Efficient Continuous Object Tracking with Virtual Grid in Wireless Sensor Networks

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***Abstract*— For tracking a continuous object, mass communications are generated in the sensor field because of their huge scale and extensive diffusing property. Due to the severe resource constraints of sensor nodes, the redundant information and communications should be reduced in order to prolong the life time of WSNs. Although there have been numerous studies on continuous object tracking, most of the proposed schemes have focused on reducing the redundant boundary nodes and control messages through static/dynamic clustering in space domain. However, it is not enough to reduce the redundancy only with space domain. Redundantly sampled reporting packets could be a cause of generating redundant long range transmission, which is an important source of energy consumption. For reducing the redundancy, we need to consider not only the method to reduce the redundancy in space domain but also an adaptive sampling scheme in time domain. However, adaptive sampling is difficult to design in continuous object tracking because local sensor nodes hard to figure out how far the continuous object is diffused. To solve this problem, we suggest a new scheme which picturizes the diffusing object by dividing the sensor field into several cells like a pixel on TV and samples reporting time based on pixel image. In addition, we use pictured image of diffusing object for selecting the boundary information of diffusing object in space domain to reduce the redundant boundary information. To present the sensor field as an image, we adopt a virtual grid which divides the sensor field into several cells under the static clustering WSN architecture. The performance of proposed scheme is verified with simulation and the results show that the total number of control messages, reporting packets and boundary nodes can be reduced.**

Keywords- Continuous Object Tracking, Virtual Grid, Data Reduction

I. INTRODUCTION

One of the common application areas in WSNs is continuous object tracking which detects and monitors the diffusing objects, so called continuous objects, like a toxic gas, wild fire, bio-chemical materials, and so forth [1]. In continuous object tracking, mass communications and information are generated in WSNs because thousands of sensor nodes are deployed in wide fields and they collaborate with each other in order to detect and monitor the widely diffusing objects and report the detected events to the sink. To prolong the life time of WSNs, it is important to reduce the redundant communications and information as much as possible, as long as the reduced data does not deteriorate the recognition quality of diffusing object.

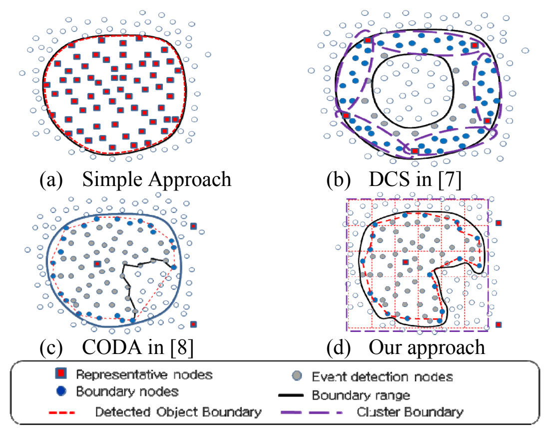

Figure 1. Comparison of boundary detection methods

To reduce redundant communication, there have been enormous research efforts on continuous object tracking such as DCS [7], CODA [8], COBOM [9], and DEMOCO [10]. Most of them use static/dynamic clustering schemes to reduce the redundant information in space domain. These schemes can reduce more communications than that of the simple approach (figure 1(a).) where all sensors are directly report their detection event to the sink whenever they detect the event. However, the schemes presented above have two weak points. The first is that all schemes assume that the representative nodes, which have a responsibility to report the detected boundary to the sink, periodically report their monitored boundary. It may cause the generation of several unnecessary long distance communications when the diffusing object is improperly sampled in time domain. The second is that several sensor nodes may be selected as boundary nodes like in figure 1(b). It causes to increase the size of packets, the number of reporting packets and control messages in space domain. Some other mechanisms, like CODA [8], can detect contour type boundary, but if the object shape is concave form, then it may acquire different shape of boundary information from original diffusing object, like in figure 1(c).

