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A two-tier strategy for priority based critical event surveillance with wireless multimedia sensors

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Abstract Surveillance plays a vital role in protecting infrastructure facilities of a country and improving detection of cross-border activities. Compared to traditional surveillance systems, wireless multimedia sensor networks (WMSN) provide distinct advantages. In this paper we consider the problem of critical event surveillance in a region of interest with the help of WMSN. The challenge here is deployment cost, energy-efficient routing and preservation of coverage and connectivity of the network. To keep the deployment cost minimum, we propose a two-tier strategy consisting of (a) densely deployed low cost audio tier nodes and (b) sparsely placed high cost video tier nodes to monitor critical events occurring in a given area. The audio nodes perform the preliminary event detection task, whereas, the base station activates the rotatable-video nodes on a demand basis. Depending upon the cost of potential damage, an event is assigned a priority, and based upon that priority an event is assigned either energy efficient or a delay tolerant path along the audio and video tiers. We also propose two integer linear programming formulations *MEAT* and *MEVT* for minimization of energy consumption in audio and video tiers separately. We then present two approaches, namely *Greedy* and *DCSEG,* and compare them with a popular existing approach under various scenarios. Simulation results show considerable reduction in the number of active audio and video sensor nodes per event which leads to low deployment cost and reduction of average energy consumption in the network.

Keywords Wireless multimedia sensor network (WMSN) · Surveillance · Deployment · *ILP* · Energy-efficient scheduling

List of symbols

RoI	Circular deployment
v_0	Sink
R_c	Communication range
$h(u)$	Minimum hop count of node u from v_0
R_{sa}	Audio sensing radius
$d(u)$	Node degree of u
R_{tha}	Audio threshold range
δ_{uv}	Normalized delay cost of uv edge
$\varPhi$	Horizontal viewable angle
$\Psi(u, v)$	Energy cost between node u and v
$\vec{v}$	Video working direction
Φ	Maximum energy cost for an edge in the network
α	Video azimuth angle
e_{uv}	Normalized energy cost of uv edge
β	Video elevation angle
c_{uv}	Total cost of uv edge
$D(\alpha)$	Set of possible values of α
w_1	Path delay weight
R_s	Video sensing radius
w_2	Energy consumption weight
FOV	Field-of-view
V_v	Set of video nodes

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1 Introduction

Surveillance is an important dimension in protecting infrastructure facilities and border management framework for a country. Moreover, critical event detection is important for any country which shares a large length of its territorial boundaries among its neighbours. Such event detections are also vital to protect infrastructure facilities of national importance. Wireless multimedia sensor network (*WMSN*) provides several advantages as compared to traditional surveillance system [1]. Wireless Multimedia Sensor Network enables the retrieval, processing, and storage of multimedia content such as audio, video, and scalar data [2, 3]. These networks grant enlarge and enhanced view of an event in addition to multiple viewpoints of an event. However the advantages associated with *WMSN* come at the cost of added deployment cost and high energy consumption in the network. *WMSN* produce voluminous data that require huge processing and transmission energy [2], and may remain operational without any recharging or maintenance after deployment. Moreover the gathered data may have various levels of priority for each event. Therefore, an efficient architecture combined with an energy-aware strategy is very important for such critical surveillance systems. Further a critical event detection application prioritises low delay routes over energy efficient paths. On the other hand, routine surveillance events prefer energy-efficient paths for transfer of data. Based on a given scenario, a surveillance application may generate a periodic or an event-driven data. Data generated by a periodic application follows a predictable pattern for a long run of duration, whereas, event driven applications produce huge volume of data over a short interval of time. The gathered data is then sent to the sink over a connected network using a routing protocol.

Selection of a particular routing strategy for a given surveillance scenario is driven by various factors like delay, energy, and transmission cost. An event in surveillance application should be treated according to its priority. Based upon the type of an event, an appropriate path is selected for sending the gathered data to the sink. Figure 1 illustrates the multi-path scenario for an event in case of randomly deployed sensors. For a given event two routes are shown in the figure. One is the delay-tolerant path having a smaller number of hops but with high energy consumption. However, the figure shows an alternative energy-efficient route exists that takes more time for a message to reach the destination. The multi-path routing protocol should provide energy-efficient routes as well as network coverage and connectivity.

