This is the pre-peer reviewed version of the following article: Distributed topology management for wireless multimedia sensor networks: exploiting connectivity and cooperation, which has been published in final form at https://doi.org/10.1002/dac.2770. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Use of Self-Archived Versions.

Distributed Topology Management for Wireless Multimedia Sensor Networks: Exploiting Connectivity and Cooperation

Sudip Misra, *Senior Member, IEEE,* Goutam Mali, Ayan Mondal
School of Information Technology, Indian Institute of Technology, Kharagpur, India
Email:{smisra, goutam.mali, ayanmondal}@sit.iitkgp.ernet.in

Abstract

In this paper, we propose a distributed topology management algorithm, named *T-Must*, which orchestrates coalition formation game between camera and scalar sensor nodes, for use in wireless multimedia sensor networks. In the proposed solution, connectivity among the peer camera sensor nodes is maintained and coverage is ensured between them. Only the scalar data are not sufficient to describe an event in a particular monitored area. In many cases, multimedia data (specifically, video data) are required to provide more precise information about the event. As the camera sensor nodes, which sense and transmit multimedia data, are costlier than the scalar sensor nodes, the former are deployed in the monitored area in lesser numbers compared to the latter ones. In case of camera sensor nodes, power consumption due to sensing is also significant, similar to power consumption for the transmission and reception of packets. Therefore, in this work, in order to increase the network lifetime, topology is controlled by forming coalition between the camera and scalar sensor nodes. Upon occurrence of an event, the scalar sensor nodes send scalar data to their associated camera sensor nodes. If the scalar data received from scalar sensor nodes cross a pre-configured threshold, the associated camera sensor node in the coalition starts sensing the event, captures the video data, and forwards the video data towards other coalitions or sink.

I. Introduction

This paper addresses the problem of topology management in a wireless multimedia sensor networks (WMSN). Usually, a WMSN deployment consists of a combination of different camera sensor nodes, or camera sensor nodes in conjunction with scalar sensor nodes (e.g. temperature, light, and motion sensor node) [1–5]. However, in many WMSN applications, it is required to have video data from the monitoring area. The physical scalar data are not sufficient enough to throughly monitor events such as forest fire, intruders, toxic gases, or location detection of survivors in a rescue operation in the monitoring area. Video data are more informational than the simple scalar data. The following examples motivate how video data help to monitor a region under observation.

Sudden accident in coal mine can increase temperature, and the level of CO_2, methane, and other gases. Using only scalar sensor nodes, it is difficult to know the condition of the affected people in the monitored region. However, if camera sensor nodes are present, they can capture the video of the event region and send such information to the base station. So, video data can provide better monitoring of the affected region.

Video data enable end users to visually identify the real impact of an event, be conscious of what is happening in the environment, and plan actions accordingly, to detect objects, intruders, or analyze scenes. Due to sensing, transmitting, and other communication mechanism, energy constraints in the camera sensor nodes (CSs) are stricter [1] than those in the scalar sensor nodes (SSs), because video content creates a huge amount of data that has to be processed, transmitted, and forwarded.

Along with transmission, sensing also consumes substantial energy in case of camera sensor nodes [6], [7]. So, in order to prevent continuous sensing of a monitored area, a camera sensor node is triggered for sensing and transmission of video data in case of special events, based on scalar data measurements taken by the scalar sensor nodes. As both the scalar and camera sensor nodes are scatteredly deployed over the whole region, the mapping between such sensor nodes is a crucial aspect of study. Large amount of energy is expended on communication involving video data. Consequently, congestion is triggered, which, in turn, leads to packet loss. It incurs energy consumption of the nodes unnecessarily, thereby reducing network lifetime. To avoid such unwanted circumstances, we propose coalition formation involving scalar and camera sensor nodes using *coalition formation game*, so that a subset of scalar sensor nodes reports to a particular camera sensor node. In each coalition, one camera sensor node acts as a coalition head (CH) and a subset of scalar sensor nodes plays as coalition members (CM). We also ensure connectivity among camera sensor nodes and full coverage by them.

The remainder of the paper is organized as follows. Section 2 summarizes the related work. Section 3 states the energy consumption model for message transmission and reception. In Section 4, we state the deployment of both CSs and SSs, and problem overview. In Section 5, we provide system model. Topology maintenance is illustrated in Section 6. In Section 7, we discuss simulation setup and performance evaluation of the proposed approach considering different performance metric. Finally, Section 8 concludes the paper.

II. Related Work

There are many different ways to extend the network lifetime of WMSNs at network protocol and device levels. In this Section, we discuss only the approaches related to the proposed method. The proposed approach is based on coalition formation of heterogeneous nodes consisting of scalar and camera sensor nodes. In each coalition, the scalar sensor nodes sense and transmit scalar data to camera sensor node upon occurrence of an event. When an anomaly occurs, associated camera sensor nodes sense and transmit video data. This increases the lifetime of the network by not unnecessarily surveilling the monitored field continuously with network cameras.

A number of clustering algorithms are proposed in the last few years. They only considered generating minimum number of clusters to enhance network lifetime and data throughput [8–11], and provide load balancing [12], [13] and fault tolerance [14]. Since the sensing coverage of the cluster heads, and in most cases, the connectivity among them, is not a major concern in WSNs, none of these clustering algorithms is designed to select cluster-heads in the process of achieving maximum coverage. In our case, coverage, connectivity, and network lifetime maximization are the main objectives. In [15], topology discovery and management is considered by selectively activating optimum number of nodes by applying Markov Decision Processes (MDP). As the proposed approach in our work considers both CSs and SSs, the approach proposed in [15] cannot be applied.

To increase the network lifetime, different MAC-level protocols [16–20] are proposed for saving limited battery power. In a work [21] by Tseng *et al.* , a network-layer protocol is taken into consideration only to prolong the lifetime of the nodes in the routing path computed. None of these protocols considers how the overall network lifetime can be improved. They do not take into account coverage and connectivity, whereas the proposed protocol considers network lifetime, coverage, and connectivity.

Misra *et al.* [22] considered the coverage of the monitored region and connectivity among the homogeneous sensor nodes. This algorithm is not designed for use in WMSNs having heterogeneous sensor nodes in terms of circuit complexity, battery power, and so on.

Dai and Akyildiz [23] studied the camera selection problem. This work considers the interaction between the scalar and camera sensor nodes. It focuses on camera orientation and how the orientation contributes to entropy. Upon the occurrence of an event, the set of cameras providing the highest entropy is chosen as candidates for transmitting data to the sink. On the other hand, the SensEye [24] project considers the deployment of scalar sensor nodes, and Pan Tilt Zoom (PTZ) cameras, and explore the problem of dynamic camera actuation. Vibration sensor nodes are used to detect moving objects and activate the necessary cameras to record the event. Three levels of camera (from CMUCam to PTZ) are used. Instead of focusing on the event coverage issues for redundant data elimination, SensEye focuses primarily on the quality of object tracking. In addition to this, it can be applied only indoors, where there are no energy constraints.

Andrew and Kemal [25] studied the problem of distributed camera actuation. The camera and scalar sensor nodes are randomly deployed. The camera sensor nodes, which obtain event information, exchange their FoVs with their neighbors, before they decide to be actuated. The size of the event area is determined by counting the number of scalar sensor nodes. Based on this information, the camera sensor nodes which hear from higher number of scalar sensor nodes, are given higher priority in actuation. The nodes with lower priority need to wait to hear from other camera sensor nodes about the spot already covered by them. The camera sensor nodes are randomly deployed and their connectivity is not ensured. Also, due to random deployment of camera sensor nodes, the full coverage of the event cannot be ensured.

Peiravi *et al.* [26] proposed multi-objective two-nested genetic algorithm, named Strength Pareto Evolutionary Algorithm (SPEA), to get optimum clustering of homogeneous WSN. It works well compared to LEACH and other GA-based clustering methods. However, it cannot be used in our case, as in our topology, heterogeneous sensor nodes are considered, and ensuring event coverage is an important aspect.

