and exit of the target within the vicinity V_i of a sensor s_i, be t_E^i and t_X^i, respectively. As a result, the time spent by the target within V_i, $\Delta_i^{in} = t_X^i - t_E^i$. The time spent outside the vicinity, V_i, of sensor s_i before entering the vicinity V_{i+1} of the sensor s_{i+1}, $\Delta_i^{out} = t_E^{i+1} - t_X^i$.

This has been shown in Figure 2. Given the time of entry and exit of the target for all the sensors that have detected the target and an estimate of the speed v of the target, it is possible for a central device to estimate the distance, $d_i^{in} = \Delta_{in}^i \times v$, traveled by the target within the vicinity of a sensor s_i. Similarly, it is also possible to estimate the distance $d_i^{out} = \Delta_{out}^i \times v$ traveled by the target after exiting the vicinity of sensor s_i and before entering the vicinity of sensor s_{i+1}. On the basis of the distances, d_i^{in}, and d_i^{out}, we define the problem of target tracking as: Compute track of the target, given

- the distance d_i^{in}, traveled by the target within the circular vicinity V_i of a sensor s_i and the distance d_i^{out}, traveled by the target after exiting vicinity V_i of sensor s_i and before entering the vicinity V_{i+1} of sensor s_{i+1}, $i = 1 \ldots N$, where N is the number of sensors that have detected the target,
- location $O_i = (x_i, y_i)$, of sensor s_i (O_i is center of circular vicinity V_i), and
- radius r_i of circular vicinity V_i of sensor s_i.

For the sake of simplicity, we consider that all the sensors have equal sensing range, $r = r_i \ \forall i$ but analysis holds true even for different ranges r_i.

IV. Proposed Approach: Band Method

Band method uses the distance d_i^{out} to compute a band in which the trajectory of the target lies. Further, the distance d_i^{in} is used to reduce the width of the band. Band method assumes that the target moves in a straight line with a constant speed inside and outside the vicinity of the sensors. In that case, it is possible to estimate the distances, d_i^{in}, and d_i^{out}. Note that we use this method for non-linear motion as well which introduces small errors.

Obtaining the band within which the track of the target lies involves following steps:

- Step 1: Compute a band between the two vicinities V_i and V_{i+1}, $BandInterSensor_i$, using distance d_i^{out},
- Step 2: Compute a band inside vicinity V_i, $BandIntraSensor_i$,
- Step 3: Reduce the width of $BandInterSensor_i$ using distance d_i^{in} and d_{i+1}^{in}.

We discuss above steps in the following sections.

A. Obtaining $BandInterSensor_i$

Let d_i^{out} is the distance traversed by the target in a straight line after exiting from circle V_i before entering circle V_{i+1} (Figure 3). Computing $BandInterSensor_i$ involves obtaining points C and D on V_i and points C' and D' on V_{i+1}. The $BandInterSensor_i$ is obtained by joining points CC' and points DD'. The region bounded by line segments CC' and DD' contain the track of the target. Below, we present a method to obtain points $C, C', DandD'$.

Given d_i^{out}, the point C is identified on the circle V_i such that a circle Z, with center C and radius d_i^{out} is just touching the circle V_i at point A' (Figure 4a). Moving the point C towards F on circle V_i would result in the circle Z moving away from the circle V_{i+1} resulting in no point A' on circle V_{i+1}. As a result, the identified point C is the farthest point on V_i from which the target can exit if it has to enter the circle V_{i+1} after traveling

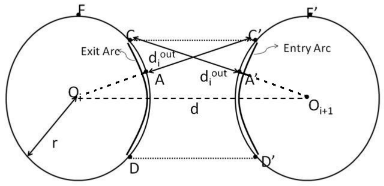

Fig. 3. Obtaining a band between two circular vicinities.