This paper suggests an efficient scheme to improve above two weak points. It focuses not only on adaptively

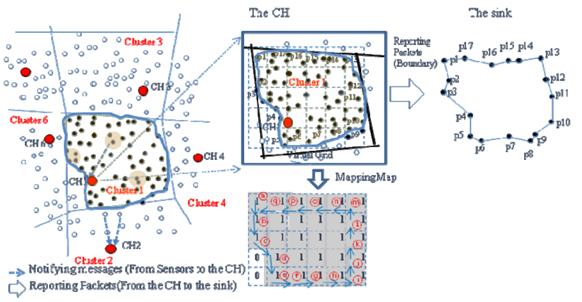

Figure 2. The Virtual Grid Based Continuous Object Tracking

adjusting reporting period in accordance with the moving speed of diffusing object but also on reducing the number of control messages and boundary nodes by detecting the boundary like in figure 1(d). The ultimate goal of detected boundary of proposed scheme is shown in figure 1(d). The boundary of diffusing object is represented not as several sensor nodes but as a set of few sensor nodes which are located at the outmost boundary of contaminated sensor nodes. In addition, the detected shape of diffusing object is as similar as the original shape of diffusing object unlike that of the CODA [8].

However, adaptive sampling is difficult to design in continuous object tracking because local sensor nodes hard to figure out how far the continuous object is diffused. To solve this problem, we suggest a new scheme which picturizes the area of diffusing object by dividing the sensor field into several cells like a pixel on TV. To suppress the reporting packet in time domain, we compute diffusing extent of object based on cell image and adaptively report the boundary information to the sink only when the 2-D shape of diffusing object is changed over the predetermined threshold. To suppress the redundant information in space domain, we select the boundary information using hybrid scheme that selects a boundary sensor nodes by considering region (cell) and individual sensor nodes at the same time. We extract boundary information through the Boundary Traverse Algorithm (BTA) and extract the boundary nodes from boundary cells and individual sensor information mapped at the boundary cells. We also introduce tolerable error bound based data reduction scheme, polyline reduction. This is for reducing the number of boundary nodes via line simplification algorithm [3].

To make an image of sensor field, we adopt virtual grid, which virtually divides the sensor field into several cells like pixels on TV, under the static clustering WSNs structure like in figure 2. To determine proper virtual grid size, we use the fact that it is not true that the users always want to get precision measurement. They allow some extent of error and we call it tolerable error bound or resolution of detection.

Compared with the DCS [7] and the CODA [8], this scheme has two advantages. The first, it can reduce the number of boundary nodes with minimizing the distortion of the detected shape of diffusing object. The second, it can reduce the number of long distance transmissions of reporting packets for transmitting the boundary information through adaptively selecting the reporting period in accordance with the moving speed of diffusing object.

The rest of the paper is organized as follows: We first review research on data reduction and continuous object tracking in Section II. In Section III, we present our proposed continuous object tracking mechanism. Section IV presents the simulation results. We conclude the paper with Section V.

II. Related Works

There have been numerous researches on data reduction for detecting and tracking of individual object [2]. In [4][5][6], dead reckoning, dual-predication, Kalman filter based dual-prediction, and MPEG style prediction mechanism are proposed to reduce the reporting packets between the sensor and sink. For continuous object tracking, numerous papers have been presented to detect and track the boundary of diffusing object [7][8][9][10][11]. In the DCS [7], only the boundary nodes participate in constructing dynamic cluster, and boundary information are gathered by the CHs, then it is sent to the sink periodically. In the CODA [8], the Cluster Head (CH), a sensor node which takes the responsibility for reporting the detected information to the sink by generating reporting packets, computes convex hull to detect the boundary of continuous object under the proactively constructed static cluster environment. Since it uses convex hull algorithm, the shape that the CH generates may be different from the original shape of diffusing object if the shape of diffusing object is concave form. In [9], Zhong et al. propose localized continuous contour mapping algorithm where only a representative node on the boundary reports detecting result to the sink after it makes a cluster based on BN-array. The DEMOCO [10] uses Change Value Nodes (CVNs) messages and CompareOneZero (COZ) messages to detect boundary of diffusing object with as few as sensor nodes, and selects the representative node located outside the diffusing object. The TG-COD [11] uses two-tier grid to detect boundary of diffusing object.