Madani *et al.* [27] consider two routing protocols which work well both for static and mobile WSN. It provides high network lifetime, high packet delivery ratio, and high network throughput. However, heterogeneous networks involving CSs and SSs are not considered. Using this clustering approach, the coverage of the event occurrence cannot be ensured. So, it cannot be used for our proposed WMSN topology.

III. Energy Consumption Model

Energy consumption in wireless sensors is measured based on transmission and reception [28].

$$P_T(d) = P_{T0} + P_A(d) = P_{T0} + \frac{P_{Tx}(d)}{\eta}$$
$$P_R = P_{R0} \tag{1}$$

where P_T and P_R denote the power consumption due to transmission and reception, respectively, P_A is the power consumption of the power amplifier, d is the distance between the transmitter and receiver, P_{T0} and P_{R0} are the power consumption of the transmitting and receiving circuitry, respectively, P_{Tx} is the output power at the antenna which depends on the distance d, and η is the drain efficiency of the power amplifier.

Considering a channel in which path loss is predominant, and secondary effects such as multipath and doppler are negligible, the received power at the receiver at distance d from the transmitter is given by:

$$P_{Rx} = \frac{P_{Tx} \times G_{Tx} \times G_{Rx} \times \lambda^2}{(4\pi)^2 \times d^\alpha \times L}; \tag{2}$$

where, P_{Tx} is the transmitted power, G_{Tx} is the transmitter antenna gain, G_{Rx} is the receiver antenna gain, L (≥ 1) is the system loss factor, λ is the wavelength in meters, and α is the path loss exponent. For free space, the value of α is 2 dB. The gain of an antenna is related to its aperture A_e by:

$$G = \frac{4 \times \pi \times A_e}{\lambda^2}. \tag{3}$$

G_{Tx} and G_{Rx} are dimensionless quantities. The system loss factor (L) is due to the transmission line attenuation, filter losses, and antenna losses in the communication system. When there is no loss in the system hardware (i.e., $L = 1$), the received power P_{Rx} can be expressed as:

$$P_{Rx} = \frac{P_{Tx}}{A \times d^\alpha}; \tag{4}$$

where A is determined by $\frac{(4\pi)^2}{G_{Tx} \times G_{Rx} \times \lambda^2}$. From Equations (1) and (4), we can determine the power consumption for transmission between two nodes as follows:

$$P_T(d) = P_{T0} + \frac{P_{Rx} \times A \times d^\alpha}{\eta}. \tag{5}$$

Considering $\xi = P_{Rx_{min}} \times A$, where $P_{Rx_{min}}$ is the minimum reception power for a variable communication, the minimum power consumption to transmit data from one sensor node to another is given by:

$$P_T(d) = P_{T0} + \frac{\xi \times d^\alpha}{\eta}. \tag{6}$$

So, the minimum energy consumption to transmit a packet of N bits from one sensor node to another with a constant

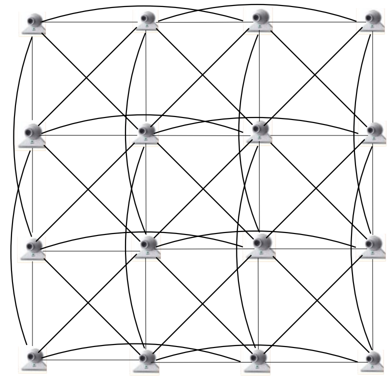


Fig. 1: Grid based deployment of camera sensors

data rate R is given by:

$$E_T(d) = \frac{P_T(d) \times N}{R}. \tag{7}$$

Similarly, energy consumption to receive a packet of N bits by a sensor is given by:

$$E_R = \frac{P_R \times N}{R}. \tag{8}$$

IV. Node Deployment and Problem Overview

A. Deployment of Camera Sensor Nodes

CSs are deployed in a grid-based architecture over the whole region, so that they are positioned at the grid intersection, and can interconnect with their peers. To preserve full sensing coverage of the entire area under observation, the side of each grid is considered to be equal to the sensing range of the CSs. It is assumed that the transmission range of a sensor node is at least twice its sensing range. So, each CS can communicate with many other CSs in its surrounding. After CSs deployment, the grid structure made of CSs looks as shown in Fig. 1.

B. Connectivity of Camera Sensor Nodes

We use the following three communication primitives:

- *broadcast* (u, m) : It is used by node u to send a message m with power p_{max}, which is the maximum power cost for transmission. It results in all nodes in the set $\{v|p(d(u,v)) \leq p_{max}\}$ receiving m.
- *send* (u, v, m, p) : It is used by node u to send message m to v with power p. This is used for point-to-point communication.
- *receive* (u, v, m) : It is used by node u to receive message m from v.

After the deployment of CSs, their connectivity plays a major role in maximizing the network lifetime. The larger the transmission power, the more is the energy cost for communication, and the more is the interference caused at the other nodes. To reduce transmission power and also the effect of interference to the other nodes, a *relative neighborhood graph (RNG)* is created from the given transmission graph. By creating RNG, minimum power is assigned to each camera sensor, so that connectivity among the neighbors is preserved with minimum power consumption. Thus, network lifetime is maximized.

In case of CSs, though sensing and computation cause increased energy consumption, considering energy cost due to transmission is also a significant factor for increasing network lifetime. In order to maintain connectivity with its neighbors, a CS operates with maximum transmission power, which is the power cost for broadcast communication. It is assumed that the transmission cost is symmetric. So, a packet from CS_i can reach CS_j at certain power consumption level and packet from CS_j can also reach CS_i at the cost of same power consumption. We want to maximize the network lifetime by assigning minimum power for communication, while maintaining network connectivity. The reduced power level of communication also helps in reducing interference. The transmission structure of the network connecting CSs is modeled as a $RNG(G) = (V, E_{rng})$ with an associated edge cost function $c\colon E_{rng} \rightarrow [0, p_{max}]$, which gives the minimum power necessary to use the link. A packet from CS_i can reach CS_j if the transmission power $p(CS_i)$ satisfies $p(CS_i) \geq c(CS_i, CS_j)$. So, the power consumption of CSs when forming coalitions with SSs decreases, thereby increasing the lifetime of the network, while the CSs are connected. Given the transmission graph $G(V, E)$ and an edge cost function $c\colon E \rightarrow [0, p_{max}]$, a graph $RNG(G) = (V, E_{rng})$ is created with $E_{rng} \subseteq E$ and power assignment $p(u) = max_{(u,v)\in E_{rng}} c(u, v)$. To guarantee connectivity between the CSs, the properties of RNG are used in this section.

1) Relative Neighborhood Graph: The Relative Neighborhood Graph (RNG) [29] is a graph reduction method. Given an initial graph G, the RNG extracted from G is a graph with reduced number of edges, but with the same number of vertices. CSs are the vertices of the initial graph G. If two CSs communicate directly, there is an edge between them. Two CSs communicate with each other, if their distance is less than the communication range. In the initial graph, all CSs have the same communication range. To create RNG from the initial graph, an edge between two CSs is removed, if there exists another CS which is at lower distance from both the CSs. To preserve the connectivity of the CSs in the whole network, each CS preserves the connectivity with its neighbors.

Definition 1. *Let $G = (V, E)$ be a graph representing the camera sensor network, and V is the set of vertices representing CSs. $E \subseteq V^2$ is the set of edges defined by $E = \{(u, v) \in V^2 | u \neq v \wedge d(u, v) \leq R\}$, where $d(.)$ is the distance between u and v, and R is the communication range of the CS.*

Definition 2. *The set of 1-hop neighbors of a CS u is denoted by $N(u)$ and is defined by $N(u) = \{v \in V | (u, v) \in E\}$. $|N(u)|$ is used to denote the number of neighbor CSs of the CS u.*

Definition 3. *$RNG(G) = (V, E_{rng})$ is the relative neighborhood graph corresponding to the graph $G = (V, E)$, where $E_{rng} = \{(u, v) \in E | \nexists w \in (N(u) \cup N(v)) \wedge d(u, w) < d(u, v) \wedge d(v, w) < d(u, v)\}$.*

The RNG edge construction approach is depicted in Fig. 2. The lune between u and v must be empty of any other node w for (u, v) to be included in the RNG. The intersection of the circles of radius $d(u, v)$ of nodes u and v helps in creating the lune boundary.