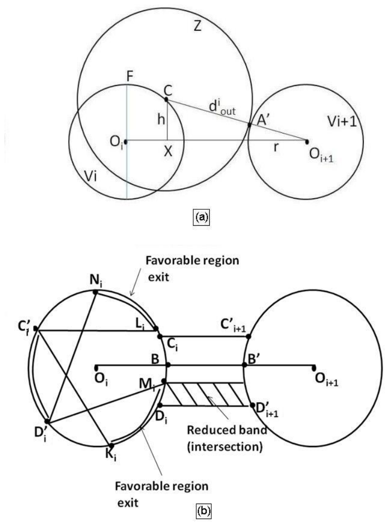

Fig. 4. (a) Height h of band. (b) reduction of band

distance d_i^{out}. Note that A' is the point of intersection of the line joining O_{i+1} and C and the circle V_{i+1}.

Similarly, it can be proven that C' is the farthest point on circle V_{i+1} from where target can enter V_{i+1} after leaving V_i and travelling distance d_i^{out}. The point on circle V_i from which target must have left to enter V_{i+1} is A. Note that point A and point C' are symmetrical to point A' and C. We have an elegant proof of the above concept which we omit due to space constraints.

Similarly, we can identify points D and D' on lower semicircle of V_i and V_{i+1} symmetrical to points C and C'. Again, point D is the farthest point from where target can leave V_i and point D' is farthest point from where target can enter V_{i+1}. As a result, we obtain a band or a region enclosed by segments $|CC'|$ and $|DD'|$ which always contains the trajectory of the target.

We define $BandInterSensor_i$ as the band bounded by segments CC' and DD'. The band is identified by the minor Arc (CD) defined as $ExitArc_i$ and the minor Arc$(C'D')$ defined as $EntryArc_{i+1}$. See Figure 3. The band $BandInterSensor_i$ is thus represented as:

$$BandInterSensor_i = Band(ExitArc_i, EntryArc_{i+1}), \quad (1)$$

where $Band(ExitArc_i, EntryArc_{i+1})$ is a band resulting out of joining endpoints CD of arc $ExitArc_i$ and endpoints $C'D'$ of arc $EntryArc_{i+1}$ as in Figure 3.

$BandInterSensor_i$ has a width of $2h$ where h (see Figure 4) is given by

$$h = (1/2r)\sqrt{((2r)^2 - r^2)(r^2 - d^2))} \quad (2)$$

The detailed mathematics behind the width h is based on simple trigonometry principles (Pythagoras theorem) applied on triangle O_iCX and triangle $O_{i+1}CX$ of Figure 4. The width $2h$ of the band can be further reduced as detailed in the next section.

B. Reduction of band $BandInterSensor_i$ to $BandRInterSensor_i$

In this section, we consider reducing width of band $BandInterSensor_i$. We do this by estimating the exit arc on the vicinity of sensor s_i on the basis of the distance d_i^{in} traveled inside the circle V_i. Given that $BandInterSensor_i$ has been estimated, we also have an estimate of entry arc $C_i'B_i'D_i'$ on V_i (see Figure 4b). Consider entry of target from point C_i'.The target can exit from two points K_i and L_i after traveling distance d_i^{in}. As the point of entry of the target moves towards D_i', the exit point K_i would move towards point M_i and point L_i move towards point N_i, resulting in an exit arc K_iM_i and L_iN_i. This has been shown as "favourable region of exit" in the Figure 4b.

The exit arc on vicinity V_i therefore is a result of intersection of $C_iB_iD_i$, and $(K_iM_i \cup L_iN_i)$. That is,

$$ExitRArc_i = C_iB_iD_i \cap (K_iM_i \cup L_iN_i) \quad (3)$$

$ExitRArc_i$ is arc M_iD_i in the example in Figure 4b.

Using similar logic and using distance d_{i+1}^{in}, it is possible to estimate an entry arc $EntryRArc_{i+1}$ on the vicinity of sensor V_{i+1}. $EntryRArc_{i+1}$ is an intersection of arc $C_{i+1}'B_{i+1}'D_{i+1}'$ and $(P_{i+1}R_{i+1} \cup S_{i+1}Q_{i+1})$ where arc $P_{i+1}R_{i+1}$ and arc $S_{i+1}Q_{i+1}$ are "favourable" regions of entry on vicinity V_{i+1} obtained using distance d_{i+1}^{in}. That is,

$$EntryRArc_{i+1} = C_{i+1}'B_{i+1}'D_{i+1}' \cap (P_{i+1}R_{i+1} \cup S_{i+1}Q_{i+1}) \quad (4)$$

Finally, the band $BandInterSensor_i$ is reduced to the band between the resulting exit arc on vicinity V_i given by Equation 3 and entry arc on vicinity V_{i+1} given by Equation 4.