III. Efficient Continuous Object Tracking with Virtual Grid

In this section, we illustrate proposed scheme, virtual grid based continuous object tracking, in detail.

A. Basic Operation Concept

The overview of proposed scheme is shown in figure 2. When the sensor nodes in the cluster detect the event, they transmit this information with 'notifying message' to the CH. On receiving this information, the CH maps the position of sensors to the virtual-grid, and alters virtual-grid data structures. Mapping map presents whether one of sensors in the cell detects the event. Its state is presented with two states, "true" or "false". Whole sensor field is presented like an image by this mapping map. And then, the CH extracts boundary information and selects the most suitable reporting time. When the reporting condition is satisfied, the CH detects the boundary cell in mapping map by using the BTA which traverses outmost cells, which is set to "1", on the mapping map. The boundary sensor nodes are extracted from boundary cells and other virtual grid data structure. To get more data reduction, we apply line simplification algorithm on extracted boundary nodes.

B. Virtual-Grid Construction

A proposed scheme is developed under the assumption that sensor nodes in WSNs are disseminated densely enough, and they can realize their location by using various localization mechanisms or GPS. WSNs use static cluster architecture which comprises many proactively constructed clusters. In each cluster, there is one CH which knows its own cluster size and acts as a representative node, and lots of sensor nodes which are deployed in the cluster field for event detecting purpose. The virtual grid is constructed on the CH's memory. As we aforementioned, the CH can know its cluster size at the cluster construction phase, and the grid distance *d* is informed by user. With grid distance *d* and cluster size, we can calculate dimension of cluster at the Cartesian coordinate which the position of the CH become origin point. This virtual-grid information, origin point of coordination and dimension of grid, are transmitted to the sink at this phase. The sink can know the whole virtual-grid information of WSNs by combining the cluster information transmitted from various CHs.

To implement virtual grid on the CH, proposed scheme defines three data structures, Mapping Map (MM(i,j)), Representative Map (RM(i,j)), and Map Count (MC(i,j)) which are two dimensional arrays for saving diffusing object information. The MM(i,j) saves the state of cells whether the sensors mapped in this cell detect the event or not and is used for detecting the boundary of diffusing object. The RM(i,j) saves the mapping sensor nodes and is used for extracting the boundary sensor nodes for reporting purpose. The MC(i,j) saves how many of sensors are mapped into this cell and is used for changing the value of mapping map.

C. Mapping Sensor Event to the Virtual-grid

The sensors can be contaminated, called detection event, by diffusing object or be released, called releasing event, from contamination. Whenever sensors detect the one of two events, they inform their event information, the type of event and position of sensor, to the CH by using notifying message. When the CH receives the detection event, it computes the index of virtual grid, index i and j, using the CH's and sensor's position information and grid distance *d.* The equation to compute the grid cell index can be presented as follows:

$$i = floor((x_i - x_{ref})/d) + ceil((x_{ref} - x_{\min})/d), \quad (1)$$
$$j = floor((y_i - y_{ref})/d) + ceil((y_{ref} - y_{\min})/d)$$

Where (x_{ref} ,y_{ref}) is a reference point of virtual grid, (x_i ,y_i) is a received sensor position, *d* is grid distance, and x_{min},y_{min} is the least x and y value of sensor position in the cluster. Using these indices, the MC(i,j) and the MM(i,j) values are changed as following schemes.

$$MC(i,j) = \begin{cases} increase\ 1,\ if\ type\ is\ detection \\ decrease\ 1,\ if\ type\ is\ releasing \end{cases} \quad (2)$$
$$MM(i,j) = \begin{cases} 1,\ if\ MC(i,j) != 0 \\ 0,\ else \end{cases}$$

The MC(i,j) is changed first according to the event type. If event type is detection, then increase the value of this data structure, else decrease it. The MM(i,j) is changed in accordance with the MC(i,j). The latest received sensor position is saved at RM(i,j) only when the event is detection.

