A DISTRIBUTED TRIANGULAR SCALAR CLUSTER PREMIER SELECTION SCHEME FOR ENHANCED EVENT COVERAGE AND REDUNDANT DATA MINIMIZATION IN WIRELESS MULTIMEDIA SENSOR NETWORKS

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ABSTRACT

This research reports a novel algorithm inspired by clustering paradigm for providing improved event coverage, while actuating reduced number of cameras. The main objective of the current proposal is concentrated on reducing the amount of redundant data transmitted due to overlapping of field of views of cameras, while enhancing the occurring event area coverage. The basic framework of the algorithm is divided into three phases. Initially, the monitored region is divided into number of compartments. Afterwards, in each of the compartment three scalar cluster premiers are selected effectively. Subsequently, whenever event takes place, these scalar cluster premiers report their corresponding cameras regarding its occurrence and the cameras collectively decide their order of actuation. The least camera activation, enhanced coverage ratio, reduced event-loss ratio, improved field of view utilization, minimized redundancy ratio and decreased energy expenditure for camera activation achieved from the investigation validate the efficacy of the proposed approach.

KEYWORDS: Primitive Cluster Premier, Secondary Cluster Premier, Tertiary Cluster Premier, Coverage Ratio, Redundancy Ratio, Active Camera Count.

In this modern era of present-day technology, sensors are used in almost all spheres of life. Their prevalent viability and adoration is essentially due to their exclusive advantages and versatility to be deployed in any herculean environment. Sensors find a lot of applications like habitat tracking, environmental monitoring, industrial diagnosis, agricultural control, disaster relief, seismic activity monitoring, and battle field monitoring, etc. In most of the cases, sensors are deployed for ensnaring the event information in inaccessible remote areas. They are scattered across huge regions of interest so as to detect and monitor the occurring event information pertaining to the monitored region. Hence, covering the event region intellectually and capturing the event information efficiently have been a predominant problem of consideration.

Wireless Sensor Networks (WSNs) are the networks, which consist of autonomous sensors for monitoring the physical as well as environmental conditions. Wireless Multimedia Sensor Networks (WMSNs) are extensions of WSNs where scalar sensors are employed along with the cameras. Scalars are those sensors, which can capture the textual information and cameras can capture both audio as well as video information. Further, it is well known that battery constrained sensors are deployed in the regions to be monitored. However, as the cameras consume higher amount of energy than the scalars, they are normally kept in turned off state and they undergo activation only when scalars present within their DOFs apprise them regarding the occurrence of any event.

The camera sensors possess two primitive parameters namely, Field of View (FOV) and Depth of Field (DOF). FOV is the angle at which a camera can trap the accurate image of an object and DOF is the distance within which a camera can take the accurate image of an object [Newell and Akka, 2011]. A camera can either be a directional camera or an omni-directional camera based on the FOV angle. If a camera takes image of an object along a particular direction, it is said to be a directional camera. On the contrary, if it takes image of an object uniformly along all the directions, then it is said to be an omni-directional camera. Further, a scene may be shot from several camera angles simultaneously. The preference of employing omni-directional cameras is that they can provide more panoramic photographs of occurring event information, thereby capturing the concerned land marks and the habitats more appropriately and effectually over prolonged period of time than the directional cameras, which own fixed orientations. Basically, redundant data transmission takes place due to overlapping of FOVs of cameras. As we know, more is the value of DOF of a camera; more area will be covered by the concerned camera. However, excess increase in values of DOFs, leads to increased overlapping superimposed zones among the FOVs of cameras.

Several approaches have been devised till now for minimization of redundant data. A Distributed

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Collaborative Camera Actuation based on Scalar Count (DCA-SC) is a recently proposed approach for minimizing the amount of redundant data transmitted [Newell and Akka, 2011]. In this paper, the cameras collaboratively decide which among them are to be activated based on descending order of their scalar count (SC) values. SC value of a camera represents the number of event detecting scalars present within the FOV of the concerned camera sensor. Similarly, another scheme namely, Distributed Collaborative Camera Actuation based on Sensing-Region Management (DCCA-SM) actuates the cameras based on the amount of residual energy contained by them [Luo et.al., 2012]. However, this scheme suffers from a major drawback that the number of cameras actuated cannot be significantly minimized for reducing the amount of redundant data transmission. Such transmissions of redundant data lead to unnecessary energy as well as power expenditure. Therefore, our goal is to actuate only the minimum number of cameras in such a manner that the amount of redundant data transmission is minimized, while providing improved coverage of event region to be monitored.