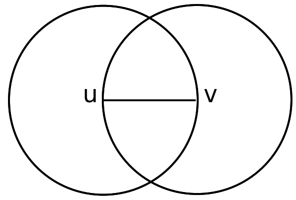


Fig. 2: Edge construction in RNG

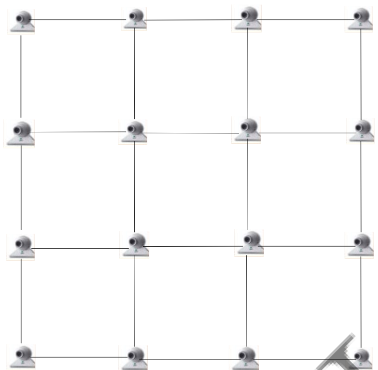


Fig. 3: RNG of camera sensors constructed from initial graph (Fig. 1)

Theorem 1. *$RNG(G) = (V, E_{rng})$ preserves the connectivity of $G = (V, E)$, i.e., $RNG(G)$ is strongly connected if G is strongly connected.*

Proof: Suppose G is strongly connected. For any two vertices (CSs) u, $v \in$ V(G), there exists at least one path $p = (u_0 = u, u_1, u_2, \ldots, u_{t-1}, u_t = v)$ from u to v, where $(u_i, u_{i+1}) \in RNG$ for $i = 0, 1, \ldots, t-1$. Since (u_i, u_{i+1}) is connected, (u, v) is also connected. ■

Definition 4. *$RNG(u)$ is the set of neighbors of a CS u in $RNG(G)$ graph. $RNG(u) = \{v \in N(u) | (u, v) \in E^{rng}\}$. $|RNG(u)|$ is used to denote the number of nodes in $RNG(u)$.*

The $RNG(G) = (V, E_{rng})$, consisting of CSs, is constructed from the initial graph $G = (V, E)$ using Algorithm 1. Minimum energy is assigned to the CSs for broadcasting message to their respective neighbors. So, energy consumption of each CS due to communication with its neighbors will be reduced over the whole network, thereby increasing the network lifetime. Fig. 3 shows the constructed RNG.

Complexity Analysis of Relative Neighborhood Graph Formation Algorithm (RNG):

We analyze the time and message complexity for the Relative Neighborhood Graph Formation Algorithm. The time complexity is defined as the total run time for all CSs during the execution of the algorithm. On the other hand, the message complexity is defined as the total number of messages transmitted during the execution of the algorithm. For broadcasting a Hello message, $O(n)$ time units are spent for n CSs. The total time units for receiving broadcast messages for n CSs are $O(kn)$, where k ($k << n$) is the maximum number of neighbors for each CS. The cost for forming RNG for n CSs is $O(n^2)$. The total cost for n CSs for minimum power assignment to each CS in the RNG

Algorithm 1: Relative Neighborhood Graph Formation

Input: Parameters of camera sensor nodes of initial graph G=(V,E).

Output: The Relative Neighborhood Graph (RNG(G)=(V, E_{rng})) from initial graph (G) with minimum power assigned to each camera sensor node.

for *each CS* $v \in V$ **do**
  $RNG(v) \leftarrow 0$;
  $p(v) \leftarrow 0$;
for *each CS* $u \in V$ **do**
  broadcast (u, "$Hello$");
for *each CS* $u \in V$ **do**
  for *each CS* $v \in N(u)$ **do**
    if $E_{res}^{CS_u}$>0 *AND* $E_{res}^{CS_v}$ **then**
      ▷ $E_{res}^{CS_u}$ and $E_{res}^{CS_v}$ are the residual energies of CS u and v respectively
      $RNG(u) \leftarrow RNG(u) \cup v$;
for *each CS* $u \in V$ **do**
  for *each CS* $v \in RNG(u)$ **do**
    for *each CS* $w \in RNG(u)$ **do**
      if $(v == w)$ **then**
        continue;
      if $(d(u,w)<d(u,v)$ *AND* $d(v,w)<d(u,v))$ **then**
        $RNG(u) \leftarrow RNG(u) \setminus v$;
for *each CS* $u \in V$ **do**
  for *each CS* $v \in RNG(u)$ **do**
    if $(c(u,v)>p(u))$ **then**
      $p(u) \leftarrow c(u,v)$;

formed is $\text{O}(ln)$ time units, where l ($l<<n$) is maximum number of RNG neighbors. Hence, the time complexity of forming $RNG(G) = (V, E_{rng})$ from $G = (V, E)$ is $\text{O}(n)$ + $\text{O}(kn)$ + $\text{O}(n^2)$ + $\text{O}(ln)$ = $\text{O}(n^2)$. On the other hand, the total message complexity for forming RNG is $\text{O}(n)$ + $\text{O}(kn)$ = $\text{O}(kn)$, where the first one is for sending broadcast messages, and the latter one is for receiving broadcast messages from at most k neighbors by one CS.

C. Deployment of Scalar Sensor Nodes

SSs are deployed in a randomly uniform manner over the whole region, assuming that all SSs have the same sensing capabilities. The minimum number of SSs (SS_{num}) required to monitor an area (A) is given by the Equation (9), where r_s represents the sensing range of each scalar sensor node [30] [31].

$$SS_{num} = \frac{2A\pi}{{r_s}^2\sqrt{27}} \tag{9}$$

After deployment of camera and scalar sensor nodes, the topology formed consisting of heterogeneous sensor nodes is shown in Fig. 4.

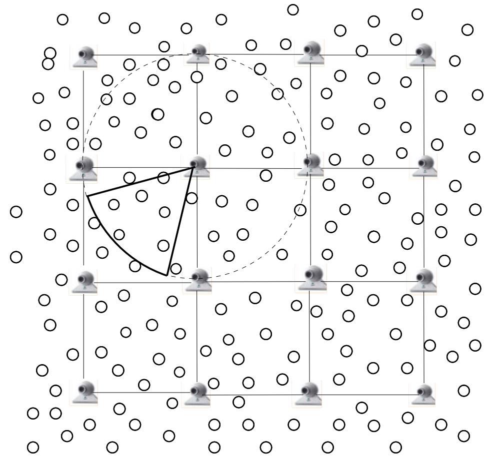


Fig. 4: Wireless Multimedia Sensor Networks Topology

D. Assumptions

We have made the following assumptions in this work.

A1. The characteristics of the deployment region is known in advance, so that SSs can be deployed in a uniform random manner.

A2. CSs are able to change their sensing orientation.

A3. CSs are positioned at the grid intersection.

A4. SSs do not send any false (or missed alarm) that affects the reliability of an event.

E. Problem Overview

We are motivated to provide a solution under the constraints of event coverage and connectivity among CSs, and the network lifetime of the CSs. Specifically, our objective is to design a distributed topology management scheme, named T-Must, to provide certain features and reporting of events, occurring at any time from the event area to the control center. The features of the proposed solution are the following.

- The coverage of the event is rendered in negligible time, before the event propagates larger than a certain threshold.
- All the live CSs are connected.
- There is a shortest path from the CS at the event area to the control center.
- The average lifetime of the network is increased.

The CSs are placed using grid-based architecture, so that connectivity among the peers is preserved and full coverage of the monitored field is maintained. The SSs are uniformly distributed in a random fashion over the whole region.

The initial topology is constructed by adopting distributed coalition between the SSs and CSs, so that each SS coalesces with the proper CS, based on its utility with minimum energy consumption for information exchange. Each CS includes in a coalition those SSs which are within its sensing range. In the topology maintenance phase, the SSs apply a switching rule to switch from one coalition to another, in order to maintain balance in energy consumption over the whole network.