D. Efficient Tracking Scheme

At the CH, the boundary information of continuous object is needed to be sent to the sink for tracking. The accuracy of tracking and redundancy of communication has some trade-off relationship in accordance with the reporting frequency and the moving speed of diffusing object. There may have little tracking error if we send this information with low frequency when the speed of object is slow. On the other hand, the reporting frequency should be high in order to guarantee tracking accuracy if the diffusing object moves fast. If we use periodic reporting mechanism, both requirements couldn't be simultaneously satisfied with when the moving speed of diffusing object is changed. To alleviate these problems, this paper adapts hybrid mechanism that the reporting frequency becomes low when the diffusing object slowly moves. In other cases, it uses periodic reporting. The sampling scheme to select the suitable reporting time by using virtual-grid is shown as follows:

$$Sampling \begin{cases} 1\ ,\ when\ t_n - t_{n-1} > \Delta t,\ and\ MM(i,j)\ change \\ 0\ ,\ else \end{cases} \quad (3)$$

Where t_n, t_{n-1} are current time and the latest reporting time respectively, and Δt is the given reporting period. Through the monitoring of the MM(i,j), we can know whether the virtual grid is changed or not. Every reporting interval Δt, the CH checks whether the MM(i,j) is changed or not. And, only when the mapping map is changed, the CH sends the boundary information to the sink. With this mechanism, the number of reporting packet in the CH can be constrained according to the following equation. This equation is presented as a function of the number of cells in a cluster and speed of diffusing object.

$$number\ of\ sampling <= \min(N_{cell}, (t_{escape} - t_{enter})/\Delta t) \quad (4)$$

Where N_{cell} is a number of cell in a cluster, and t_{escape}, t_{enter} are entering and leaving time of diffusing object into a cluster and Δt is a given reporting period.

E. Boundary Detection Scheme

In order to acquire boundary nodes, we need to extract the boundary cells from the MM(i,j), and then, we can finally acquire the boundary nodes using the extracted boundary cells and the sensor node information mapped at the RM(i,j). Boundary cell detection problem may be defined as follows: In the CH, given a set of cell C = {c0, ... , cn} in the cluster, we need to find out the boundary cells CB = {c0', ... , cn'} such that CB⊆C and all elements of CB satisfy following condition. For all ci'∈CB, neighbor cells of ci'(left, right, up, and down cell) should have more than one "0" and "1" value in its mapping map, the MM(i,j). In figure 2, we traverse the mapping map to find out whole boundary cells which satisfy above definition. The finding process starts from cell ⓐ with counter clock wise until the last finding cell becomes ⓐ. Using the sequences of boundary cells which is acquired as a result of finding process and the sensor nodes mapped at the RM(i,j), we are able to select pure boundary nodes of diffusing object. The full pseudo–code for detecting the boundary from virtual-grid structures is presented in figure 3.

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1: Check cluster boundary cells if it is redundant or not
2: Start cell = leftmost upper cell which the MM(i,j) is '1'
3: Save Start Cell to Boundary Cell(i++)
4:next_search_cell.i,j = starting boundary cell index
5:search_cell.i,j = upper cell of Start Cell
6:while (boundary.i,  boundary.j!= Start Cell)
7:   for (all adjacent neighbor cell in MM(i,j))
8:          index (m, n)  = find next cell from the
               search_cell.i,j with counter clockwise
9:      if (MM(m,n) == 1 || MM(m,n) == 'visit mark') {
10:            boundary.i ,j= m, n
11:            if (MM(m,n) == 1)
12:                MM(i,j)  = 'visit mark'
13:                Save the boundary to Boundary Cell(i++)
14:            endif
15:            search_cell.i,j = next_search_cell.i,j
16:            next_search_cell.i,j = m, n
17:            break;
18:     }
19:     else  search_cell.i,j = (m,n)
20:  end for
21:end while
22:Get the Boundary Nodes from RM(i,j) and Boundary
    Cell Array, and restore all visit marks to '1' in the MM(i,j)
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Figure 3. Pseudo-code of Boundary Traverse Algorithm (BTA)

