A Realistic Coverage Model with Backup Set Computation for Wireless Video Sensor Network

Vijay Ukani, Keyur Patel and Tanish Zaveri

Abstract—**Wireless Video Sensor Network (WVSN) are gaining increasing popularity due availability of low-cost CMOS camera and miniaturization of hardware. For many applications, it is difficult to have a pre-engineered deployment of video camera sensors which leads to redundancy. Owing to sectored coverage and random deployment, it becomes challenging to model video sensor coverage to find redundancy and suppress redundant video transmission. Several efforts have been made to model coverage redundancy considering 2-dimensional coverage. Field of View (FoV) of the camera sensor is in 3-dimensions, thus it is very difficult to model the coverage and identify overlap area for realistic camera. 3-dimensional coverage is largely an unexplored problem. In this paper, a realistic 3-dimensional pyramid camera coverage is assumed and backup set of nodes are computed. Backup set of a node is a set of video sensor nodes that collectively covers coverage area of the node under consideration. The approach presented in the paper identifies minimal cardinality set of backup nodes that can be used to adaptively duty cycle the video capture and transmission. The result shows that the number of nodes required to remain active to cover the sensor field is reduced and in turn average energy consumption of the network also reduces.**

Index Terms—**Video Sensor Networks, 3-D coverage, Backup set Computation, Energy Efficiency, Redundant Deployment, Node Duty Cycling**

I. INTRODUCTION

Video Sensor has gained significant attention towards the research in recent years due to miniaturization of hardware and availability of low cost CMOS camera. Available bandwidth needed for video transmission over resource constrained WSN has also increased with advancement in technology. Wireless Video Sensor Network (WVSN) has wide range of applications specifically in surveillance. It can complement any application deployed with traditional sensor with provision visual coverage of the phenomenon leading to reduction in false alarm rate and increasing accuracy.

Most of the deployment of WSN are in hostile environmental conditions which makes replacement/replenishment of batteries difficult or infeasible. Thus network lifetime and hence energy consumption will always remain an open issue to optimize. Video Sensor node consist of small size camera sensor to monitor the area. It encodes the captured video and forward the packet to the base station. Major source of energy consumption in the process is raw video capture by camera

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sensor, encoding of raw video stream, and communication effort required to transmit compressed video to base station. In many applications, pre-engineered deployment may not be feasible leading to random orientation of camera nodes which leads to certain area of the field be covered by multiple camera. Also video transmission is bandwidth and energy hungry due to high volume of data. Redundant deployment and coverage exaggerates the problems. In case of any event in the area with overlapping camera coverage, event information will be captured and transmitted by multiple nodes. Identification of this overlap and exploiting it in controlling the capture/transmission can help in alleviating the problem of energy consumption.

A typical architecture of WVSN has video sensor nodes along with other standard sensors useful for monitoring the phenomenon (refer Fig. 1). They work collaboratively to report the event information over multiple hop to the sink node which in turn sends the information to monitoring node.
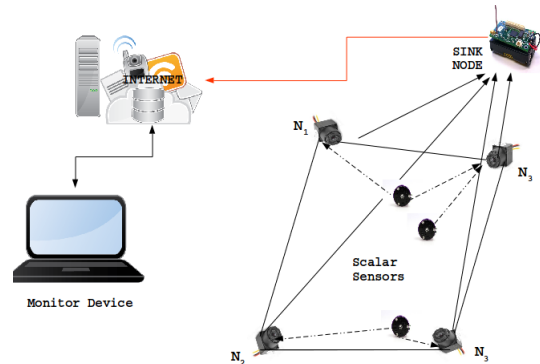

Fig. 1: Wireless Multimedia Sensor Network

Several areas for the increasing the network life time and achieving energy efficiency includes scheduling of the video capture, efficient routing protocol, minimization of the data processing etc. Several energy and QoS aware routing protocols[1], [2], [3], [4], [5], [6] were proposed in literature to achieve energy efficient, reliable and real time communication. Several efforts have been made to model capture region of camera node and identify backup set of node assuming 2-dimensional coverage[7], [8]. This backup set information along with several other parameters can be used to adaptively duty cycle the camera capture rate, reducing number of nodes that are required to remain active.

Capture region of a camera is called as Field of View (FoV) as shown in Fig. 2. If a node has the sufficient number of the backup set node that cover some threshold say 90% of the FoV,

the node can reduce the frame capture rate or stop capturing altogether. Frame rate of camera has direct effect on quality as well energy and bandwidth requirement. Increase in number of nodes with backup set, reduces the frame capture rate of the video node and increase the life of the Video sensor.