DCA-SC and DCCA-SM, as discussed earlier, are two approaches that attempt to cover the monitored region with less camera actuation. However, redundancy in data transmission is still there due to overlapping of FOVs of actuated cameras. Besides, complete elimination of redundant data transmission is unavoidable since event information loss would occur if the redundancy causing cameras are kept in turned off state. Hence, our objective is to develop an optimal algorithm that activates significantly reduced number of cameras in such a way that it minimizes the amount of redundant data transmission while providing enhanced event coverage as compared to DCA-SC and DCCA-SM.

In current research, we have devised a novel approach called Distributed Triangular Scalar Cluster Premier Selection (DT-SCPS) that divides the entire monitored region into a number of compartments and selects three scalar premiers namely, primitive cluster premier, secondary cluster premier and tertiary cluster premier effectively in each of the compartments. The scalar premiers are selected intellectually in such a manner that the scalar having the lowest mean distance among all the scalars in a compartment is chosen as the primitive cluster premier. The secondary cluster premier is the farthermost scalar, present at 60° counter-clockwise direction along the baseline from the primitive cluster premier in the corresponding compartment. Similarly, the tertiary cluster premier is the scalar whose average mean distance from both the other cluster premiers is the smallest. The selection of all the scalar premiers is realized in such a manner that the cameras actuated by them ensnare information regarding any kind of event while covering more distinct portions of the monitored region, thus, minimizing the amount of overlapping among the FOVs of cameras, which form the ultimate objective of this research proposal.

The rest of the paper is organized as follows: Section II discusses the related work done in the field. Section III elaborates the proposed approach. Section IV details the simulation frame work and result discussions. Finally, in Section V, we conclude the paper.

RELATED WORK

Significant amount of research work have been carried out for providing better coverage of the monitored region. The DCA-SC and DCCA-SM approaches as discussed in Section I consider the activation of camera sensors; while minimizing the amount of redundant data transmitted. Similarly, the idea of cover set that has been used in [Zorbas et. al., 2010]; helps in monitoring all the desired targets. The algorithm presented in this work divides the nodes into cover sets and generates maximum number of cover sets. Besides, the approach presented in [Wang et. al., 2009] concentrates on the notion of directional coverage, where each of the individual targets is associated with differentiated priorities. Moreover, the paper discusses the issue of priority-based target coverage and chooses a minimum subset of directional sensors that can monitor all the targets, while propitiating their prescribed priorities.

The analysis of the coverage process induced on a one-dimensional path by a sensor network is modeled as a two-dimensional Boolean model [Ram et. al., 2007]. Furthermore, the path coverage measures such as breach, support, length to first sense and sensing continuity measures such as holes as well as clumps are also characterized in the same work. In another approach [Cai et. al., 2007], priority is given on redundant data elimination, where a local elimination algorithm that removes the redundant messages locally in each state of the automaton is proposed. Similarly, a method is proffered in [Girault, 2002] for removing redundant messages in parallel programs which has been distributed automatically. This proposed algorithm uses program control flow i.e., contains gotos. The control flow is a finite deterministic automaton with a DAG of actions in every state. Additionally, a data similarity based redundant data elimination technique has been described in [Ghaddar et. al., 2010]. In this paper, an algorithm is depicted to measure similarity between data collected towards the base station such that an aggregator sensor sends minimum amount of information to the base station.

PROPOSED APPROACH

We have devised a novel approach called "Distributed Triangular Scalar Cluster Premier Selection (DT-SCPS)" scheme for actuating less number of cameras that cover distinct portions of event region effectively while providing improved event coverage along with lowered redundancy in data transmission.

Relevant Definitions and Terms

Some of the relevant definitions and terms used in our proposed approach are discussed as follows:

Definition 1: Coverage Ratio can be defined as the portion of the area of an occurring event that is covered by all the actuated cameras with respect to its total area.

More is the value of coverage ratio, more effectively the event region is covered. Mathematically,

Coverage ratio = pec/te (1)

Where, pec: portion of event area covered by all the activated cameras and te: total area of occurring event

Definition 2: Event-loss Ratio is the ratio of portion of area of event which is not covered by activated cameras to the total area of occurring event.