F. Cluster boundary node elimination

When the diffusing object crosses more than one cluster region, diffusing object may be detected as if it is separated at the cluster boundary because each cluster detects the boundary for the sensor nodes only within the cluster region. There are no ways to inform whether detected object diffused beyond this cluster to the other CH. To solve this problem, we adopt local investigation scheme that all cluster boundary cells in the mapping map are investigated in advance in order to check if the cluster boundary cells are global boundary of diffusing object. The condition to be a redundant cluster boundary cell is as follows:

$$\begin{aligned} &RM(i,j)t_n == RM(i,j)t_{n-1} \text{ and} \\ &((MM(i,j) \text{ and} \\ &\forall \text{ existing neighbor cells}[up, down, left, right] \text{ of } MM(i,j)) == 1 \end{aligned} \quad (5)$$

The cells which are located at the boundary of clusters are regarded as redundant cells only when itself and all exiting neighbor of upper, down, left, right cells are contaminated with diffusing object, and the RM(i,j) isn't changed. However, we do not care what the MM(i,j) value of diagonal neighbor cells, such as MM(i-1, j+1), will be. The minimum and maximum indices used to determine the global boundary at the above condition should be 0 and dimension of virtual grid respectively. When the MM(i,j) cell is turned out a redundant boundary cluster cell, we temporarily set 'visit mark' (-1) at the mapping map. Once it is marked with 'visit mark', this cell will be skipped at boundary searching phase as be shown at line 9 in figure 3. These marks are restored to '1' at the end of the BTA.

G. Reducing the number of boundary nodes

When we find out the boundary nodes, we can reduce the number of boundary nodes using polyline reduction algorithm applied in [3]. The set of boundary sensor P = {v1, ... , vn} can be reduced to P' = {v1', ... , vn'} in which perpendicular distance between P and P'(dist(P, P')) is less equal some threshold value, ε, by using Douglas and Peuker line simplification algorithm.

IV. PERFORMANCE ANALYSIS

In this section, we evaluate the performance of proposed mechanisms in the network simulator Qualnet ver. 4.0 [12].

A. Model and Evaluation Metrics

In our simulation, we assumed that the sensors are randomly disseminated in 300m x 300m square area, and the field is separated into 9 cluster zones. We also assume that the sink is located at the outside of the square area which can be reached one hop transmission from the nearest outmost sensors in square area. The number of sensors disseminated in the field is varied in order to evaluate the effectiveness of proposed scheme. A circle shaped continuous object expands its size, and the expansion speed is varied according to the parameter settings. Circle was initially centered at (150,150), and the expansion was continued until the circle radius *r* reaches 150m. The performance of proposed scheme was evaluated on the three metrics: the number of control messages, boundary nodes, and reporting packets. We compared them with that of the DCS and the CODA.

B. Results

In time domain, we compare the number of reporting packets. Figure 4 compares the number of reporting packets with the various reporting intervals under the condition that the reporting interval is 1sec and 5sec, respectively, and the grid distance is 10m, and diffuse velocity is 1m/sec. The proposed scheme generates less reporting packets than that of other two mechanisms when the object slowly moves. Figure 5 compares the number of reporting packets with various velocities under the condition that the reporting interval is 1sec, and the grid distance is 10m. It shows that the proposed mechanism is more effective when the diffusing object slowly moves. The reason is that if the object slowly diffuses, it takes long time to escape the cell boundary in which this mechanism establishes as a threshold for generating reporting packets.

In space domain, we compare the number of control messages, reporting packets and boundary nodes. In order to compare the number of control messages, we varied the number of nodes from 900 to 5400 with every 900 step. In figure 6, the number of control messages is presented as a function of sensor deployment densities. Figure shows that the number of control messages proportionally increases as the number of nodes increases. The CODA and proposed scheme generate relatively less control messages than that of the DCS. The reason is that these two mechanisms generate only detection event for transmitting detection event to the CH, but the DCS makes a lot of extra communications for detecting the event detection nodes and for gathering the boundary nodes. The proposed scheme shows that it generates slightly less control messages than that of the CODA. The reason is that the CODA uses extra communication, "Sense message"[8], when the diffusing object crosses more than one cluster.