From the literature we find that to achieve all the above objectives, sensor nodes deployment will require a multi-tier architecture [4]. Studies also indicate that the use of multi-tier architecture leads to lower energy consumption, lower monetary cost and is an effective way to manage the network resources [5, 6]. A hierarchical level exists in a multi-tier environment where the sensor nodes are organized based on their functionalities and capabilities [5]. The capabilities of sensors in different tiers differ in terms of sensing type, sensing range, and sensing shape. The first tier sensors consist of low cost and low processing capabilities whereas the second tier is equipped with high cost and high processing capability nodes. Sensing coverage is another important performance metric for critical surveillance applications. One of the recent papers in surveillance application [7] uses deterministically deployed *Rotatable* and *Directional* (R&D) sensors to achieve temporal coverage by adding the rotating capability to the video nodes. In [8] the authors investigate optimal camera placement providing *multi-perspective* coverage for large-scale outdoor remote surveillance missions. However, in a critical surveillance scenario such deterministic deployment may not be a feasible option due to the terrain characteristics.

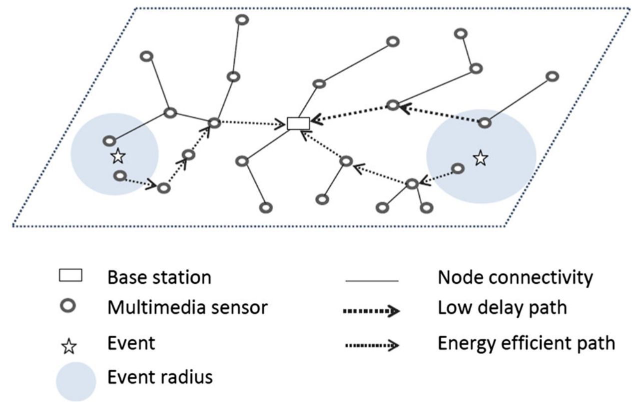


Fig. 1 Multipath scenario for randomly deployed sensors

From the above discussion we see that a tiered architecture exists for surveillance application in which audio and R&D sensors can work together to achieve the task of critical event detection. Our work also presents a two-tier architecture strategy where audio and video nodes are randomly deployed in the *Region of Interest* (RoI). These low cost audio nodes are densely deployed, while high cost video nodes are sparsely deployed over audio and video tier respectively. Our energy conservation scheme is designed for an event driven model in a heterogeneous environment. Audio sensors may work continuously to capture discrete event detection whereas video nodes are woken on demand basis. In a critical surveillance scenario whenever an event occurs, audio nodes immediately send data to the base station with the help of a connected network. The audio nodes provide a preliminary coverage while the video nodes are woken only when there is a demand. This is important because the energy cost of a video sensor is significantly higher compared to an audio node. Further, our strategy leads to low deployment cost, energy efficient approach and provides the required level of coverage for the network.

The main contributions of this paper are summarized as follows:

- We categorize events as *nominal* or *critical* where, a *critical* event requires to be handled in a *low-delay* mode upon its detection by a node. A *nominal* event is taken care of in usual mode. Depending upon the event characteristics, either a *low-delay* or a *low-energy* consumption path to the sink is selected with the help of a proposed tree based algorithm.
- We also present an energy-aware scheduling approach in which the audio nodes share the event detection information with the base station which in turn wakes up the rotatable video nodes on demand basis.
- Further, we formulate two ILPs, one for energy minimization of audio traffic and the other for the minimization of the video traffic.
- Finally, we propose two new approaches, *Greedy* and *DCSEG* (*Directional Cover Set with Energy Greedy*), and compare them with a popular existing approach known as *DCS-Greedy* [11] for various scenarios while preserving coverage and connectivity.