Less is the value of event-loss ratio; greater will be the coverage of the occurring event region. Mathematically,

Event-loss ratio = penc/te (2)

Where, penc: portion of event area not covered by all the activated cameras and te: total area of occurring event.

Definition 3: Redundancy Ratio is defined as the ratio of total portion of overlapping area of FOVs of cameras belonging to occurring event region to the total unique portions of event area that is covered by the cameras. Mathematically,

Redundancy ratio = pecof/tupec (3)

Where, pecof: portion of event area covered by overlapping of FOVs of cameras belonging to occurring event region and tupec: total unique portions of event area that is covered by all the activated cameras.

As the redundancy ratio goes on increasing, accordingly, the amount of overlapping among FOVs also increases. Hence, reduced value of redundancy ratio is preferable for attaining minimized energy expenditure.

Definition 4: Field of view Utilization can be defined as the ratio of the portion of the area of an occurring event that is covered by all actuated cameras with respect to total area of FOVs of all the actuated cameras.

More value of Field of View Utilization ensures that more redundancy can be eliminated. Mathematically,

Field of view Utilization = pec/tfac (4)

Where, pec: portion of event area covered by all the activated cameras and tfac: total area of FOVs of actuated cameras.

Some of the important terms devised in our proposed algorithm are as follows:

(i) Compartmental Cluster Count (CCC): It is the total number of event reporting scalar premiers present within the camera sensor's DOF which are present at the same compartment of the concerned camera sensor's location.

(ii) Non-Compartmental Cluster Count (NCCC): It is the total number of event reporting scalar premiers present within the camera sensor's DOF which are present at different compartment (s) from the camera sensor's location.

(iii) Total Cluster Count (TCC): It is the sum of all the compartmental as well as non-compartmental scalar premiers belonging to a particular camera sensor.

(iv) Active Camera Count (ACC): It represents the total number of cameras to be activated to cover the prevailing event zone.

Distributed Triangular Scalar Cluster Premier Selection (DT-SCPS) Method

The entire framework of the proposed DT-SCPS algorithm runs through the following three phases:

(a) Phase 1: Initialization and Scalar Premier Selection

Initially, all the scalar sensors and camera sensors are randomly deployed. Scalars and cameras broadcast My Scalar Information Message (MSIM) and

My Camera Information Message (MCIM) respectively. MSIM and MCIM are the messages which contain the ids and location information of scalar and camera sensors respectively. These messages are broadcasted by the concerned sensors to the remaining sensors. Several data structures are maintained by the sensors for storing information regarding their id, location (X, Y) and occurring event information for deciding the order of camera activation, which are listed as follows:

(i) Waiting List (WL): WL retains the ids of all the cameras in ascending order.

(ii) Current Activation List (CAL): CAL contains the ids of all the cameras which are to be activated according to the prescribed order of actuation after the occurrence of an event. At the beginning, CAL list is initialized to 0.

(iii) Ordering List (OL): OL is retained by all the cameras which contains the ids of only those cameras which cover the event region. Initially, OL is initialized to 0. After event occurrence, OL contains the corresponding ids of cameras in descending order of their TCC values.

(iv) Current Basic Cluster Premier List (CBCPL) The CBCPL contains the ids of event detecting scalar premiers present within the DOF of a camera sensor which has been activated, while considering the actuation of any camera sensor. CBCPL is kept during the running of the network and it is initialized to 0 at the beginning.

(v) Event Detecting Cluster Premier (EDCP): EDCP is a table maintained by each camera sensor which contains the ids of event reporting scalar premiers present within FOV as well as DOF of concerned camera. Initially, EDCP is also initialized to 0.

After receipt of MCIM and MSIM, the sensors estimate the Euclidean distance between each other. The Euclidean distance between any two sensors $S_i(X_i, Y_i)$, $S_j(X_j, Y_j)$ can be represented mathematically as follows:

$$\text{Dist}(S_i, S_j) = \sqrt{(Xj - Xi)^2 + (Yj - Yi)^2} \quad (5)$$

Where, $\text{Dist}(S_i, S_j)$ represents the distance between sensor S_i and sensor S_j.