Several efforts have been made for computing backup set assuming 2D coverage model[8], [7], [9], [10] where the FoV of a node is modeled as a triangle with Angle of View (AoV) being the angle of triangle and Depth of Field (DoF) being the height. However 2D modeling of FoV does not represent practical camera coverage. A 3D camera FoV model was proposed in [11] where FoV was assumed to be of cone shape. An efficient method for identifying nodes with overlapping coverage with 3D coverage is proposed in this paper. The proposed model identifies a minimum sized set of nodes and still covering significant 3D area of a Video Sensor node. The goal of the paper is computation of backup set assuming 3D coverage model and exploiting the backup set information in controlling the FPS of the camera module.

II. COVERAGE MODEL

The 3D FoV of a camera node is defined by horizontal and vertical AoV, Depth of View, position of camera in 3D space and orientation of camera. The coverage area is modeled as pyramid as shown in Fig. 2. FOV of the Sensor camera depends on the AoV (angle between two horizontal ends and Vertical ends). DoF is the distance between the camera location and the end point of its range. DoF can be infinite but it is assumed to be finite value as the object captured by camera should be sufficiently large and clear enough to be identified.
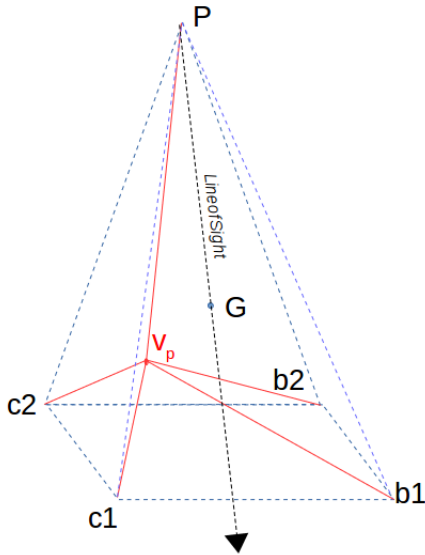

Fig. 2: FoV of video sensor

Point P is position of the camera node $P(x, y, z)$. θ_v and θ_h are vertical and horizontal AoV. Points { c_1, b_1, c_2, b_2, G } can be computed using the DoF, AoV and the position of the camera node as described in next section. Point G indicates

the center of gravity of the pyramid. V_p is a arbitrary point inside FoV of node V.

III. BACKUP SET COMPUTATION

All corners of pyramid is computed with respect to the given $LineOfSight$, the direction of camera and AoV, DoF. The volume of the pyramid is computed as in Eq. 1. where l is distance between c_1 and c_2, w as distance between c_1 and b_1, height is the distance between P to base plane.

$$V = \frac{l * w * height}{3} \tag{1}$$

V_p is arbitrary point present in the FoV of Node V. It forms 4 tetrahedrons with four sides of the pyramid. One of them is (P, V_p, c_1, c_2). Volume V_i of tetrahedron i is computed as in Eq.2.

$$V_i = \frac{\sqrt{2}}{12} * h * Area_{base} \tag{2}$$

where h is the height from apex P to respective base plane. V_{temp} is total volume of computed by adding volumes of all tetrahedrons and pyramid created with V_p.

$$V_{temp} = V_{base} + V_i \ for \ i = 1 \ to \ 4 \tag{3}$$

Where V_{base} is the volume of pyramid with apex as V_p and base plane as c_1, c_2, b_1, b_2. Eq. 4 tests presence of point V_p within FoV of a node and returns true or false accordingly.

$$f(FoV, V_p) = \begin{cases} true, & \text{if } V = V_{temp}. \\ false, & \text{otherwise.} \end{cases} \tag{4}$$

Now node can test presence of a point within FoV.

IV. PROPOSED APPROACH

Due to random deployment most of the nodes have overlapping coverage with other nodes. Computation of this overlap for 3D becomes a momentous task. Goal of the proposed model is to compute percentage overlap between FoVs different nodes and then backup set which is set of nodes which collectively covers the significant part of FoV.

Every video node is required to exchange its FoV parameters with its neighbors. FoV includes $(p, b_1, b_2, c_1, c_2, G)$ where p is position and remaining are corner points of the FoV and G is center of gravity of FoV. Backup set of a node should cover more than certain threshold of total FoV of the said node. In order to assure the same, all corner points of FoV should be covered by other nodes. Fig. 2 shows the location of points. Each Node V compute the following sets from the neighbor's locations and the FoV.

