Event Localization in Wireless Sensor Network using Binary Sensors

Vaishali S. Deshmukh, Arvind V. Deshpande, Parikshit N. Mahalle
Department of Computer Engineering, Smt. Kashibai Navale College of Engineering
Pune, India - 411041
mailto:vsd@gmail.com, avdeshpande63@rediffmail.com, aalborg.pnm@gmail.com

Abstract— Sensor networks are gaining importance as they have vast potential for diverse application areas like monitoring, localizing and tracking of environmental phenomenon. The sensors are constrained by extremely scarce resources, unreliable communication link and faulty nodes. There is a need to address these harsh operating conditions. Real time sensitive applications which require fault free observations from sensor nodes is another challenging task in wireless sensor network scenario. Binary wireless sensor network is an extension of wireless sensor network where sensors give binary outputs. This paper focuses on the suitability of binary sensors for event localization purpose. In the sequel, this paper presents application of binary sensors for event localization in wireless sensor network. Comprehensive literature survey on event localization in context of wireless sensor network is presented and discussed. Evaluation of related work is also presented in order to understand gap analysis. The mathematical model of binary sensor operation and the pseudo code for wireless sensor network functioning with and without faulty binary sensor node is presented and discussed. Finally paper concludes with an use case explaining event localization in wireless sensor network using binary sensors.

Keywords—Binary wireless sensor network, Region of Coverage

I. INTRODUCTION

Sensor technology has evolved to detect variety of sensing phenomenon. The necessity of applications has motivated the development of variety of sensors like electromagnetic, acoustic, and so on [1]. To reduce the cost of network, the sensors used are low cost. Wireless Sensor Networks (WSN) is primarily used in detecting, locating and tracking physical phenomena and in surveillance applications. These networks consist of considerable amount of sensors which gather information about the phenomenon for which they are designed, process the gathered data and send the information to sink node.

WSN is composed of small devices that have sensing, data processing and communication capabilities for wide range of applications. Sensor network are systems made up of many small sensors deployed in an area to sense events. Sensors have limited power supply which puts a limit on their functioning. The functions performed by sensors like communication to neighboring node, processing the data are constrained by power supply. They send their observations either in raw form or quantized form.

The process to determine the position of the event occurrence which the sensor detects in the network is called event localization or event positioning. Event can be stationary or mobile. Stationery event like fire occurrence in an forest area requires the location information of event to be sent to the sink node whereas in case of mobile event like underwater surveillance of crocodile in a river needs to monitor dynamically the movement of crocodile. The sensed location of the event as well as the direction in which sensed event is proceeding needs to be tracked. Two classes of applications arise based on type of event. In one class, applications require only position information of event and in other applications require dynamically tracking the event trajectory over the time. These applications can be addressed efficiently using binary sensors.

II. RELATED WORK

WSN is subject to strong resource constraints, such as slow processors, small memory sizes, short battery life, a low-bandwidth and unreliable network connection. Moreover scarcity of power supply places additional limits on its use. Even if utilization of node resources is minimized, resources will eventually be depleted causing nodes to fail, especially in subsections of the network that have high activity. The sensor network has a burden to produce timely results, communication overhead to be low, use local information. Sensors should accommodate themselves to failures and changes in network conditions. To overcome above problems, Binary Wireless Sensor Network (B-WSN) can be used.

In [2], architecture for localization algorithm to be used in B-WSN is proposed and discussed. It consists of three main components, sensor state estimation, localization and smoothing. The health state of a sensor is determined using estimator. The estimator compares the expected sensor alarm status to the actual sensor alarm status based on the distance between the target and the sensor. Smoothing component filters the current location estimate using particle filter. Fault model talks about various sensor faults which
might occur in B-WSN. Simulation results points to tracking error and estimation error in presence of different types of faults. The algorithm localizes the target including observations from faulty sensor.

DSA2 [3] presents sensor activation algorithm for target tracking for B-WSN. In this algorithm some sensors are in the sleep mode and some are awake. Some sensors are kept in sleep mode to save energy while some are activated in the field with a possibility to detect the targets. The localization concept is based on Centroid estimator which is sensitive to false negative sensor nodes. The observation from all sensors which are awake and are in the sensing range contributes to target tracking. Simulation is done in Matlab. Simulation results point towards improved energy-quality tradeoff of DSA2 as compared to Randomized activation.

SNAP[4] proposes an estimation algorithm that constructs a likelihood matrix by adding +1 or -1 contributions from the sensor nodes. The contributions depend upon status of sensor node whether alarmed or non-alarmed. It consists of Grid formation followed by likelihood matrix construction followed by maximization. SNAP variants SNAPm and SNAPe are discussed. Simulation tests the performance of SNAP with respect to other estimators. Centroid (CE), maximum likelihood estimator (ML) and add on Positive (AP). SNAP is computationally less demanding but slightly less accurate as compared to ML.