The entire region to be monitored is assumed to be square in shape (During implementation, we have considered a $500 \times 500\ m^2$ region. Further, the concerned region is divided into square shaped compartments in such a manner that the length of each square's side (D) is equal to one tenth of the length of the area to be monitored (L).

$$D = 2 \times DOF = \frac{L}{10} \quad (6)$$

Where, D: Side length of each compartment and L:Length of the monitored area (500 m)

The side length of each compartment is chosen as (2 × DOF) so as to minimize the amount of overlapping among FOVs of actuated cameras, while selecting scalar premiers intellectually in each of the compartments for getting effective results. Since we have used omni-directional cameras, thus, the diameter along which it captures image of any object is (2 × DOF). Hence, the value of side length of each compartment is taken as twice of DOF value so that reduced number of cameras will be activated, while ensnaring larger amount of unique area. In our context, DOF value is taken as 25 m during implementation. Hence, (2 × DOF) value is 50 m, which is equal to (1/10)th of the length of the monitored region.

In each of the squared compartments, three scalar cluster premiers are selected as discussed in Section I which is portrayed in Fig. 1. Scalar Cluster Premiers or Scalar Premiers (SPs) are the scalars belonging to any of the compartments of the monitored event region. The SP acts as the chief representative of its neighboring scalars, which represent a cluster belonging to that particular compartment. A scalar premier called Primitive Cluster Premier (PCP) is selected in each of the compartment of the monitored region in such a way that it has lowest mean distance among all the scalars pertaining to that particular compartment. The line joining the central point of the concerned compartment with the coordinate position of PCP is chosen as the Base line. Subsequently, the Secondary Cluster Premier (SCP) is selected from the PCP such that it is present at farthest distance from the PCP at an angle 60° along counterclockwise direction from the coordinate position of PCP across the Base line.

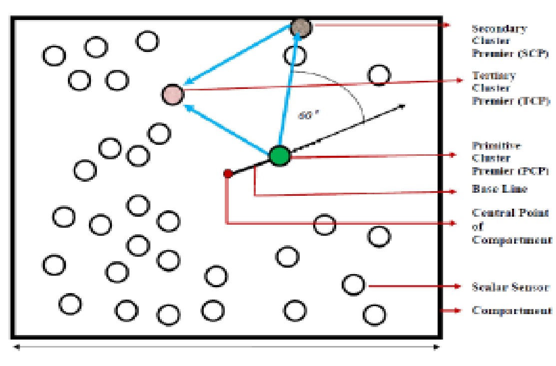


Figure 1: Selection of scalar premiers in a compartment in proposed DT-SCPS approach

Afterwards, a Tertiary Cluster Premier (TCP) is selected, which is the scalar premier whose average mean distance from both PCP and SCP is the smallest among all the scalars belonging to the concerned compartment. In this manner, three scalar cluster premiers are selected in each of the compartments. The set of sensors including the three selected scalar cluster premiers, which belong to the same compartment are regarded as the Compartmental Members (CMs).

(b) Phase 2: Event Occurrence and Addressing

At the beginning of this phase, an event takes place and the scalar premiers (i.e. PCPs, SCPs, TCPs) present at the event region detect the event on behalf of their scalar sensing neighbors. Two sensors i and j are said to be Sensing Neighbors, if their Euclidean distance Dist(i, j) < 2RS [11], where RS is the sensing range of the sensors.

Based on the scalar premiers from whom a camera receives the event information, the cameras are categorized into two types: Layer Apprised Camera (LAC) and Non-Layer Apprised Camera (NLAC). LAC is the camera that is informed regarding the event information from scalar premier(s) belonging to the same layer (i.e. compartment). However, NLAC is the camera that is informed regarding the event information from scalar premier(s) belonging to some other layer than the concerned camera sensor.

When event takes place, each scalar premier reports its corresponding camera regarding the occurring event by sending the Event Detect (ED) message. ED is a message that is sent by a scalar premier to a camera sensor, when the scalar premier detects an event. The ED message consists of the id, location information of concerned scalar premier and the occurring event information. Moreover, the corresponding camera represents the camera within whose FOV the scalar premier lays. Subsequently, the cameras calculate their Compartmental Cluster Count (CCC) and Non-Compartmental Cluster Count (NCCC) values. Afterwards, their respective Total Cluster Count (TCC) values are updated accordingly. Thus, the sum of all the compartmental and non-compartmental cluster members is currently available with each of the cameras.

