API²T: a bit of Improvement for Applications in Critical Scenarios

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ABSTRACT
Location awareness in wireless sensor network (WSNs) application is often too expensive to be achieved by endowing each node with a GPS receiver. Approach based on range-free methods, where nodes can estimate their location basing on neighbors and nodes that known their position (anchors), can be envisaged. This paper deals with the optimization of APIIT algorithm in wide area WSN scenario for critical scenarios applications.

The new version, called API²T, is able to face the incorrect estimation of node localization by reducing missing detection probability and, thus, providing a better accuracy as shown in the simulation results. In particular, a remarkable performance improvement is provided for random topologies and low density of anchors, as it might happens in emergency scenarios.

Keywords

1. INTRODUCTION
Many wireless sensor network (WSNs) applications depend on nodes being able to accurately determine their locations. As a matter of fact, localization awareness is an important issue in many WSN applications, such as environment monitoring to properly sense and identify a phenomenon, vehicle tracking and geo-tagging or even for improving networking schemes, when adopting, for instance, location-based routing protocols that eliminate the need for route discovery and, thus, saving significant amount of energy.

Potential massive scale scenarios make unrealistic to rely on a planning phase or even to adopt a uniform deployment of sensors. If sensor nodes are randomly scattered, instead of resorting to globally available beacons or expensive localization system like GPS, it could be viable to leverage on the WSN self-organization features to establish local coordinates. However, this approach presents the drawback of facing nodes constraints in terms of limited power and reliability, and reduced communications range, usually with a modest number of neighbors. As a consequence, it might be adopted an hybrid approach, in which certain anchor nodes are exactly localized by means of an absolute positioning system, while other nodes are approximately localized using several algorithms relying on anchors coordinates system.

Localization techniques for WSN can be divided into two categories: range-based and range-free methods.

Range-based localization estimates the absolute distance between a sender and a receiver by evaluating either received signal strength (RSSI) or time difference of arrival (TDOA) or angle of arrival (AOA). They require additional hardware capabilities (increasing cost and size of nodes), whilst providing a localization accuracy conditioned by the time variability of the propagation channel [1],[2].

On the other hand, range-free localization approaches no longer try to estimate the absolute node-to-node distance, requiring simpler hardware capabilities, but requiring a higher number of available nodes and offering lower accuracy.

These methods can be classified in local techniques as Centroid localization [3] and APIIT [4],[5],[6],[7], or hop counting techniques, like DV-Hop scheme [8] and Amorphous Localization [9].

In the reference scenarios adopted in the following, nodes are randomly distributed with small-to-medium density and slowly moving while the anchors are static.

The application we are interested in is concerned with location services for critical and emergency situations, with the aim of providing real-time information regarding the nodes positions to a remote control center. It could be the case of monitoring areas open to the public, such as:

- places of historic and cultural relevance;
- seats of everyday commercial and leisure;
- government and administration buildings;
- industrial and transportation systems.

A timely and accurate WSN nodes localization is crucial for providing safety and also to effectively manage emergency situations occurring in the above-mentioned scenarios by notifying the presence of anomalous operative conditions, that can be useful for the coordination and planning of search, rescue and disaster relief operations.

It is worth noticing, that in these cases the availability and accurateness of GPS signals is not always assured due to the urban canyon effect [10], thus it might be adopted a range-free location scheme.

In particular, this paper focuses on APIIT algorithm and proposes an improved version, called API²T, allowing better performance and comparable complexity in severe propagation conditions. First of all, it has been derived a lower bound for localization accuracy, then the performance has been analyzed with respect to several parameters, as the number of nodes and anchors or the propagation environment, always pointing out a remarkable gain.

The remainder of the paper is organized as it follows: Sec.II.A describes basic APIIT algorithm, while Sec.II.B introduces several
enhancements leading to the API²T proposal. In Sec.III the simulation results are presented, to investigate the main figures of the proposed approach. Finally conclusions wrap up the paper.

2. PROPOSED OPTIMIZATION PROCEDURE

2.1 APIT: State of the Art

The APIT method [7] decomposes the local area into triangular regions whose vertices are beaconing nodes (anchors). Then it estimates if a target node is inside or outside these triangular regions allowing to the node to narrow down the area in which it can potentially reside (Point -In-Triangulation test - PIT). In addition, it uses a grid algorithm to calculate the maximum area in which a node will likely reside (Aggregation PIT, APIT). At this point, APIT calculates the center of gravity of the intersection of all of the triangles in which a node resides to determine its actual position.

The basic idea behind the APIT test is to evaluate the belonging of a node to a triangle by using neighbors’ information to emulate the node movement, taking therefore advantages of high density.

A drawback of the algorithm is represented by an incorrect decision because APIT can only evaluate a finite number of directions, depending on the number of neighbors.

Since the number of neighbors is limited, an exhaustive test on every direction is impossible, and consequently two kinds of errors could arise as outlined in from [7]:

- In2Out error (Missing detection) can happen when mobile node is near the edge of a triangle while some of its neighbors are outside the triangle and, consequently, it could move towards an outer nodes, erroneously believing to be outside.
- Out2In error (False alarm) can happen when mobile node is outside a triangle and its neighbors are irregular placed such that none is further from/closer to all three anchors, this making mobile node to assume to be inside the triangle.