$P|G = \{v' \in N_v : v' \text{ covers points } p|g\}$
$B = \{v' \in N_v : v' \text{ covers points } b_1 \text{ and } b_2\}$
$C = \{v' \in N_v : v' \text{ covers points } c_1 \text{ and } c_2\}$
$PG = \{P \cap G\}, BG = \{B \cap G\}, CG = \{C \cap G\}$
$Gg = \{$nodes with their point g in v's FoV and covering node v's point g$\}$
where N_v is set of neighbor nodes.

The coverage of a point within FoV is determined by Eq. 4. All nodes present in the computed set have overlapping with

node V. In order to compute 3D overlap as shown in Fig. 3, random points are generated within the range indicated by Eq. 5 and Eq. 6. These points are tested for its presence within FoV of node V and in case of within FoV of V, tested for its presence in other node. Percentage of such points determine the percentage overlap.

$$(x|y|z)_{min} = min(x|y|z \; coordinates \; of \; all \; FoV \; points) \tag{5}$$

$$(x|y|z)_{max} = max(x|y|z \; coordinates \; of \; all \; FoV \; points) \tag{6}$$

Computation of backup set requires set of nodes with overlap greater than defined threshold. In order to compute backup set of size 3, Cartesian product of 3 sets CG, BG and PG ($\{BG \times CG \times PG\}$) is computed[7]. Percentage overlap is computed using the same method as described earlier but now rather than using single node, complete set of nodes are used. Any backup set with overlap less than threshold is discarded from the selected set.

For the enhancing the lifetime of network, it desired to keep minimum number of active nodes and still cover maximum area. There are possibilities where one or two nodes covers the FoV of node. Small sized backup set will help the node to duty cycle more, as less number of nodes are to required remain active. Instead of making it mandatory to include all three corner points in the backup set, the proposed approach explores small backup set with overlapping coverage area greater than defined threshold.
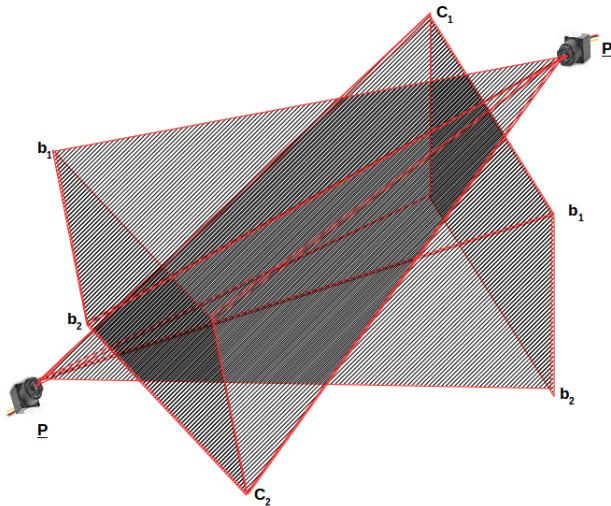

Fig. 3: Overlap between two nodes

Fig. 3 demonstrates overlapping area of the two camera sensor node. It shows that G point(Center Point of the pyramid) is covered in each other's FoV. FoV of node V is almost fully covered by single node v_1. Similarly in Fig. 4 node V is almost fully covered by node $v_1 + v_3$ as well as $v_2 + v_3$ forming a backup set of size 2. Eq. 7 computes backup set with size 2 or size 1. Size 2 backup set has two nodes from different set, one from Gg and other from MAX. Backup set

of size 1 computed when Node id v_i is common in both the sets and area cover by v_i is more than threshold.