Note that the union or intersection of arcs may result in a disjoint arc. We combine such a disjoint arc as a continuous arc by combining the two extreme points of the disjoint arc. The continuous $ExitRArc_i$ and the $EntryRArc_{i+1}$ are thus computed by combining disjoint arcs. The reduced band $BandRInterSensori$ is thus represented as

$$BandRInterSensor_i = Band(ExitRArc_i, EntryRArc_{i+1}) \quad (5)$$

where $ExitRArc_i$ and $EntryRArc_{i+1}$ are reduced continuous arcs.

We do band reduction procedure only if d_i^{in} is smaller than the diameter of V_i or $2r$ where r is the range of the sensor s_i. We also compute a reduced band inside each vicinity V_i given by

$$BandRIntraSensor_i = Band(EntryRArc_i, ExitRArc_i) \quad (6)$$

As a result, the complete track is given by

$$Track = \{E, X\} \quad (7)$$

where E is the set of entry arcs $EntryRArc_i$ on the vicinity V_i of sensor s_i, $\forall\ i$, $i = 1 \dots N$ and X is the set of exit arcs $ExitRArc_i$ on the vicinity V_i of sensor s_i, $\forall\ i$, $i = 1 \dots N$.

In case N sensors have detected the entry and exit of the target, $(N-1)$ inter-sensor bands and $(N-2)$ intra-sensor bands could be computed. As a result, there would be $(N-1)$ of $BandRInterSensor_i$ and (N-2) of $BandRIntraSensor_i$.

The tracking error over complete track in Band method is computed as the average of average width of all bands. We define the average width of a band as follows:

$$\mathcal{W}_i^{band} = \frac{sd(ExitRArc_i) + sd(EntryRArc_{i+1})}{2} \quad (8)$$

where $sd(.)$ is the shortest distance between the extreme points of an arc.

As a result, the tracking error over the complete track is:

$$\mathcal{E}_{track}^{band} = \frac{\sum_i^{(N-1)} W_i^{BInterS} + \sum_i^{(N-2)} W_i^{BIntraS}}{(2N-3)} \quad (9)$$

where $W_i^{BInterS}$ is the average width of band $BandInterSensor_i$ and $W_i^{BIntraS}$ is the average width of band $BandIntraSensor_i$ defined by Equation 8.

V. Experiments and results

A. Experimental setup

The simulation of sensor network and the motion of the target is done in NS2. The experiment is setup in NS2 in such a way that random stabilization time is introduced to detect target. The time spent by target in sensor vicinity is approx 3 sec and stabilization time introduced is on an average 0.5 sec. The area of simulation is 2000m X 2000m. We use grid topology for our experiments. However, initial experiments show that the proposed method performs well with random topology as well. The mathematical models and tracking algorithm is implemented in MATLAB.

We have evaluated the proposed approach assuming that the motion of the target can be modeled as a constrained random walk in a 2D plane. The target moves with a constant speed, v. We assume that we have an estimate of the speed of the target. There are many methods of estimating speed of a moving object. We have implemented a technique in which the boundary sensors sense the target multiple times by reducing its sensing range. We then compute the speed of the target on the basis of estimated average distance that it may have traveled inside the vicinity of the sensor. The proposed speed estimation is accurate with around 5-8% error. We have not discussed the details and results of speed estimation method in this paper due to space constraints.

The randomness in the motion of the target is incorporated by allowing target to change its direction θ at a random time between ω_{min} (0 sec) to ω_{max} and by allowing target to change its direction of motion by a random angle in the range of $\pm\theta_{max}$. Following are the default values of parameters used in the experiments:

- Sensing range of a sensor, r = $10m$,
- distance between center of two sensors, d = $25m$,
- speed of the object, v= $5m/sec$,
- the maximum angle in which the motion of the target change the direction, θ_{max} = 60^o, and
- the maximum time before which the target would change its direction, ω_{max} = $10sec$.