The rest of the paper is organized as follows: Sect. 2 discusses the previous work related to our proposed algorithms. The system model and the problem statement are presented in Sect. 3. Section 4 provides the proposed schemes of the paper. Simulation and performance evaluation is given in Sect. 5. Finally we conclude the paper sharing key points along with future scope of work in Sect. 6.

2 Related work

In this section we provide an overview of the existing work, including their limitations. An interesting application scenario for *WMSN* is in the field of critical event surveillance and monitoring systems. These systems have sensor nodes with different capabilities in terms of sensing, processing and communication. The network generates different types of traffic such as audio and video traffic, which needs to be supported via a suitable architecture [1]. Multi-tier architecture provides a suitable framework for surveillance systems by grouping multi-media nodes into different tiers. The multi-tier architecture is also advantageous for various other issues such as scalability, fault-tolerance, management etc. Since our work focuses over multi-tier architecture, we describe here some of the obtainable work in this respect. The authors of [5, 6] present a multi-tier architecture with various design objectives for applications ranging from environmental monitoring to freight train monitoring. To achieve various QoS parameters such as sensing coverage, connectivity, and network longevity, the authors of [9] presents the idea of arrangement of sensor nodes into multi-tier architecture. Multi-tier strategy for surveillance systems also lowers the deployment cost of the network. For instance, in a typical surveillance scenario we can have (a) densely deployed low cost audio tier nodes, and (b) sparsely placed high cost video tier nodes to monitor critical events occurring in a given *RoI*.

In addition to multi-tier architecture surveillance applications also requires sensing coverage and connectivity as important design parameters. Sensing coverage can be of two types such as omni-directional or highly directional coverage. The authors in [10] investigate the problem of *k*-coverage where each point of interest in the deployment field is sensed by at-least *k* sensing nodes. Similarly, when multiple cameras cover an event from different *working directions* it is referred as *multi-perspective* coverage [8]. *Multi-perspective* coverage improves the surveillance quality by providing multiple viewpoints of an event. A recent framework of *temporal* coverage for surveillance applications is proposed by the authors of [7]. This framework also reduces the number of directional sensors as each of these sensors provides 360 degree *temporal* coverage. Moreover sensing capability of the network also increases as each of the sensors can switch to several directions [11, 12]. Coverage and connectivity maintenance protocols for randomly deployed directional sensor networks are discussed in [13]. Connectivity of the network transmits the collected data to the sink with the help of a routing protocol. Routing can have various flavours such as static, dynamic, on-demand, fault-tolerant, single-path, and multi-path etc. However multipath routing is an effective strategy which is commonly used in resource-constrained WSN. Multi-path routing can use several parameters such as delay, residual energy etc. as routing metrics [14] where *infrastructure-based* multipath routing discovers and maintains multiple paths before data is being transmitted [15].

Surveillance applications may have various other metrics which need to be fulfilled. For example if an event is of high priority, then delay metric should take preference over minimization of energy. On the other hand if event priority is of average priority, then minimization of energy is the most important metric. Several metrics exists for the design of the weighted tree for the connected network [16–19]. The authors of [16] present a weighted formula for the network edge with hop count and path weight as its component. Results show trade-off of one component with the second yields different trees with interesting parameters for data routing. Upadhyayula and Gupta [17] have investigated three tree construction algorithms under latency and energy-efficient design objectives. The authors of [18] propose a new cost metric for event driven routing model where the metric balances the energy consumption in the network with the help of a balancing factor. Whenever a tree is developed, edges of the connecting nodes that has already consumed enough energy will be assigned a high cost. This reflects in the tree formation, as such edges will be discouraged in future formations. Similar scenario is used in the design of an edge cost function by authors of [19]. Here the cost function avoids the use of nodes with less residual energy and maximizes the minimum lifetime of the network. Thus, this approach helps to balance the energy consumption scenario and leads to an increase in the longevity of the network.