V. System Model

Topology management consists of two phases: *topology construction* and *topology maintenance*. The initial topology is constructed by coalescing the SSs and the CSs. A SS reports the sensed data to the CS, and each CS to the other CSs or control center. When scalar data received by a CS cross a certain threshold, it starts sensing video data and sends the sensed data towards the control center. For this, the SSs are considered to be within the respective CS's sensing range. In this paper, we propose to promote (and, thus, formulate) cooperation between the scalar and camera sensor nodes using a coalition formation game framework [32], [33], [34], [35]. During coalition formation, some energy is lost due to information exchange. Every SS is considered to be omni-directional. Every CS has a field of view (FoV). Each of these sensor nodes has the capability of changing its sensing orientation.

A. Utility function

To optimize the reduction of energy consumption of CSs for sensing an event, the CSs form multiple coalitions with different SSs. The CSs choose those SSs that can report the event within their sensing range (R_s^{cs}). The coalitions are disjoint. The SSs primarily act as players, and the CSs coordinate with the SSs for coalition formation. The energy cost, E_T^{ik}, spent on communication between the i^{th} SS and the k^{th} CS is measured using Equation (7). Using coalition game theory, topology is constructed by information exchange between the SSs and CSs, so that energy consumption for information exchange reduces, and the SSs are within the CSs' sensing ranges. So, the utility function for the i^{th} SS for coalition formation with the k^{th} CS is defined as follows:

$$U_i(E_T^{ik}, E_R^{cs_k}) = \begin{cases} 1 - \frac{E_T^{ik}}{E_{res}^{ss_i}} + 1 - \frac{E_R^{cs_k}}{E_{res}^{cs_k}} & \text{if } d(ss_i, cs_k) < R_s^{cs_k}, \\ 0 & \text{otherwise.} \end{cases} \tag{10}$$

or

$$U_i(E_T^{ik}, E_R^{cs_k}) = \begin{cases} 2 - \frac{E_T^{ik}}{E_{res}^{ss_i}} - \frac{E_R^{cs_k}}{E_{res}^{cs_k}} & \text{if } d(ss_i, cs_k) < R_s^{cs_k}, \\ 0 & \text{otherwise.} \end{cases} \tag{11}$$

where, $E_{res}^{ss_i}$: Residual energy of the i^{th} SS

$E_R^{cs_k}$: Receiving energy cost for the k^{th} CS

$E_{res}^{cs_k}$: Residual energy of the k^{th} CS

Utility indicates the willingness of a SS to form coalition with a CS. The higher value of utility of a SS with respect to a CS indicates that the SS is highly willing to form coalition with that CS.

When an event occurs in a particular area, the source CS sends the data from the event area to the control center using the shortest path. The CSs along the routing path for that particular event are depleted of their residual energies. So, the SSs associated with the CSs in the respective coalitions may continue to remain in the same coalition, or leave that coalition to join the neighbor coalition by using their utilities. Therefore, after each event occurrence, the SSs, as players, can move among neighbor coalitions, so that better coverage of the event can be rendered and reported to the live CSs.

B. Initial Topology Formation: Coalition Formation Game

Topology construction is strongly based on cooperation, in which the SSs connect and cooperate with the CSs in communication, to increase the network lifetime. Coalition formation game theory provides analytic tools to study the behavior of SSs as rational players. It is used to form topology in a distributed manner.

The strategy of a player is to form coalition, and payoff is the utility defined in Equation (11). Thus, the introduction of cooperation between SSs can be modeled as a coalition game with *non-transferable utility* (NTU) [36].

Definition 5. *A coalition game with non-transferable utility (NTU) is defined by the pair (N, v), where N is the set of players and v is a mapping such that for every coalition $S \subset N$, $v(S)$ is a closed convex subset of R^S that contains the utility vectors that the players in S can achieve.*

For the proposed game, the mapping is defined as:

$$v(s) = \{x(S) \in R^S \Big| x_i(S) = U_i, \forall i \in S\}. \quad (12)$$

Definition 6. *A subset of CSs which are neighbors to the i^{th} SS is defined as $N(SS_i) = \{CS_j \in V \Big| d(SS_i, CS_j) \leq R_T^{SS_i}\}$, where $R_T^{SS_i}$ is the transmission range of SS_i.*

Coalition formation is described in Algorithm 2.

After executing the algorithm, the coalition produced looks as in Fig. 5

Example

We illustrate how the coalitions are constructed based on utility. Every SS forms its coalition, based on its maximum utility. We take only small portion from our large data set to describe the SSs and their utilities to form the topology. Coalition number indicates the corresponding CS. Fig. 6 illustrates the SSs and their corresponding utilities to form the respective coalitions.

The SSs sense and transmit data to the coalition head (CH) over a single hop. The CSs relay data outside the coalition towards other CHs or BS. However, when the value of the data sensed by a SS crosses a threshold, the CS starts sensing the event and sends video data outside the coalition to a CH in another coalition or to the BS. Thus,

Algorithm 2: T-Must Initial Topology Formation

Input: Parameters of scalar and camera sensors.
Output: The initial topology partitioned into disjoint set of coalitions.

for *each CS* $u \in V$ **do**
  $S_u \leftarrow 0$;
for *each CS* $u \in V$ **do**
  broadcast (u, "$Hello$");
for *each SS* $t \in T$ **do**
  $MaxU \leftarrow 0$; $s\_index \leftarrow 0$; $c\_index \leftarrow 0$;
  for *each CS* $J \in N(SS_t)$ **do**
    Utility of SS t, U_t is calculated by equation (10);
    if $(U_t \geq MaxU)$ **then**
      MaxU$\leftarrow U_t$; s_index $\leftarrow$ t; c_index $\leftarrow$ J;
  send $(s\_index, c\_index,$ "s_index"$, P_{s\_index,c\_index})$;
  if $(d(c\_index, s\_index) < R_S^{c\_index})$ **then**
    receive $(c\_index, s\_index,$ "s_index"$)$;
    $S_{c\_index} = S_{c\_index} \cup SS_{s\_index}$;

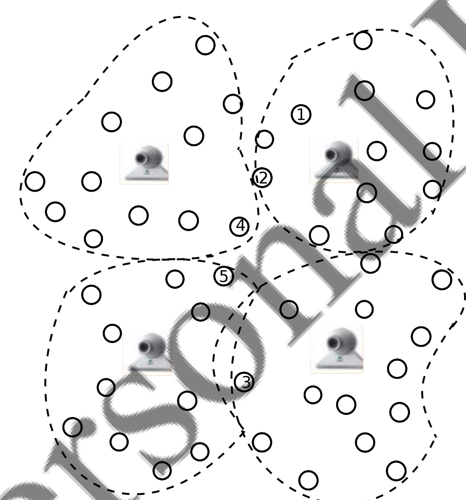


Fig. 5: Initial topology

by constructing topology using coalition game theory, the total energy consumption by the camera and scalar sensor nodes is reduced significantly, thereby increasing the network lifetime.

Property 1. *In the proposed game, the coalition value of each coalition S_i is equal to the utility of each SS in that coalition.*

So, the coalition value for the coalition S_i is represented as:

$$v(S_i) = \{U_1(S_i), U_2(S_i), \ldots, U_{|S_i|}(S_i)\}. \tag{13}$$

Consequently, the proposed (N, v) coalition game has a non-transferable utility. The coalition value $v(S_i)$ cannot

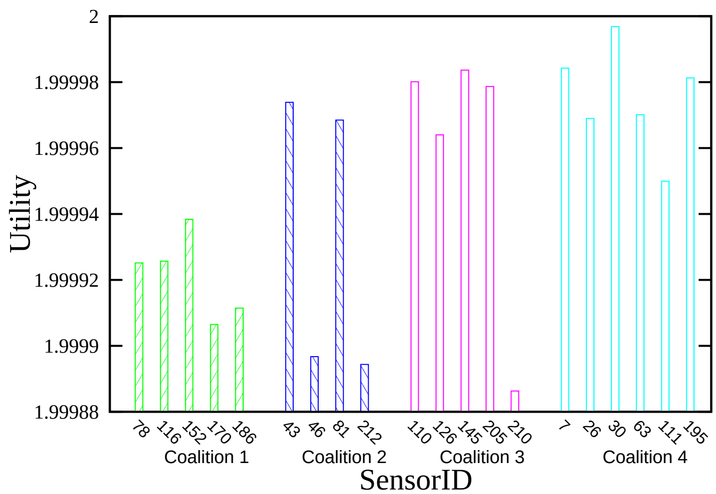


Fig. 6: SensorID vs Utility

be arbitrarily apportioned among the players of a coalition. In general, coalition game-based problems seek to characterize the properties and the stability of the grand coalition of all the players, as it is assumed that the grand coalition maximizes the utilities of the players [36]. For the proposed algorithm, grand coalition will never form.