Figure 5 shows two instances of track of the target. The actual trajectory is shown as a dotted line. In Figure 5(a) $\theta_{max} = 30^o$ and in Figure 5(b) $\theta_{max} = 120^o$. It can be observed that the estimated band is narrower in Figure 5(a) than the estimated band in 5(b). The figure is just to demonstrate effectiveness of model in the tracking, results and analysis of experimentation is discussed in rest of this section.

B. Sensitivity Analysis

In this section, we evaluate how sensitive our method is to various parameters viz. parameters related to deployment of sensors and parameters related to motion of the target. In this paper, we present results of evaluation of the effect of change in range r, speed of target v, and maximum angle θ_{max}. We calculate the error on the basis of average tracking error $\mathcal{E}_{track}^{band}$ in Equation 9 and compare results of the proposed Band method with the existing method of same infrastructure described in Section II and shown in Figure 1(b).

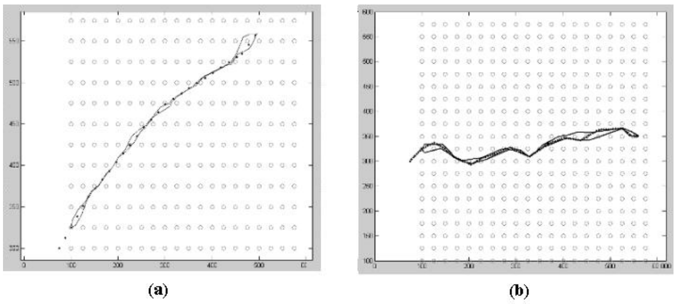

Fig. 5. The actual trajectory and estimated trajectory using Band method. (a) $\theta_{max} = 30^0$ (b) $\theta_{max} = 120^0$.

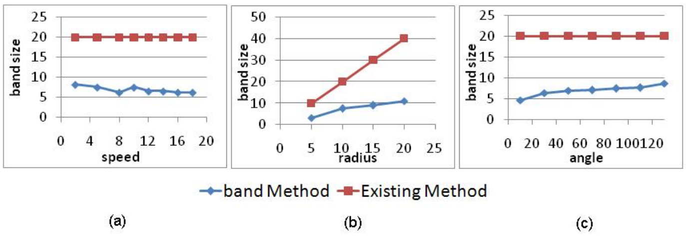

Fig. 6. Effect of speed v of target (a), sensing range r of sensor (b) and max angle θ_{max} (c) value on tracking error in Band method

Effect of speed of the object Figure 6(a) shows the effect of change in the speed of target v on the average width of the band of our method which is almost half of existing method. It can be observed that the width of the band decreases as the speed increases. The reason behind this trend is that, as the time spent by the target in the vicinity of the sensor decreases, the probability of the target changing its direction decreases as well. This results in better estimate of the distance traveled inside the vicinity of the sensor. As a result, a better estimate of the band is computed.

Effect of sensing range of sensor Figure 6(b) shows the effect of change in the sensing range r of the sensor on the average width of the band. It can be observed that the width of the band increases as the sensing range increases. The reason is same, as radius increases target spends more time and thus distance estimation becomes poor. As the range increases, the width of the band computed by the existing method increases much sharply than the size of the band computed by our method, proving our method more effective in scenarios of large ranges.

Effect of maximum angle in which the object can change its direction Figure 6 (c) shows the effect of maximum angle in which the direction of motion of the target can change. It can be observed that the size of the band computed by band method increases as the angle θ_{max} increases. The reason behind such a behaviour is that as θ_{max} increases, the motion of the target deviates more from the straight line motion which is principle of proposed approach. As we deviate from the assumption the estimation error increases. However, increase in the band size is still not that much as compared to the existing approach proving our method suitable for all scenarios.

VI. Conclusion and future work

We present Band method in this paper to track the target with a sparse sensor deployment. Band method computes a band in which the track of the target lies. The method uses time of entry and exit of target in the vicinity of the sensors. We present evaluation results and show that the proposed approach tracks the target with a good accuracy. In future, we plan to relax the assumption of constant speed of the target and perform more experiments with different sensor topologies. We plan to come up with a trade off metric to evaluate infrastructure and accuracy efficiency. Also, we plan to design a new approach to track the target using piece-wise linear functions.

VII. References

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