(c) Phase 3: Camera Collaboration and Actuation

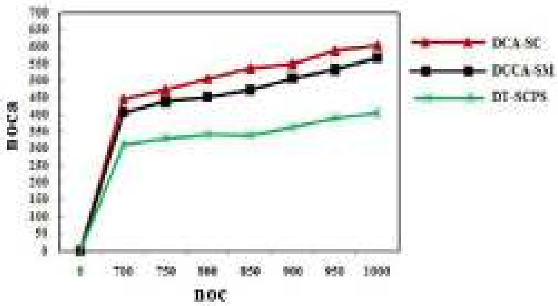
In this phase, each camera broadcasts a message called Scalar Cluster Premier Count Message (SCPCM) which contains their respective TCC values and ids. Each of the cameras now knows each other's TCC values and updates their OL accordingly. However, the condition is that ids of only those cameras are added to Ordering List, which has positive TCC values. The camera from which no SCPCM is received, its id is removed from the Waiting List and the concerned camera is decided to be kept in turned off condition as the camera is not going to capture the occurring event information.

The camera that comes first in the Ordering List is activated first. Subsequently, the activated camera broadcasts UCPM message to rest of the cameras. This message contains the ids of event detecting scalar premiers present within the DOFs of the activated cameras. The ids of scalar premiers maintained in UCPM are then added to CBCPL. Afterwards, the camera which comes next in the Ordering List i.e., the camera having next highest TCC value compares the ids of scalar premiers present in UCPM with the ids of scalar premiers present in its EDCP table. If the ids of scalar sensors of both the cameras match completely, then the camera is not activated. In case a mismatch is noticed, then the concerned camera having next highest TCC value undergoes activation. Its id is then immediately removed from the Waiting List as well as Ordering List and it is added to Current Activation List (CAL), which contains the ids of activated cameras. Such matching and mismatching process of SP ids continues till the Ordering List becomes empty. At this point of time, the number of cameras present in the CAL gives the total number of activated cameras i.e. Active Camera Count (ACC) value in the proposed DT-SCPS approach.

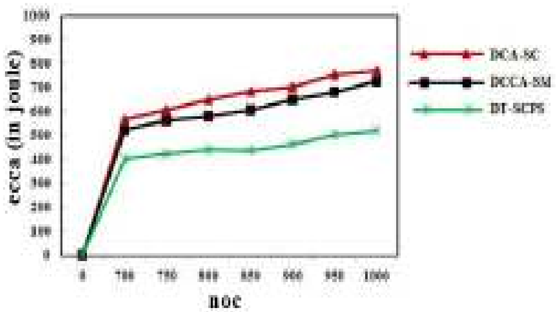
SIMULATION AND PERFORMANCE EVALUATION

In this section, we have developed a customized simulator written in C++ to evaluate the performance of the proposed DT-SCPS approach. The performance evaluation of our proposed system has been carried out based on the following assumptions: (i) all the sensors are randomly deployed, (ii) the sensing range of scalars and FOVs of cameras are considered to be circular, (iii) the sensors are assumed to have fixed positions. (iv)all the sensors are assumed to be time synchronous. (v) all the messages are assumed to be broadcasted sequentially. The DOF value is taken as 25 m while varying the number of camera sensors and the sensing range of scalars is taken as 10 m throughout the implementation. We have varied the number of cameras and observed their effect on the number of cameras activated in case of DCA-SC [1], DCCA-SM [2] and our proposed approach DT-SCPS. The comparative performance assessment is done on the basis of the following performance metrics:

(a) number of cameras activated, (b) energy consumption for camera activation. (c) coverage ratio, (d) event-loss ratio, (d) redundancy Ratio, (e) field of View Utilization.