Property 2. *For the proposed (N, v) game, disjoint independent coalitions will be produced in the network.*

Proof: For grand coalition formation, all players (SSs) should be in grand coalition. But in our proposed approach, the SSs form coalition with CSs for topology management. When all SSs choose one CS (say S_i), the grand coalition will be formed if $d(CS_i, SS_j) < R_S^{CS_i} \forall j \in N$ and $d(CS_i, SS_j) < R_T^{SS_j}$. However, our proposed approach cannot satisfy above condition. Therefore, in our case, SSs will produce disjoint coalitions with their near CSs.

■

Coalition formation is a topic of high interest in game theory [37]. An important goal is to find algorithms for characterizing the coalition structures that form a network where grand coalition is not possible.

Definition 7. *A collection of coalitions, denoted as S, is defined as the set $S = \{S_1, S_2, \dots, S_m\}$ of mutually disjoint coalitions $S_i \subset N$. If the coalition collection spans all the players of N(i.e., $\cup_{j=1}^{m} S_j = N$), the collection is a partition of N.*

VI. Topology Maintenance

Energy consumption of both the CSs and SSs may become disproportional with the lapse of time. Topology maintenance is taken into account after each event occurs in the monitored region. To ensure fair energy consumption for both types of nodes, and reliable sensing of events by CSs, the topology should be adaptive in nature. Therefore, the SSs should have preference over CSs in respect of their association with one another.

Definition 8. *For any player $i \in N$, a preference relation or order $\succeq_i$ is defined as a complete and transitive binary relation over the set of all coalitions that the player i can possibly form, i.e., the set $\{S_k \subseteq N; i \in S_k\}$.*

Therefore, for a player $i \in N$, given two coalitions $S_1 \subset N$ and $S_2 \subset N$ such that $i \in S_1$ and $i \in S_2$. $S_1 \succeq S_2$ implies that player i prefers to be a member of coalition S_1 over S_2, or i is indifferent between S_1 and S_2. Further, using the asymmetric counterpart of $\succeq_i$, denoted as $\succ_i$, $S_1 \succ_i S_2$ indicates that player i strictly prefers being a member S_1 over S_2. A suitable preference relation $\succeq_i$ indicates that player i strictly prefers being a member of S_1 over being a member of S_2. For every application, an adequate preference relation $\succeq_i$ can be defined to allow the players to quantify their preferences, depending on their parameters of interest.

For the proposed coalition formation game, we propose the following preference relation for any $SS_i \in Nas$:

$$S_1 \succ_i S_2 \Leftrightarrow w_i(S_1) > w_i(S_2), \tag{14}$$

where $S_1, S_2 \subset N$ are two arbitrary coalitions containing SS_i i.e., $i \in S_1$ and $i \in S_2$, and w_i is a preference function defined for any $SS_i \in N$ and any coalition S, such that $i \in S$, as follows:

$$w_i(S) = \begin{cases} x_i(S), & \text{if } E_{res}^{ss_i} > 0 \text{ AND } E_{res}^{CS_s} > 0 \\ -\infty, & \text{otherwise} \end{cases} \tag{15}$$

where $x_i(S)$ is the utility received by SS_i in coalition S as given by Equation 15.

A. Topology Maintenance: Coalition Restructuring Rule

In order to restructure the topology based on the SSs preferences, we propose the following rule :

Definition 9. *Switch Rule: Given a partition* $\Pi = \{S_1, S_2, \dots, S_m\}$ *of SSs set* N, SS_i *decides to leave its current coalition* S_j*, for some* $j \in \{1, 2, \dots, m\}$ *and join another coalition* $S_k \in \Pi \cup \{\phi\}, S_j \neq S_k$*, thereby forming another partition* $\Pi' = \{\Pi \setminus \{S_j, S_k\}\} \cup \{S_j \setminus \{i\}, S_k \cup \{i\}\}$*, iff* $S_k \cup \{i\} \succ_i S_j$*. Hence,* $\{S_j; S_k\} \rightarrow \{S_j \setminus \{i\}, S_k \cup \{i\}\}$ *and* $\Pi \rightarrow \Pi'$.

The switch rule provides a mechanism using which any SS is able to take an individual decision to leave its current coalition S_j and join a different coalition $S_k \in \Pi$, as long as $S_k \cup \{i\} \succ_i S_j$, as per Equations (14) and (15).

Performing switch rule in the T-Must topology maintenance phase is illustrated in Algorithm 3. Here, some of the SSs leave their current coalition and join a new one. The restructured topology is shown in Fig. 7.

Theorem 2. *Beginning with an initial network partition* Π_{init} *of disjoint coalitions, the topology restructuring algorithm always converges to a final network partition* Π_{final} *composed of a number of disjoint coalitions of SSs.*

Proof: The SSs leave a coalition and join a new one, using the switch rule, based on their willingness, thereby yielding a new partition of coalitions. The proposed topology maintenance algorithm is a sequence of switch operations to produce new partition of coalitions. The total number of coalitions equals the number of CSs or less than that. After a sequence of switch operations, the initial partition Π_{init} always converges to the final partition Π_{final}. ■

Algorithm 3: T-Must Topology Maintenance

Input: Initial topology consisting of the partition $\Pi_{initial} = \{S_1, S_2, \ldots, S_m\}$.
Output: The final topology consisting of the partition $\Pi_{final} = \{R_1, R_2, \ldots, R_m\}$.

for *each CS* $u \in V$ **do**
  broadcast (u, "$Hello \cup status\_info$");
for *coalition* $S_i \leftarrow 1$ ***to*** m **do**
  for *each SS* $j \in S_i$ **do**
    for *each CS* $k \in N(j^{SS})$ **do**
      ▷ switch rule starts
      if *$(i == k)$* **then**
        continue;
      else U_j is calculated using equation (10);
      if $(U_j > MaxU)$ **then**
        $MaxU \leftarrow U_j$; $c\_index \leftarrow k$;
    U_j in coalition S_i is calculated using equation (10);
    if $((U_j \ for \ S_i) < (U_j \ for \ S_{c\_index}))$ **then**
      $S_{c\_index} \leftarrow S_{c\_index} \cup \{SS_j\}$
      send (j, c_index, "ACK", p);
      send (j, i, "NACK", p);
    else
      SS_j remains in S_i;
      send (j, i, "ACK", p);
    ▷ switch rule ends

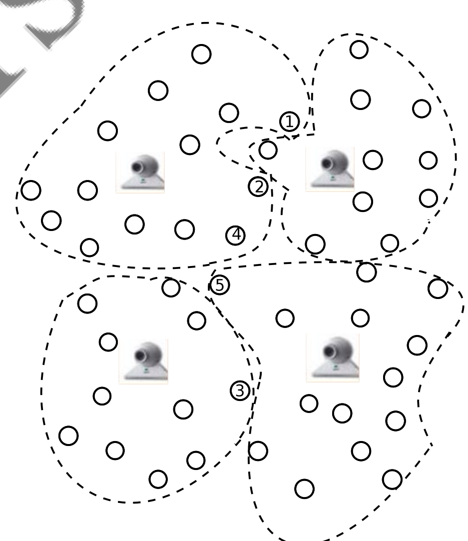


Fig. 7: Topology restructuring in the topology maintenance phase

We study the stability of the partition Π_{final} resulting from the convergence of the proposed algorithm using the concept of nash stability defined below.