$$BS(v) = Gg \cup MAX \tag{7}$$

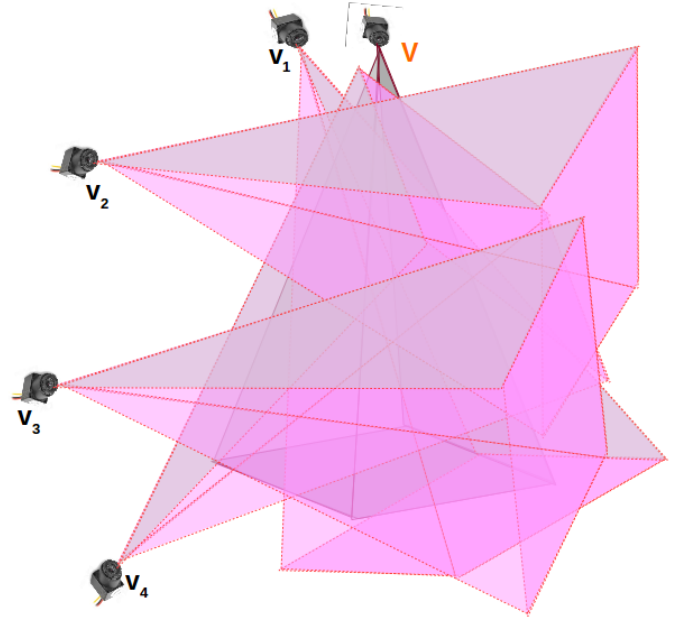where $MAX = max_{area}\{PG, BG, CG\}$

Fig. 4: Backup set $\{v_1\}$ of size one

The proposed method also explores the nodes which has the standalone backup set. This type of backup set is part of Gg or MAX and covering more than threshold requirement.

In Fig. 4 node V is covered by neighbor nodes v_1, v_2, v_3, v_4. Node v_1 covers point G of Node V and it also cover more than 85% area of the node V. Node v_1 is also cover c_1, c_2 of node V. Remaining nodes can be part of the backup set. Node v_4 cover only G point of node V. Node v_3 cover all the base points of the node V. Here node v_2 is also part of the backup set computation. From all the information final back up set of node V can be $\{\{v_3, v_5\}, \{v_2, v_5\}, \{v_1, v_5\}, \{v_1\}\}$. Here all the backup set has the size 2 or 1.

V. SIMULATION RESULT

The performance of proposed algorithm was evaluated in OMNeT++ based Castalia simulator. $M3WSN$ framework[12] which is extension to Castalia was used to support video sensor coverage modeling. TABLE I summarizes simulation scenario.

The Simulation was repeated 15 times to reduce variability in results due to randomness. Node density was altered by varying nodes from 75 to 175. After computation of FoV each node has its own FoV coordinates. Initialization of the node is varied so as to avoid the collision in the network. In Random time interval each node receives the information regarding neighbor node and FoV locations. In second phase each node start computation of backup set. Results of backup set size

Parameter	Value
Simulation Time	600sec
Sensor field	$75m \times 75m \times 75m$
Deployment	Random
No of nodes	varied from 75 to 175
Depth of Field	15m to 30m
Angle of View(AoV)	$36\,^{\circ}$ and $60\,^{\circ}$
Line of Sight	Random
Initial Energy	18720J

TABLE I: Simulation Setup

depend on the number of points covered by the neighbor node with highest overlap percentage area.

The result were collected with different horizontal AoV and varying the DoF. Ideally number of nodes to be deployed in the sensor field should be function of AoV and DoF. The objective is to just cover the sensor field with minimum number of nodes. If the nodes are uniformly placed in the field, number of nodes required to cover whole area will be $Field\_Area/Area\_of\_FoV$. As the nodes are deployed randomly there will be some overlap which need few more nodes than the computed value.

TABLE II and III compares the results by varying the number of nodes based AoV and DoF. Nodes with backup set can reduce their frame rate while other nodes continue to transmit video at full rate. Increasing of the AoV and DoF requires less number of nodes to cover sensor field. Increasing density of deployment increases chances of getting more number of backup set. Results embodied in the table is for minimum number of nodes required to cover sensor field in ideal scenario but deployed randomly which results in overlap. Area covered by all nodes together also varies with different size of AoV and DoF. Increase in number of node increases area covered and number nodes getting backup sets. Increase in number of nodes with backup results in decrease in average energy consumption. This is due to the fact that nodes with backup can safely assume that their FoV is covered by other nodes and thus they can reduce their frame rate, resulting in lesser energy consumption for such nodes.

The ultimate objective of most WSN or surveillance application is to prolong the life time of network/application. For a surveillance application, it is important to continuously capture and transmission video frames. In case redundant capture only, a node reduces the frame rate. Video encoding plays an important role in determining energy consumed for transmission. Several video encoding techniques are available for video encoding. However distributed video coding based Wyner-Ziv encoding suits best for wireless video sensor notwork due to simpler encoding and complex decoding[13]. Energy consumption of various frames of WZ encoding is used for the simulation[14].

