

A Multisink-based Continuous Object Tracking in Wireless Sensor Networks by GIS

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Abstract

Continuous Object Tracking (COT) is an important application in wireless sensor networks (WSNs) for smart grid, e.g. detecting forest fire, monitoring mud-rock flow phenomena etc. The early warning can effectively reduce the impact of geological disasters for the power system. However, due to the constrained resource of WSN, it is a challenging issue to monitor phenomena in real time for excessive amount of message exchanges between sensors and the sink. In this paper, we propose a novel multisink architecture which consists of a static sink and a mobile sink guided by Geographic Information System (GIS). The two sinks can cooperatively work in an intelligent model in which the mobile sink can calculate the right position to collect the information from boundary nodes; in which the static one can reduce much message transmission as well as energy consumption based on centroid algorithm. Meanwhile, we present a novel algorithm which can track the object more accurately. The simulation result shows that our architecture can distinctly prolong the network life time than single sink network in continuous object tracking.

Key words: continuous object tracking; smart grid; wireless sensor network; GIS

1. Introduction

Geological disasters usually cause the damages in the power system, such as forest fire, monitoring mud-rock flow etc. Moreover, wireless sensor networks (WSNs) are widely used to monitor hazardous events or emergencies, such as mud flows, forest fires. Therefore, we can utilize the WSNs in the Early Warning System of the power system, such as in smart grid. These events happen in geographic regions with continuous scenarios [1, 2, 3]. To monitor the events, we usually need to confirm the boundary of the phenomena by sensors. For example, in forest fire monitoring, we may

be interested in where the fire expanded to or the location of major boundaries of fire [4]. Therefore, it is very important but challenging to locate the nodes, called boundary node on the phenomena boundary.

Due to the limitations of resource in WSN, the applications are required less communication. However, since all the sensing data are routed back to the sink in WSN, the nodes near the sink consume more energy for forwarding the messages from farther nodes and thus carry a heavier traffic load. Consequently, those nodes are more susceptible to energy exhaustion and invalidate the network exhaust soon. Therefore, it is undoubtedly necessary to balance the energy consumption to extend the life time of WSN. Meanwhile, when we try to collect the information from the large scale WSN, it is inefficient to deploy only single sink.

We present a novel architecture to deploy multiple sinks in a large scale WSN, e.g. two sinks. One is the static sink which is deployed in the center of the monitored area; another is a mobile sink which can move to anywhere. The two sinks can cooperate with each other to track the continuous object.

Based on the novel architecture, we present an algorithm which can control the mobile sink to move to the adaptive position relative to the static sink. The aim of the algorithm is to seek the optimized position where the mobile sink can cost less energy to collect information with the static sink for tracking continuous object. To locate the optimized position, we employ the centroid algorithm, the best known partitioning clustering algorithm, which can minimize the count of hops in collecting messages [5]. Besides, we also consider about the spatiotemporal correlation which can reduce the redundant messages efficiently [3]. This model can minimize the communication between the boundary nodes and the multiple sinks.

The rest of this paper is organized as follows: Section 2 discusses previous work. In section 3, we present the system model. Section 4 presents the

proposed architecture in detail and Sections 5 analyzes the simulation of our solution. Finally in Section 6, we conclude our paper.

2. Related work

There has been abundant research on detecting and tracking targets in sensor networks [1, 2, 7, 8].

Xiang Ji et al. [1] propose a dynamic cluster-based algorithm that tracks the movement of continuous objects by monitoring the boundary of those objects. In [1], when a sensor detects the emergence of any phenomena at current time, it immediately exchanges a query message to its neighbors to confirm the reading. If the sensor receives at least one different detection status from any neighbors, the sensor becomes a boundary node. After the boundary node selection, cluster formation process takes place among the boundary nodes. However, the cluster formation explanation here is somewhat ambiguous.

Reference [2] proposes a preliminary idea of dual-sink approach. In [2], the mobile sink keeps circle around the static sink for averaging energy consumption. This approach reduces the burden of the nodes located around the static sink by mobile sink collecting data from subset of the network. As a basic paper of dual-sink in object tracking, the only purpose of this paper is to reduce the burden of static sink by giving subset of network to the mobile sink. Therefore, it only designed a simple vertiginous trajectory for the mobile sink and did not address any precise algorithm for mobile sink's movement and localization.