Definition 10. *A partition* $\Pi = \{S_1, S_2, \ldots, S_m\}$ *is Nash-stable if* $\forall i \in N$ *s.t.* $i \in S_j, S_j \in \Pi, S_j \succeq_i S_k \cup \{i\} \forall S_k \in \Pi \cup \{\phi\}$.

It follows from Definition 10 that the partition Π is Nash-stable, if no SS has an incentive to move from its current coalition to another in Π or to deviate and act alone.

Proposition 1. *Any partition* Π_{final} *resulting from the topology restructuring algorithm is Nash-stable.*

Proof: If a partition Π_{final} resulting from topology maintenance algorithm is not Nash-stable then, $\exists i \in N$ with $i \in S_j, S_j \in \Pi_{final}$ and a coalition $S_k \in \Pi_{final}$ such that $S_k \cup \{i\} \succ_i S_j$. Hence, SS_i can perform a switch operation which contradicts with the fact that Π_{final} is the result of the convergence of the proposed algorithm. Thus, any partition Π_{final} resulting from the algorithm is Nash-stable. ■

VII. Simulation setup and performance evaluation

We performed MATLAB-based simulation to evaluate the performance of the proposed algorithm, T-Must. We consider a terrain of 600×600 m^2. The CSs are positioned at the grid intersection of a grid-based monitored area. The SSs are scattered in a randomly uniform manner over the whole region. When an event occurs, the SSs in the event area inform their respective CSs. The CSs sense and send video data to the sink through either the single-hop or the multi-hop mechanism. The simulation parameters used for performance evaluation are given in Table I. We consider the following performance metrics:

- *Coverage ratio*: It is defined as the portion of the area of an event which is covered by all actuated CSs with respect to the total area monitored. If s and w be the CS's sensing range (depth of view (DoV)) and FoV respectively, and b is the area of the monitored region, then coverage ratio rendered by n CSs in the event area is given by $1 - (1 - \frac{s^2 w}{2b})^n$ [25].
- *Packet delivery ratio as an indication of path connectivity*: It is defined as the ratio of the total number of video packets received at the sink node over the total number of video packets transmitted by the source node. In our approach, the control center acts as the sink node, and the CS in the event area acts as the source node. As the video packets are of large size (e.g. 1024 bytes), when the video packets are routed from the event area to the control center, some CSs in the shortest routing path are depleted of their battery power. So, the routing paths break due to depletion of battery power. Therefore, packet delivery ratio subsumes the path connectivity property of the network.
- *Network lifetime*: This metric represents the number of live CSs at the end of each event occurrence.
- *Residual energy*: The residual energy is defined as the average of the remaining energy of all the CSs in the network at the end of each event occurrence.

Several simulation experiments are conducted to show the performance of the proposed topology over DCA-SC [25].

TABLE I: Simulation Parameters

Parameter Name	Parameter Value
Field Size	$600 \times 600\ m^2$
Number of CSs	121
Transmission Range of CSs	100 m
Sensing Range of CSs	50 m
Number of SSs	600
Transmission Range of SSs	50 m
Sensing Range of SSs	10 m
Initial Energy of CSs	100 joules
Initial Energy of SSs	20 joules
Transmit Power for Broadcast of CSs ($P_{t_{cs}}$)	47.75 mw
Power Consumption of Transmitting Circuitry (P_{T0})	15.9 mw
Power Consumption of Receiving Circuitry (P_{R0})	22.2 mw
Drain Efficiency of Power Amplifier (η)	15.7 %
Path Loss Exponent (α)	2
Constant Value (ξ)	0.0005

A. *Effect of event radius*

It is crucial to observe the coverage provided by the CSs with the increase of the event area. After long time, when some of CSs exhaust their battery energy, the event cannot always be detected immediately after its occurrence. When the event spreads over the region, some CSs get the event within its sensing region. So, we vary the size of the event area (its radius) to see its influence on the coverage ratio. In this experiment, we consider that the initial event area is $100\pi\ m^2$ and the number of CSs is 121. We compare the performance of T-Must with DCA-SC [25]. Fig. 8 shows that, with an increase in the event radius, the proposed approach renders very high coverage ratio compared to DCA-SC.

B. *Effect of number of event occurrences*

After the initial deployment of CSs and SSs in the monitoring region, the latter sense the environment continuously. When an event occurs, these nodes sense the physical phenomena and send the sensed data to their respective CSs. Upon receiving the scalar data values, the CSs are actuated. The CSs immediately start sensing the event and send image or video data to the sink or control center. When the event ends, the CSs stop sensing and become idle. The event can occur randomly over the entire region. So, the CSs exhaust their battery energy. As a consequence, the lifetime of the network, connectivity among the CSs, and coverage provided by the CSs are affected. We compare T-Must with DCA-SC based on these performance metrics.

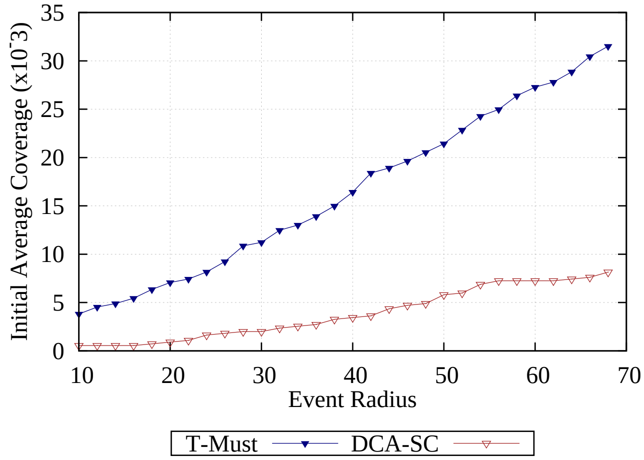
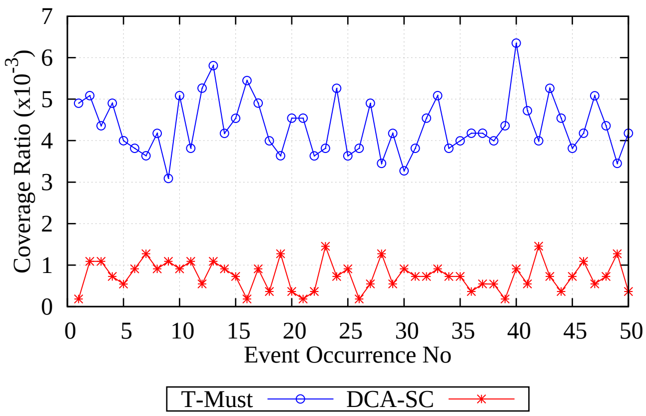


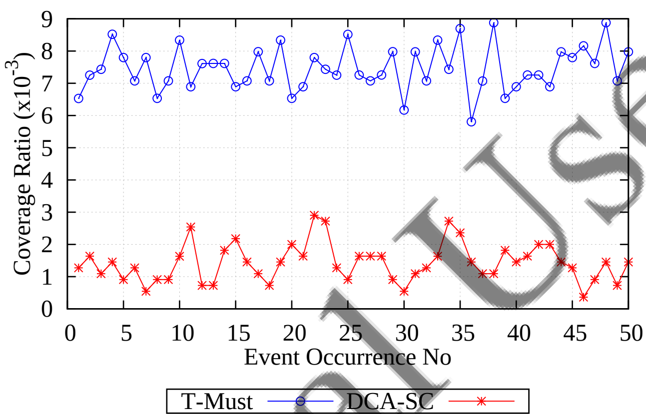
Fig. 8: Average coverage ratio rendered by camera sensor nodes when an event occurs covering different areas of the monitored region.

1) Coverage ratio: In order to compare the coverage ratio performance of the proposed approach with DCA-SC, we conducted experiments with the number of event occurrence. The radius of the event is taken as 10 m and 20 m, respectively, in the experiments. Fig. 9 reveals that when the event radius is 10 m, the coverage ratio provided by the proposed approach is greater than that provided by DCA-SC over the event occurrences. However, when the event radius is 20 m, the coverage ratio rendered by T-Must is much improved than DCA-SC, for each event over the time. It is noticeable that with increase in the event radius, the coverage ratio provided by the proposed approach increases compared to DCA-SC.