TABLE IV compares overall sensor field area covered and energy consumption. Without computing and using backup set approach network, average consumed energy is more than with backup set. With backup set there are different approach with size of backup set. Backup set size directly affects the average energy consumed of the video node. Few approaches to compute backup set size with 3 for 2-D space exists in
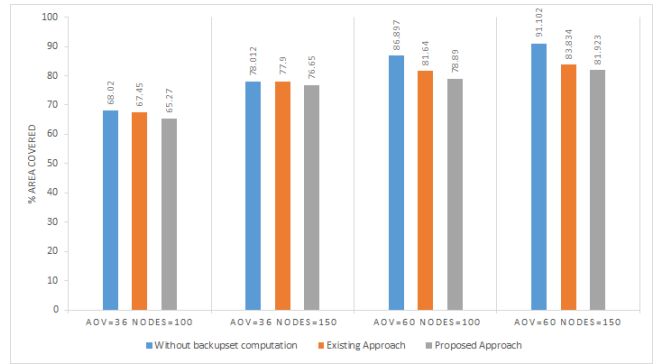

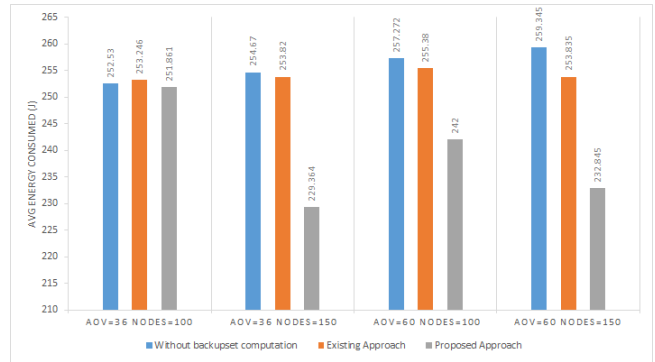Fig. 5: Percentage Area Covered

Fig. 6: Average Energy Consumed

literature. The same is reproduced for 3-D space. In proposed approach some of the back up set are of size 2 or 1. The table compares the backup set size of two with that of three. As it is difficult to have 3 nodes with sufficient overlapping with other nodes, less number of nodes gets the backup set while with backup set of size one and two, more nodes gets the backup set and thus can be duty cycled more, resulting into lesser energy consumption as shown in Fig. 6. With proposed approach more number of nodes gets the backup set and hence the average energy consumed is also less. At the same time due to some nodes assumed to be duty cycled, the overall area covered reduces as shown in Fig. 5 creating tradeoff between area covered and energy consumed.

VI. CONCLUSION

Modeling camera coverage as 3-dimensional FoV is more realistic for video camera sensor. A realistic 3-D FoV along with methods for computing backup set was proposed in this paper. Methods for finding backup sets with cardinality one, two and three were described. The observation is more the number of nodes with backup set, more are the chances of duty cycling of the node. This will decrease the energy consumption and in turn increase the lifetime of the network. The percentage area covered decreases with increase in the number of duty cycled nodes presenting a tradeoff with energy consumption.

The work can be extended to exploit the energy reserves of nodes in selected backup set and intelligently schedule duty cycling of nodes.

No of Nodes	DoF	Avg. Consumed Energy	Area Covered (%)	No of backup set
137	15	247.265	58	4
77	20	249.004	56	2
50	25	253.786	53	1
35	30	252.453	51	1

TABLE II: 3D Field coverage of $100m \times 100m$ and AoV $36\,^{\circ}$

No of Nodes	DoF	Avg. Consumed Energy	Area Covered (%)	No of backup set
70	15	248.709	69	2
40	20	246.312	55	3
26	25	251.17	54	1
20	30	253.191	57	0

TABLE III: 3D Field coverage of $100m \times 100m$ and AoV $60\,^{\circ}$

Angle of View	No of Nodes	Without backup set computation		Existing Approach			Proposed Approach		
		Area Covered %	Avg Energy Consumed (J)	Area Covered %	Avg Energy Consumed (J)	No of backup set	Area Covered %	Avg Energy Consumed (J)	No of backup set
$36\,^{\circ}$	100	68.02	252.53	67.45	253.246	0	65.27	251.861	3
	150	78.012	254.67	77.9	253.82	2	76.65	229.364	7
$60\,^{\circ}$	100	86.897	257.272	81.64	255.38	1	78.89	242	5
	150	91.102	259.345	83.834	253.835	2	81.923	232.845	19

TABLE IV: Percentage area covered and performance comparison of proposed approach

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