[5] Proposes a fault tolerant algorithm for target identification and localization in sensor networks. In this, data unification is conducted along both temporal and spatial dimensions for decreasing the false alarm rate and increasing the target position accuracy. The simulation is done in Matlab. In high density networks, the probability of reporting the existence of targets is high. The computational overhead is low. The sensor network does not consider binary sensing model.

In [6], spatiotemporal information from previous estimation steps is used to select sensors for localization scenario. Markov Chain model concept is used to depict sensor fault model. Bayesian approach is used for sensor health state estimation. Estimators are used to compute sensor health state. The parameters worked on are tracking error and state estimation error in presence of various faults. Three estimators are discussed; simple, static and dynamic. Static estimator performs better than dynamic estimator. Dynamic estimator is more sensitive to wrongly estimated source location. The proposed algorithm is not able to detect exact fault type and not able to completely remove observations from faulty sensors.

In [7], a distributed algorithm is proposed. Faults are found out by examining the correlation in the reading of nearby sensors. Based on Bayesian decision algorithm, three Probabilistic decision schemes are implemented. Optimal threshold decision scheme minimizes the effect of uncorrelated faults. Binary sensing model is used. Simulation results show that the algorithm may introduce new errors if evidence from neighboring sensors is faulty.

[8] Considers Byzantine attacks for the location estimation task in WSN where each sensor uses a binary quantization scheme to send binary data to the fusion center. Posterior Cramer-Rao lower Bound (PCRLB) metric and Fisher Information Matrix (FIM) are used to analyze the performance of the network in the presence of Byzantine attacks. The work considers two types of attack independent and collaborative.

Key points related to existing event localization methods in B-WSN are summarized in table 1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Design</th>
<th>Evaluation of Methodologies used</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3]</td>
<td>Distributed</td>
<td>● Do not consider sensor faults</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Uses Centroid estimator for localization</td>
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<tr>
<td></td>
<td></td>
<td>● Sensitive to false negatives sensor nodes.</td>
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<td></td>
<td></td>
<td>● Less accurate as compared to other estimators.</td>
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<td></td>
<td></td>
<td>● Computationally less demanding</td>
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<tr>
<td></td>
<td></td>
<td>● Do not consider possible correlations among sensor observations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Lacks fault identification technique to recognize type of fault.</td>
</tr>
<tr>
<td>[7]</td>
<td>Distributed</td>
<td>● Probabilistic decision schemes are implemented</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Optimal threshold decision scheme minimizes the effect of uncorrelated faults.</td>
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<tr>
<td></td>
<td></td>
<td>● New errors if evidence from neighboring sensors is faulty.</td>
</tr>
<tr>
<td>[9]</td>
<td>Centralized</td>
<td>● Estimator algorithms are used for tracking purpose.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● All estimators included incorrect binary observations from faulty sensors also.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Tracking Estimation suffers due to faulty sensors.</td>
</tr>
</tbody>
</table>

### III. NETWORK MODEL

#### A. Ideal Environment

In ideal B-WSN model depicted in figure.1, the actual physical location of all the sensors in the network is assumed to be known beforehand. This could be realized at the time of network deployment or through a location service. The binary sensor nodes are deployed over a region. Every node is assumed to have same sensing range. The sensor nodes are stationary. In ideal situation, the sensor nodes are assumed to be working perfectly wherein they will sense the event and report its presence by sending single bit value ‘1’ to the sink node. If the event is not sensed then the sensors remain silent. So from fig.1, it is
clear that the sensors which fall within the Region of coverage (ROC) of the event will eventually report. The sensors lying outside the ROC of event will remain silent.

**B. Practical Environment**

Practically sensors are deployed in harsh conditions with the limited resources. The sensors may fail due to variety of reasons like battery depletion, environmental rough conditions, software problem, noise etc.

Sensors exhibit erroneous behavior practically. Figure 2, shows the practical behavior of binary sensors. The sensors present even though in the ROC of event remain silent whereas some sensor outside ROC of event sends bit value '1' to sink node. This kind of behavior imposes serious implications on the performance of wireless sensor network.

### IV. MATHEMATICAL MODEL

Consider wireless sensor network, with assumption that the data observed by sensors is identical within the coverage of sensors. The observed data may vary over the time but not in space. Theoretically, if noise is ignored observed data is same for all sensors within the range. So sensor S observes data x at time t.

\[
S(t) = x
\]

But in presence of noise n, the observed data by sensor S at time t will be

\[
S(t) = x + n
\]

Each sensor has to resolve the difference in the observed data in a precise manner. Besides, an accurate representation of S(t) requires a larger number of bits. So more bits must be transmitted per observation by every sensor.