2) Packet delivery ratio: When an event occurs in the monitored region, the CSs die over time. To measure the path connectivity from the source CS in the event area to the control center, provided by T-Must, as compared to path connectivity provided by DCA-SC, experiments are conducted based upon the packet delivery ratio. Fig. 10 reveals that during the initial event occurrences, the packet delivery ratio of the proposed approach is the same as that of DCA-SC. However, as the number of event occurrences increases, the packet delivery ratio provided by DCA-SC is much reduced compared to that of T-Must. The underlying reason is the following. When an event occurs in the monitored region, video data are transferred from the source CS in the event area to the control center using the shortest path routing. The energy of the CSs along the path is depleted. The node's energy depletion due to the data transmission from one node to the next node in each hop along the path is proportional to the square of the distance between them. On the other hand, energy depletion due to data reception for each node is same along the path. As all the video data pass through The CSs near the control center, they die faster than far CSs. In case of DCA-SC, as the CSs are deployed randomly, the shortest path from the source CS in the event region to the control center makes the hop-to-hop distance close to its transmission range. All the packets from the event area can not reach the control center. Therefore, packet delivery ratio drops as the number of event occurrence increases. However, in case of T-Must, the distance between two consecutive hops along the route from the source to the sink is in most cases



(a) Event radius: 10 m



(b) Event radius: 20 m

Fig. 9: Event coverage ratio rendered by camera sensor nodes due to random event occurrences at different places on the monitored region.

half of the transmission range of the CSs. So, energy is depleted for all nodes homogeneously. The CSs near the control center die at very lesser rate. Therefore, There is high chance of having a path from source to sink. As a result, packet delivery ratio in T-Must is very high.

3) Network lifetime: Experiments are conducted to observe the performance of the proposed approach over DCA-SC with respect to network lifetime. Fig. 11 depicts that the number of live nodes in the proposed topology is always greater than the number of live nodes in DCA-SC. The underlying reason is the following. When an event occurs in the monitored region, multimedia data (video data) are transferred by the CSs from the event area to the control center using shortest path routing. The energy of the CSs along the path is depleted, and consequently some of them die. So, the number of live nodes decreases due to the increase in the number of event occurrences. The node's energy depletion due to the data transmission from one node to the next node in each hop along the path is proportional to the square of the distance between them. On the other hand, energy depletion due to data reception for each node is same along the path. The distance between two consecutive hops along the route from source to the destination is

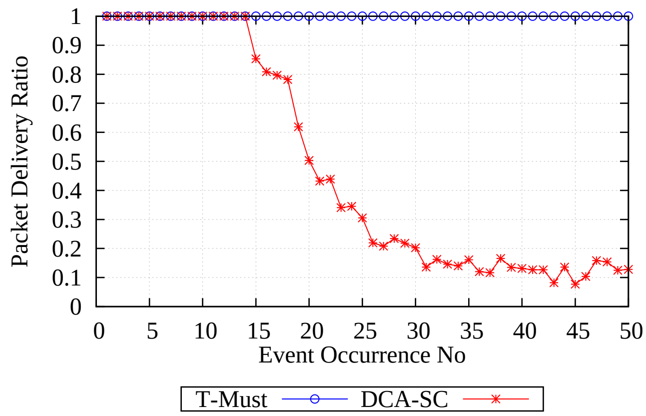


Fig. 10: Packet delivery ratio as an indication of path connectivity from the source CS in the event area to the control center after each event occurrence at different places of the monitored region.

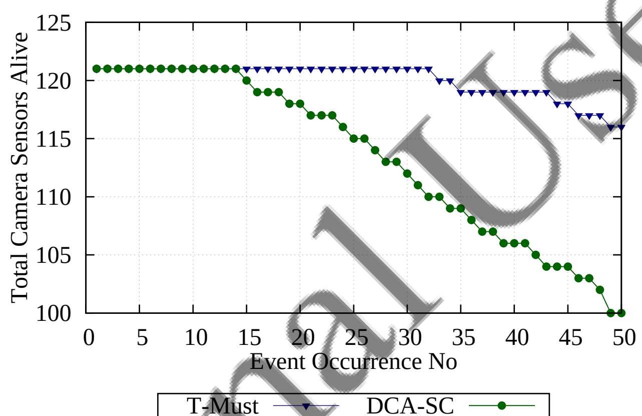


Fig. 11: Number of alive camera sensor nodes after each event occurrence.

in most cases half of the transmission range of the CSs. So, energy is depleted for all nodes homogeneously along the route for each event. In case of DCA-SC, as the CSs are deployed randomly, the shortest path from the source CS in the event region to the sink makes the hop-to-hop distance close to its transmission range. So, more power is lost on each node along the route. Thus, the number of live nodes after each event occurrence is less.

4) Residual Energy: In order to compare the performance of residual energy of the proposed approach with respect to DCA-SC, experiments are conducted for each event. It validates the result of the residual energy depicted in Fig. 11. Fig. 12 reveals that the average residual energy of the proposed approach is always greater than the residual energy of DCA-SC, due to reasons discussed in Section VII-B3.

VIII. CONCLUSION

To get precise information of a monitored region, introduction of WMSNs involving CSs and SSs is crucial in surveillance applications. It is also important to increase the network lifetime, and maintain connectivity among CSs and coverage rendered by them. The proposed distributed topology management algorithm, T-Must is viable

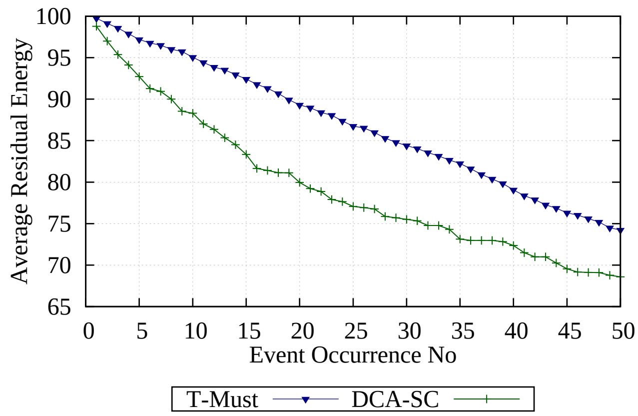


Fig. 12: Average residual energy of the camera sensor nodes after occurrence of each event.

solution to achieve these goals. Through simulation studies, we see that the proposed algorithm provides substantial performance improvement.

In the future work, we plan to investigate the following. First, we will study our proposed algorithm for the random deployment of CSs. Second, as the CSs rotate their orientation to target the event in the proposed approach, some amount of energy is lost. So, the future scope of our work is to study the mechanisms using which the CSs can preserve the coverage offered by the network without rotating the orientations. The presence of malicious or selfish nodes can affect the network lifetime. So, finally, using cryptographic algorithm in CSs, we will investigate how we can avoid attacks on those nodes.

References

[1] I. F. Akyildiz, T. Melodia, and K. R. Chowdhury., "A survey on wireless multimedia sensor networks." *Computer networks*, vol. 51, no. 4, pp. 921–960, 2007.

[2] H. Xu, L. Huang, C. Qiao, Y. Zhang, and Q. Sun, "Bandwidth-power aware cooperative multipath routing for wireless multimedia sensor networks." *IEEE Transactions on Wireless Communications*, vol. 11, no. 4, pp. 1532–1543, 2012.

[3] J. Chen, L. Zhang, and Y. Kuo, "Coverage-Enhancing Algorithm Based on Overlap-Sense Ratio in Wireless Multimedia Sensor Networks." *IEEE Sensors Journal*, vol. 13, no. 6, pp. 2077 – 2083, 2013.

[4] S. Ehsan and B. Hamdaoui, "A survey on energy-efficient routing techniques with QoS assurances for wireless multimedia sensor networks." *IEEE Communications Surveys & Tutorials*, vol. 14, no. 2, pp. 265–278, 2012.