In this paper, we use mobile sink to assist the static sink in clustering. And it reduces the data transmission burden of nodes which are around the static sink.

3. System model and Assumptions

We consider about a sensor network consisting of n normal sensor nodes uniformly deployed and two sinks: a mobile sink S_m , which can move freely in the network; and a static sink S_s , which is deployed in the center of the network as shown in Fig.1.

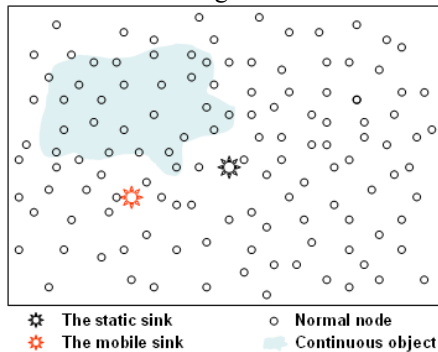


Fig 1. The considered multisink-based WSN

Depending on the GIS, we also can get the necessary positions for the sink or sensors [14]. In the network, suppose that each sensor node knows its own location by possibly using the techniques such as triangulation [6, 15] or localization [9]. And the two sink nodes know all the sensor nodes' IDs and locations. We assume that the changes of phenomena are continuous in the interval time $\Delta t_i = t_{i+1} - t_i$, where t_i and t_{i+1} are period range to detect the object. And the sinks start to detect the object after t_0 . In Table 1, we list some notations in this paper.

Table 1 Notations

S_s	The static sink.
S_m	The mobile sink.
t_i	The start time for period detection
(x_i, y_i)	The position of sensors or sinks
b_i	The boundary node
(x_i^b, y_i^b)	The position of boundary node
BN_s	The boundary nodes for the static sink
BN_m	The boundary nodes for the mobile sink

4. Continuous Object Tracking with Multisink Architecture

4.1 Initial phase

Before t_0 , there is no object. Suppose the S_s 's position is (x_s, y_s) ; the S_m 's position is (x_m, y_m) . Initially, $x_s = x_m$, $y_s = y_m$. And other normal node u_i 's position is (x_i, y_i) ($1 \leq i \leq n$).

Due to the characteristics of the continuous object, such as large area, continuous and covering many nodes etc., tracking the continuous object is different from tracking the discrete object. Normally, the main task of COT is to confirm the boundary nodes and then obtain the shape of the object.

The boundary nodes report the information of object according to the time slot periodically, i.e. t_i . After t_i , the sinks collect and transmit the location information of object to the base station. In interval time t_i , sinks will calculate the boundary history data in t_{i-1} and utilize those data to calculate the exact position where the mobile sink should move to. We give some definitions as follows [13]:

Definition 1 (Changed Value Node (CVN)): Node which detects/loses the object at current time t_i but does not at previous time t_{i-1} .

Definition 2 (CompareOneZero message (COZ message)): The CVN broadcasts a COZ message to its

neighbors. This message includes a CVN's ID and the detection status [9].

Definition 3 (Boundary Node): A boundary node u is a node that receives at least one COZ message with different detection status. For example, if u 's current detection status is 0(false) and it receives from one of its neighbors, say v , a COZ message that includes v 's reading 1(true), now u is a boundary node since u 's current detection status is different from v 's.

Moreover, the static sink broadcasts a *Hello* message [2] throughout the network with the sink information (static or mobile) and TTL which helps sensors obtain the count of hops from the static sink. The two sinks will exchange information of nodes before t_0 .

4.2 Running phase

In the running phase, the sinks start to work and wait for the detection from sensors. Once the sensors detect continuous object, the sensor will report the event to sinks. And then the sinks aggregate the messages and forward them to outside.

According to the report, the two sinks make a negotiation and decide to move S_m to the adaptive position for reducing the communication. Furthermore, in many-to-one transmission model, due to the long distance, the sensor nodes in that direction will suffer heavier communications, especially those located around the sink. Therefore, we employ the centroid algorithm [5]. Since in a cluster, if the sink locates at centroid of cluster, the cost, the sum of hops in data transmission from all member nodes to sink, is lowest, which means that the total energy consumption in data transmission is most efficient.