After the APIT test on the audible combination of anchors is exhausted, the phase of aggregation of the results starts.

Focusing on each triangular area, the values on that grid are incremented for the nodes on which the APIT test has decided to be inside a particular region.

For the nodes outside, the grid area is decremented. The result represents the maximum area in which a node will likely reside and then this maximum area is used to calculate the center of gravity for location estimation.

2.2 API²T

The new version of APIT algorithm, API²T, modifies only the phase of aggregation.

According to the APIT, it uses a counter whose value is changed depending on the presence or absence of the node in the area considered. Each square element is associated with a counter, which is incremented as it belongs to a localization triangle containing the target node, while it is decremented on the opposite case and this happens for all the elements of the grid as highlighted in the rightmost of Figure 2.

![Figure 1 – Proposed modification for API²T algorithm](image)

The changing of this counter matrix in many cases implies one kind of smoothing effect: indeed, in the case of APIT and API²T, the estimated point will be, respectively, the barycentre of a relatively large or smaller area.

The new counter matrix implies a reduced number of false alarms with respect to APIT version as shown in the next section of the results, but it has as drawback the necessity to repeat the scanning of the grid and this is not suitable for applications that require fast, repeatable location of the nodes.

3. PERFORMANCE EVALUATION

3.1 Simulated scenario and results

In performing numerical simulations, the playground over which nodes are deployed is arranged in a grid wise fashion as required by the proposed algorithm. The radio interface has been assumed compliant with IEEE 802.11g standard as to PHY and MAC layers [11].

First of all, the upper bound² of the localization error is presented in Figure 2 as a function of the number of deployed anchors for both basic APIT and API²T algorithms. It is evident that the performance is quite close each others, in other terms the introduced modification of aggregation phase does not affect the accuracy in ideal conditions.

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1 This condition can be fulfilled by typically assuming a larger radio range for neighbor nodes.

2 It represents the ideal case in which the positions of the nodes forming the triad are not affected by uncertainty.
At the increasing of ranging error $\varepsilon_r$, API$^2$T scheme points out a higher robustness as highlighted in Figure 3 for a normalized $\varepsilon_r$ equal to 10% (worst case scenario). It can be noticed a remarkable gain provided by the proposed approach, taking advantage of the cooperating nodes such that error is even decreasing with respect to this parameter, while the opposite holds in APIT.

The dramatic reduction of error mean value and variance achieved by API$^2$T can be explained by analyzing the counting matrices which is reported in Figure 5 for both APIT and API$^2$T algorithms, limiting to the worse localization case.

To give a better insight, the probability density function (pdf) of localization error is represented in Figure 4 for a case study comprised of 500 nodes and again $\varepsilon_r = 10%$. 

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Figure 5 – Comparison of counting matrices of APIT (a) and API\textsuperscript{2}T (b) algorithms for and $\varepsilon_r = 10\%$ referred to the worst localized node.

The localization areas whose perimeter is highlighted in red represent the set of nodes with higher counter values, over which the aggregation procedure is conducted. It could be noticed that API\textsuperscript{2}T achieves lower localization uncertainty since the estimated barycenter lies inside the area, while the opposite is true for APIT. This gain is more evident whenever the number of triangles (and then of anchors) is limited, and the ranging error $\varepsilon_r$ is noticeable, due mostly to the presence of missing detections.

For the sake of completeness, the localization error provided by API\textsuperscript{2}T algorithm, has been analyzed at the increasing of ranging error ($\varepsilon_r$ up to 30%) as a function again of number of deployed nodes, as depicted in Fig. 6. Though the error is of course increasing at the worsening of propagation conditions, nevertheless it is kept below 1 m, thus pointing out the robustness of the proposed approach.

3.2 Discussion

From the previous results, it is evident that API\textsuperscript{2}T algorithm is more robust against ranging error ($\varepsilon_r$). To explain this achievement it has to be noted preliminary that an increasing $\varepsilon_r$ affects the percentage of missing detection (from 2% for $\varepsilon_r = 0\%$, up to 8% for $\varepsilon_r = 10\%$), while false alarms is still unaffected. A missed detection makes a target to be assumed outside a triangle, but API\textsuperscript{2}T does not take it into account, keeping unchanged the localization matrix. Instead it is influenced by false alarms (OutToIn error), but it is due only to geometrical constraints.

4. CONCLUSIONS

This paper focuses on large scale low cost WSN applications for critical and emergency situations management, in which it is crucial to provide real-time information regarding the nodes positions. Due to the above mentioned constraints, a range-free localization approach has been adopted which is effective even in the case of limited hardware capabilities.

In particular, an improved version of APIT algorithm, called API\textsuperscript{2}T, is proposed allowing better performance and comparable complexity in severe propagation conditions. First of all, it has been derived a lower bound for localization accuracy, then the performance has been analyzed with respect to several parameters, as the number of nodes and anchors or the propagation environment, always pointing out a remarkable gain.

To conclude with, it is worth noticing that API\textsuperscript{2}T approach could be applied even to localize mobile targets, though the counter updating procedure is able to reliably support only low mobility scenarios\textsuperscript{3}.

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6. REFERENCES


3 The case in which also anchors are moving within an area is more difficult to be accomplished.