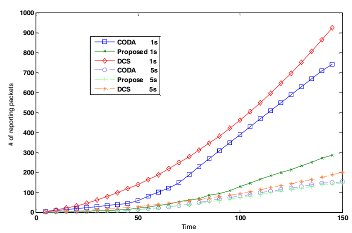

Figure 4. Total number of reporting packets as a function of reporting period

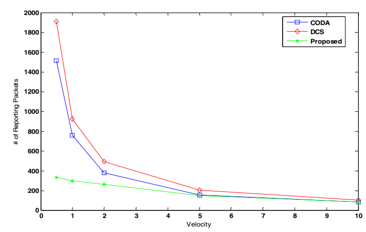

Figure 5. Total number of reporting packets as a function of expansion velocity of object

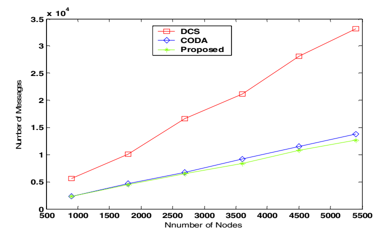

Figure 6. Total number of control messages when the number of sensor nodes increases

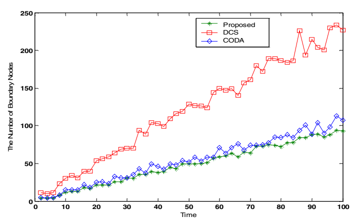

Figure 7. The number of boundary nodes when the object expands the size

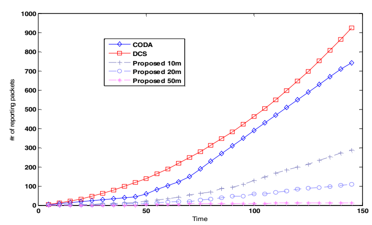

Figure 8. Total number of reporting packets as a function of cell size

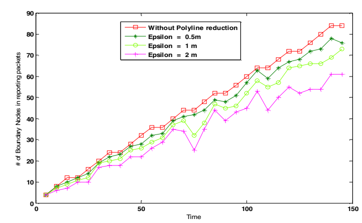

Figure 9. The number of boundary nodes over time with the ε value

Figure 7 compares the number of boundary nodes of the DCS, CODA, and proposed scheme under the condition that the number of deployed sensor nodes is 2700, and the grid distance is 10m. Figure shows that the number of boundary nodes of proposed scheme can be significantly reduced compared to the DCS, and slightly reduced compared to the CODA. Figure 8 compares the number of reporting packets with the various grid distances when the reporting interval is 1sec, and the diffuse velocity is 1m/sec. It shows that the larger the grid distance, the more reduction of reporting packets we can get. Figure 9 compares the number of boundary nodes with the various polyline reduction parameters, ε, under the condition that the number of sensor nodes is 1800, and the grid distance is 10m. The graph shows that about 24% of data reduction is achieved when ε is 2m, and it also shows that the number of reduced boundary nodes is proportionally increased with the ε. In order to compare the number of reporting packets, we varied the reporting interval, grid distance, and diffusing velocity, from 1 to 5, 10m to 50m, and 0.5m/sec to 10m/sec respectively under the environment where the sensor nodes are disseminated 1800 nodes in the field. The number of reporting in graph means accumulated number of reporting packets.

V. CONCLUSION

This paper suggests boundary node detection method and sampling method based on virtual-grid under the static cluster-based WSNs for detecting and monitoring the continuous object. Proposed scheme reduces the reporting packets by using cell-based sampling mechanism where the CH transmits the reporting packet only when the mapping map is changed and reduces the number of boundary nodes by using virtual-grid based mapping and boundary search algorithm. The simulation results show that the number of control messages, reporting packets and boundary nodes can be reduced compared with that of the DCS and the CODA. We are going to keep more study on sophisticated tracking scheme using virtual grid for continuous object tracking in WSNs.

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