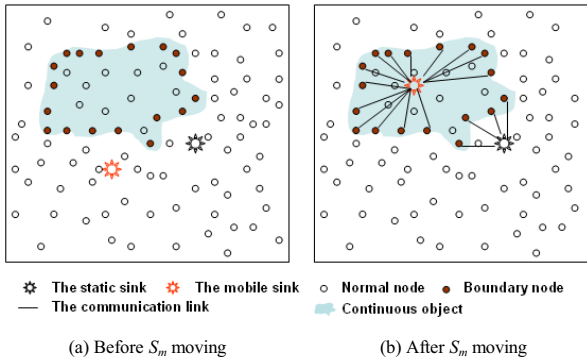


Fig 2. The running time multibased WSN

Firstly, all the sensors which detected the continuous object are considered as the boundary nodes and report the event to the sink (default static sink). The static sink will calculate the information and exchange them with mobile sink as shown in Fig 2.

Suppose a boundary node set BN is as follows:

$$BN = \{b_1, b_2, \dots, b_m\} \quad (1)$$

Where b_i is a boundary node, the position of b_i is (x_i^b, y_i^b) .

Step 1. Calculating the centroid of the continuous object.

According to the report from b_i , S_s can calculate the next position for the mobile sink by a series of equations as follows:

$$x_0^b = \frac{\sum_{i=1}^m x_i^b}{m} \quad (2)$$

$$y_0^b = \frac{\sum_{i=1}^m y_i^b}{m} \quad (3)$$

Where (x_0^b, y_0^b) is the centroid of the continuous object. Given two subsets $BN_s, BN_m \subseteq BN$, and $b_i^s \in BN_s, b_i^m \in BN_m$, then

$$BN = BN_s \cup BN_m \quad (4)$$

$$BN_s \cap BN_m = \phi \quad (5)$$

The boundary node b_i^s sends the report to S_s ; and b_i^m sends the report to S_m .

Step 2. Calculating the position of the mobile sink.

Given the mobile sink moves to the point (x_0^b, y_0^b) , that is, $x_m = x_0^b$, and $y_m = y_0^b$. Then S_s divides the boundary nodes into two new groups by the distance (count of hops) from S_s and S_m . The boundary nodes which are near S_s belong to BN_s and others belong to BN_m as the following

algorithm:

Algorithm 1 Dividing the boundary nodes

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1:   $x_m = x_0^b; y_m = y_0^b;$ 
2:  for  $i = 1$  to  $|BN|$  {
3:    if  $distance(b_i, S_s) < distance(b_i, S_m)$  {
4:       $b_i \in BN_s;$ 
5:    else
6:       $b_i \in BN_m;$ 
7:    }
8:  }

```

$$9: \quad x_m = \frac{\sum_{i=1}^m x_i^m}{|BN_m|}, y_m = \frac{\sum_{i=1}^m y_i^m}{|BN_m|} \quad // \text{locate again}$$

10: **return**

According the result of algorithm 1, the mobile sink S_m will move to the position (x_m, y_m) .

Step 3. The mobile sink connects the boundary nodes from BN_m .

Once arriving at the position, the mobile sink broadcasts a *Hello* message to its members with the sink information (mobile) and TTL which helps sensors obtain the count of hops from the mobile sink. Then the boundary nodes send the report to S_m . Considering about the energy consumption, it is not necessary to report by all boundary nodes. Those boundary nodes whose statuses do not change during Δt will reduce the frequency of reporting [11,12].

Furthermore, according to the spatiotemporal correlation, we can choose a representative node which actually sends data to the sink. Only a few representative nodes will be selected among BNs in order to save energy.

Step 4. Adjusting the position of S_m when the shape of continuous object changes.

For minimizing the consumption of energy, the mobile sink should change position with the change of continuous object. Since the continuous object can move, expand or shrink, the boundary nodes are also changing. When the quantity of boundary nodes changed status are beyond a threshold (e.g. 10%), the sinks should redivide the boundary nodes.

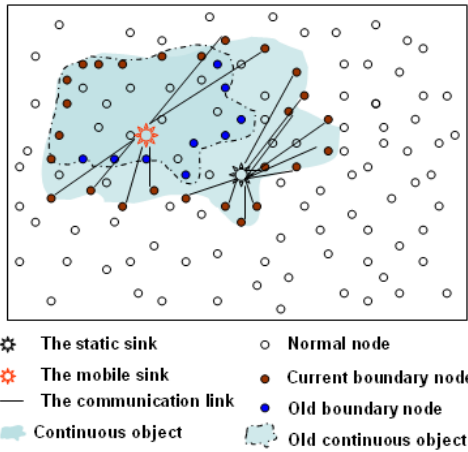


Fig 3. To monitor the changed continuous object

Therefore, whichever sinks want to redivide the boundary nodes, it should exchange the information as step 2. And then, the mobile sink can get the new position as shown in Fig 3. In Fig 3, we also see that

the boundary nodes in both previous time and current time do not send messages to the sinks, because there are no changed information.

5. Simulation

To demonstrate the proposed approach, we design a sensor environment simulation incorporating a $100 \times 100 \text{ m}^2$ network, where 100 nodes are deployed. The static sink is at the coordinates (50,50). Detailed parameters for the simulations are shown in Table 2.

Table 2 Simulation parameters

Parameter	Value
Region area	(0,0) to (100,100)
Quantity of sensor	100
Static sink	(50,50)
Initial Energy	2J
Packet size	500 Bytes
E_{elec}	50 nJ/bit
ϵ_{fs}	10 pJ/bit/m ²
ϵ_{amp}	0.0013 pJ/bit/m ⁴
E_{DA}	5 nJ/bit/signal

We consider about two situations of the network: with single sink and with two sinks. As shown in Fig 4., we simulate COT in our network and the single sink network. Because the mobile sink can collect information actively, the communication overhead has been reduced about 50%. The mobile sink not only reduces the count of hops but also collects information from the representative boundary nodes. When the boundary sensor nodes are decided, all the nodes send data to both static sink and mobile sink in multi-hop way.

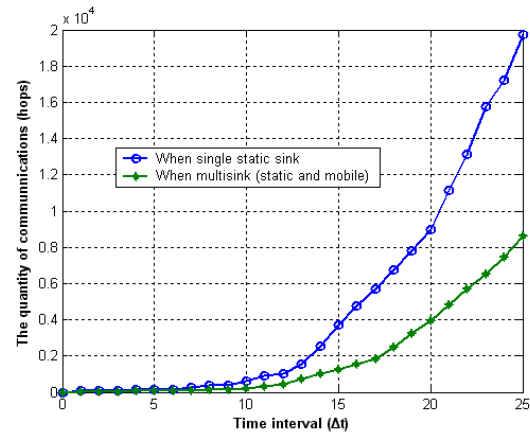


Fig. 4 Comparison of single sink and multisink architecture in communication

In Fig 5., we compare our solution with the network which also consists of two sinks: one is the static sink and another is the mobile sink. The only difference is that the mobile sink in compared network moves freely

without any control. As the shown in Fig 5, our solution can reduce the communication about 30%. The main reason is that our solution adopts the centroid algorithm which can save the energy consumption efficiently.

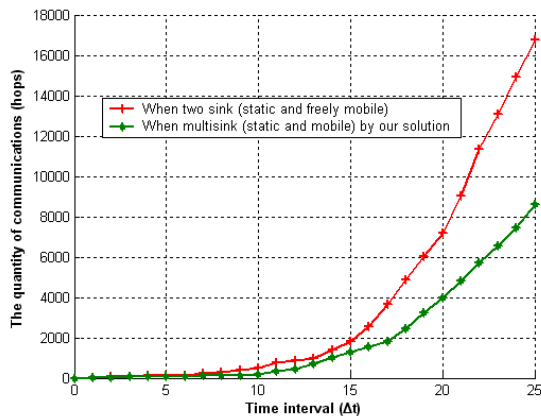


Fig. 5. Comparison of two sinks and multisink architecture in communication.

6. Conclusion

In this paper, we propose a multisink-based continuous object tracking approach supported by GIS for the power system. It uses centroid algorithm to calculate the optimal position for mobile sink by static sink, which can reduce the energy consumption in data transmission, and then extend the life time of whole network. The simulation results show that our solution significantly outperforms the previous work in terms of energy-efficiency.

Our future work will include further precision of mobile sink's movement and consider about the situation in which there are many sinks (more than 2).

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