[5] M. H. Cheung, H. Mohsenian-Rad, V. W. Wong, and R. Schober, "Utility-Optimal Random Access for Wireless Multimedia Networks." *IEEE Wireless Communications Letters*, vol. 1, no. 4, pp. 340–343, 2012.

[6] V. Raghunathan, S. Ganeriwal, and M. Srivastava, "Emerging techniques for long lived wireless sensor networks." in *IEEE Communications Magazine*, vol. 44, no. 4, 2006, pp. 108–114.

[7] M. Rahimi, R. Baer, O. I. Iroezi, J. C. Garcia, J. Warrior, D. Estrin, and M. Srivastava, "Cyclops : in situ image sensing and interpretation in wireless sensor networks." in *Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems*. ACM, 2005, pp. 192–204.

[8] S. Bandyopadhyay and C. J. Edward, "An energy efficient hierarchical clustering algorithm for wireless sensor networks." in *INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies*, vol. 3, 2003, pp. 1713–1723.

[9] O. Younis and S. Fahmy, "Distributed clustering in Ad-Hoc sensor networks: A hybrid, energy-efficient approach." in *INFOCOM 2004. Twenty-third Annual Joint Conference of the IEEE Computer and Communications Societies*, vol. 1, 2004.

[10] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks." *IEEE Transactions on Wireless Communications*, vol. 1, no. 4, pp. 660–670, 2002.

[11] A. Mehmood, S. Khan, B. Shams, and J. Lloret, "Energy-efficient multi-level and distance-aware clustering mechanism for WSNs." *International Journal of Communication Systems*, 2013, 10.1002/dac.2720.

[12] G. Gupta and Y. Mohamed, "Load-balanced clustering of wireless sensor networks." in *IEEE International Conference on Communications, 2003. ICC'03*, vol. 3, 2003, pp. 1848–1852.

[13] Low, C. Ping, C. Fang, J. M. Ng, and Y. H. Ang, "Efficient load-balanced clustering algorithms for wireless sensor networks." *Computer Communications*, vol. 30, no. 4, pp. 750–759, 2008.

[14] G. Gupta and Y. Mohamed, "Fault-tolerant clustering of wireless sensor networks." *Wireless Communications and Networking, 2003. WCNC 2003*, vol. 3, pp. 1579–1584, 2003.

[15] S. Misra and A. Jain, "Policy controlled self-configuration in unattended wireless sensor networks." *Journal of Network and Computer Applications*, vol. 34, no. 5, pp. 1530–1544, 2011.

[16] S. Misra and D. Mohanta, "Adaptive listen for energy-efficient medium access control in wireless sensor networks." *Multimedia Tools and Applications*, vol. 47, no. 1, pp. 121–145, 2010.

[17] F.-C. Jiang, D.-C. Huang, C.-T. Yang, C.-H. Lin, and K.-H. Wang, "Design strategy for optimizing power consumption of sensor node with Min (N, T) policy M/G/1 queuing models." *International Journal of Communication Systems*, vol. 25, no. 5, pp. 652–671, 2012.

[18] M. S. Chowdhury, N. Ullah, M. A. Ameen, and K. S. Kwak, "Framed slotted ALOHA based MAC protocol for low energy critical infrastructure monitoring networks." *International Journal of Communication Systems*, 2012, doi: 10.1002/dac.2435.

[19] N. Ullah, M. S. Chowdhury, P. Khan, and K. S. Kwak, "Multi-hop medium access control protocol for low energy critical infrastructure monitoring networks using wake-up radio." *International Journal of Communication Systems*, 2012, doi: 10.1002/dac.2487.

[20] M. Alam, M. Hussain, P. Khan, B.-H. Kim, and K. S. Kwak, "A MAC protocol for the mixed scenario of omnidirectional and directional nodes in an ad hoc network." *International Journal of Communication Systems*, 2013, doi: 10.1002/dac.2570.

[21] C.-C. Tseng, H.-C. Wang, F.-C. Kuo, K.-C. Ting, and B.-E. Xie, "On the impact of temperature on path selection for wireless ad-hoc sensor networks." *International Journal of Communication Systems*, vol. 26, p. 11161128, 2013.

[22] S. Misra, M. P. Kumar, and M. S. Obaidat, "Connectivity preserving localized coverage algorithm for area monitoring using wireless sensor networks." *Computer Communications*, vol. 34, no. 12, pp. 1484–1496, 2011.

[23] R. Dai and I. Akyildiz, "A spatial correlation model for visual information in wireless multimedia sensor networks." *IEEE Transactions on Multimedia*, vol. 6, pp. 1148–1159, 2009.

[24] P. Kulkarni, D. Ganesan, P. Shenoy, and Q. Lu, "SensEye: a multi-tier camera sensor network." in *Proceedings of the* 13^{th} *Annual ACM International Conference on Multimedia*, 2005, pp. 229–238.

[25] N. Andrew and A. Kemal, "Distributed collaborative camera actuation for redundant data elimination in wireless multimedia sensor networks." *Ad Hoc Networks*, vol. 9, no. 4, pp. 514–527, 2011.

[26] A. Peiravi, H. R. Mashhadi, and S. H. Javadi, "An optimal energy-efficient clustering method in wireless sensor networks using multi-objective genetic algorithm." *International Journal of Communication Systems*, vol. 26, no. 1, pp. 114–126, 2013.

[27] S. A. Madani, K. Hayat, and S. U. Khan, "Clustering-based power-controlled routing for mobile wireless sensor networks." *International Journal of Communication Systems*, vol. 25, no. 4, pp. 529–542, 2012.

[28] Q. Wang, H. Mark, and Y. Woodward, "A realistic power consumption model for wireless sensor network devices." in *Sensor and Ad Hoc Communications and Networks, 2006. SECON'06.*, vol. 1. 2006 3rd Annual IEEE Communications Society, 2006, pp. 286–295.

[29] G. T. Toussaint, "The relative neighbourhood graph of a finite planar set." *Pattern Recognition*, vol. 12, no. 4, pp. 261–268, 1980.

[30] T. Camilo, J. S. Silva, A. Rodrigues, and F. Boavida, "Gensen: A topology generator for real wireless sensor networks deployment." in *In Software Technologies for Embedded and Ubiquitous Systems*, Springer, Heidelberg, 2007, pp. 436–445.

[31] S. Slijepcevic and M. Potkonjak, "Power efficient organization of wireless sensor networks." in *IEEE International Conference on Communications, 2001. ICC 2001*, vol. 2, 2001, pp. 472–476.

[32] W. Saad, Z. Han, M. Debbah, A. Hjorungnes, and T. Basar, "Coalitional games for distributed collaborative spectrum sensing in cognitive radio networks." in *IEEE INFOCOM 2009*, 2009, pp. 2114–2122.

[33] D. Wu, Y. Cai, and J. Wang, "A coalition formation framework for transmission scheme selection in wireless sensor networks." *IEEE Transactions on Vehicular Technology*, vol. 60, no. 6, pp. 2620–2630, 2011.

[34] W. Saad, Z. Han, M. Debbah, and A. Hjorungnes, "A distributed coalition formation framework for fair user cooperation in wireless networks." *IEEE Transactions on Wireless Communications*, vol. 8, no. 9, pp. 4580–4593, 2009.

[35] W. Saad, Z. Han, T. Basar, A. Hjorungnes, and J. B. Song, "Hedonic coalition formation games for secondary base station cooperation in cognitive radio networks." in *Wireless Communications and Networking Conference (WCNC), 2010*. IEEE, 2010, pp. 1–6.

[36] R. B. Myerson, *Game Theory, Analysis of Conflict.* Cambridge, MA, USA: Harvard University Press., 1991.

[37] W. Saad, Z. Han, M. Debbah, A. Hjorungnes, and T. Basar, "Coalitional game theory for communication networks." *IEEE Signal Processing Magazine*, vol. 26, no. 5, pp. 77–97, 2009.