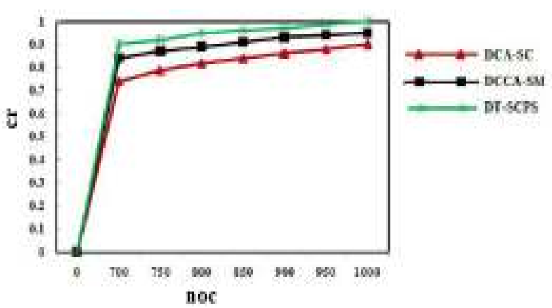
2(a)



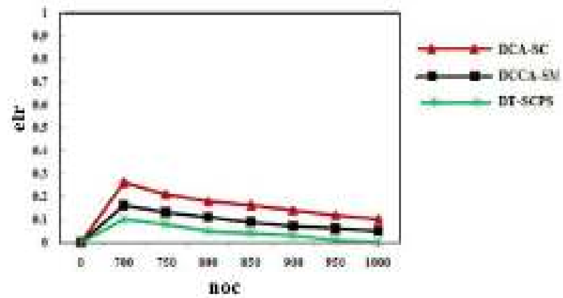
2(b)

Figure 2: Effect of varying number of cameras (noc) on (a) number of cameras activated (noca) (b) energy consumption for camera activation (ecca)

We have varied the number of camera sensors (noc) and observed its effect on number of cameras activated (noca) as shown in Fig. 2(a). It is evident from the figure that with increase in noc the noca rises gradually in all the cases. Further, since the noca is found to be the minimum in case of proposed approach. Hence, the amount of energy consumption for camera activation (ecca) is the least in our case as shown in Fig. 2(b). Fig. 3(a) portrays the effect of varying the noc on coverage ratio(cr) in case of all the approaches.



3(a)



3(b)

Figure 3: Effect of varying number of cameras (noc) on (a) coverage ratio (cr) (b) event-loss ratio (elr)

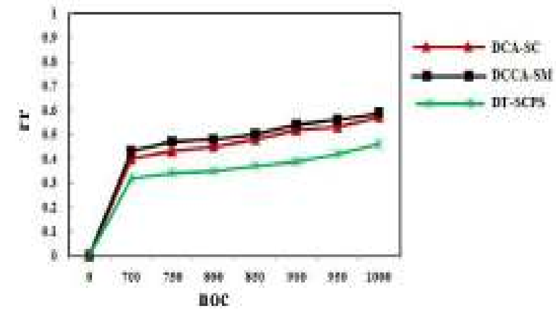


Figure 4: Effect of varying number of cameras (noc) on Redundancy ratio (rr)

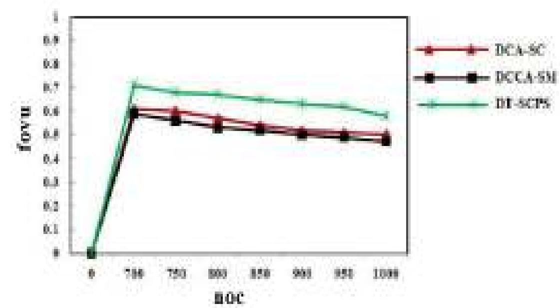


Figure 5: Effect of varying number of cameras (noc) on field of view utilization (fovu)

It is noticed that with increase in noc the value of cr rises in all the cases and is found to be the maximal in case of proposed DT-SCPS, affirming more distinct event area coverage than the other approaches. The effect of variation of noc on event-loss ratio (elr) is represented in Fig. 3(b). Since the cr is found to be the maximum in case of DT-SCPS, hence information loss minimization is achieved by our approach. Further, it is observed that with increase in noc the values of rr rises in all the approaches as shown in Fig. 4 and it is observed to be the minimum in DT-SCPS. In addition, Fig. 5 shows the effect of varying noc on field of view utilization (fovu), which is found to be the maximum in our case, thereby ensuring less amount of redundant data transmission in the proposed approach.

CONCLUSION

This research paper presents a novel algorithm called Distributed Triangular Scalar Cluster Premier Selection (DT-SCPS) that segregates the whole geographic region under consideration into several compartments and chooses three scalar premiers effectually in each of the compartments in such a manner that the cameras actuated by them provide enhanced event area coverage along with reduced redundant data transmission while ensnaring information regarding the occurring event. Experiments were carried out to evaluate the efficacy of the proposed system DT-SCPS while conducting comparative analysis with two other parallel methods, namely, DCA-SC and DCCA-SM. The experimentation was carried out while varying the number of cameras and observing their impact on several important performance metrics. The investigation results demonstrate the supremacy of DT-SCPS over the other approaches with regard to reduced camera activation, enhanced coverage ratio, least event-loss ratio, minimized redundancy ratio, improved field of view utilization as well as lowered energy expenditure for camera activation.

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