For simplicity, now consider B-WSN where sensors are programmed to output a single bit value. Such sensors are known as binary sensors. The single bit value can be either '0' or '1'. So here binary sensors will take decision based on comparison of the observed data and threshold. So in B-WSN, binary sensors will send '1' when the observed data exceeds certain threshold.

The observed data of the ith sensor, \( i = 1, \ldots, N \) at time \( t, t = 1, \ldots, M \), is given by

\[
S_i(t) = \begin{cases} 
1 & \text{if } x(t) \geq T \\
0 & \text{if } x(t) < T
\end{cases}
\]

Where \( x(t) \) is the observed data at \( i \)th sensor and \( T \) is a predefined threshold. The sensor will send only one bit information. From equation (3), if the data measured at \( S_i \) exceeds the threshold value then it will send single bit value '1' to the sink node otherwise, it will remain silent.

Applying the above binary sensor model to ideal situation, the sink node will receive bit '1' values from all the sensors which are lying in the region of coverage of event.

#### Pseudo code 1 : Sink node (\( S_k \)) status at any time step \( t \) in ideal working of Binary sensors.

```
for every time step \( t \) ( \( t=1..M \))
    { for every sensor node \( S_i \) (i=1..N)
        { if \( (x(t) \geq T) \) and \( (S_i \text{in ROC}) \) then
            \( S_k(i) = 1 \)
        Else
            \( S_k(i) = \text{NULL} \)
        }
    }
```

#### Pseudo code 2 : Sink node (\( S_k \)) status at any time step \( t \) in practical working of Binary sensors.

```
for every time step \( t \) ( \( t=1..M \))
    { for every sensor node \( S_i \) (i=1..N)
        { if [ \( ((x(t) \geq T) \) or \( (x(t) < T) \) and \( (S_i \text{in ROC}) \) or \( (S_i \text{outside ROC}) \) ]
            then
            \( S_k(i) = 1 \)
        }
    }
```

![Fig.1. Working of Binary sensors in ideal environment.](image1)

![Fig.2. Working of Binary sensors in practical environment.](image2)
\[ S_\text{t}(i) = 1 \text{ or NULL} \]

The sink node will store information from every sensor node as either ‘1’ or ‘NULL’. The sensors which do not sense the event will remain silent i.e. they will not send any bit to sink node. The sink node status in practical working of binary sensors receives arbitrary results from sensors. So it is hard to analyze the situation in case of event localization mechanism implemented with binary sensors. The sink node will process the gathered data and pass it on to the gateway node for further action.

Considering the fire detection application of binary sensors, the sink node will pass the information about nodes from which it has received bit value ‘1’ to gateway node. The gateway node will localize the area of fire and take action like raising an alarm or initiating fire control procedures based on the information received from sink node. In ideal working of binary sensors this strategy does not pose any threat but in imperfect working of binary sensors where it is susceptible to faults, the action taken by gateway node might be improper. It might happen that due to faulty information from sensors, the event area is dislocated and actions are initiated for area where there is no fire or the area with fire misses out timely action of fire control mechanism to be taken by gateway node.

**V. PROPOSED FLOW DIAGRAM OF EVENT LOCALIZATION**

![Flow Diagram](image)

Sensor Network Applications Are Characterized By Four Important Requirements like energy efficiency, scalability, failure resilience and collaboration[10].

Operation of applications despite presence of faults is challenging to explore. Adapting to the change due to unexpected failures or Byzantine behavior from sensor nodes requires proper error handling mechanism. Proposed flow diagram shown in the figure 3, highlights the necessity of reducing the impact of imperfect working of binary sensors on event localization method. The sensors are assessed to determine their condition viz. fit or unfit. The assessment criteria determine whether they are fit to participate in localization process. The sensors which are fit to participate in localization are only considered. If the sensors are evaluated as unfit they are discarded. So the high level abstraction gives idea about fault resilient event localization using binary sensors.

**VI. CONCLUSION**

The related work done in the paper presents methods of event localization for B-WSN with faults. The existing methods give estimation of event location in the presence of faults. The authors discuss the consequences of considering observations from faulty sensor in fire detection scenario. The paper underlines the need of event localization methods for variety of sensor network applications which are reliable.

Architecture for event localization with perfectly working binary sensors is proposed. Mathematical model and pseudo code presented highlight the functioning of binary sensors in the presence and absence of faults. The realization and formal verification of the proposed system is left as future work. Comparison of the results with state of the art can also be considered as future potential work.

**REFERENCES**