Minimization of network energy consumption has been investigated by several researchers from various angles [20–22]. The typical values for energy consumption in *transmit, receive, listen, and sleep* modes for a sensor node is found to be 60, 45, and 45 mW, and 90 µW respectively [21]. Further, Chen et al. [22] have demonstrated and also evaluated a novel wireless camera network system for heterogeneous sensor networks. In their work the energy consumption of a camera node in *active* and *idle* mode is assumed approximately as 970 and 550 mW respectively which we find is high compared to the other types of scalar nodes. Most commonly used energy saving strategy in sensor networks is to put the redundant nodes in standby condition [23, 24]. Other strategies such as scheduling of nodes can be done periodically or on priority basis while maintaining QoS parameters and criticality of the applications [9, 13, 25, 26]. The authors in [26] combine sleep scheduling with low delay for critical event monitoring in which an *alarm* notification transmits to the base station (BS) with a low delay path. The BS then broadcasts the alarm quickly through non-colliding traffic paths. Optimization techniques such as ILP and approximation algorithms for various sensor applications have been used in [27, 28]. Wu et al. [21] presented an efficient centralized and distributed algorithm to schedule node activities in order to reduce the energy consumption of the network. Also, given a set of directional sensors, the authors of [28] investigate the problem of minimizing their numbers while preserving coverage and presents ILP formulation for sensor placement. In [29] and [30], the authors also investigate the minimum connected sensor cover problem. The application selects minimum number of sensor nodes preserving coverage and connectivity of the network. The authors of [31] investigate the priority sensitive event detection scheme. Here, each event has an associated priority value depending on the severity and risk of damage caused by the corresponding event.

3 System model and problem statement

A node sensing and energy consumption model is assumed in this paper which is organized into a two-tier hierarchy of sensor nodes. Figure 2 illustrates the schematic representation of the hierarchical architecture. The first tier consists of audio sensors capable of detecting an event by means of an acoustic source. These are low-cost sensors and are densely deployed over a two-dimensional plane. The second tier is equipped with high-cost sparsely deployed rotational video nodes. The high-cost video sensors are required to detect events whenever such need arises.

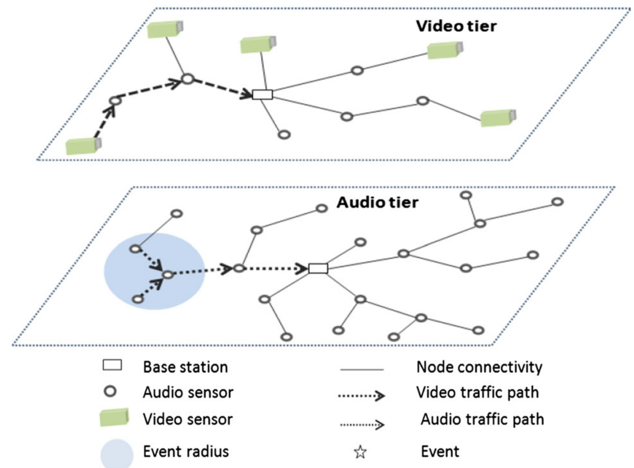


Fig. 2 *WMSN* hierarchy considered throughout the paper

The assumptions made about the network along with the multimedia node responsibilities are as follows:

- A sensing field is a circular deployment area of radius *R*. The circular field is inscribed inside a square of dimensions 2R along the two dimensional RoI.
- The sensors are randomly and uniformly distributed in a planar field where the deployment environment is free from any occlusions.
- The base station is a high power node with large computational resources. A single base station is deterministically placed at the centre of sensing field.
- We assume that the audio and video sensor nodes are aware of their location coordinates, and are time synchronized.
- All the video sensor nodes are equipped with stepper motors and rotate in a fixed unit of steps.
- The base station is aware of the network topology along with the orientation of the Rotatable-Video (RV) nodes. The base station is responsible for construction of the paths periodically and also during initialization phase.

3.1 Multimedia node characteristics

We now present the sensor characteristics for multimedia nodes in terms of sensing range. Sensing range is the distance from a node to an event which can be effectively monitored by a node. We assume sensing range for audio and video as *omni*-directional and directional respectively [32].

3.1.1 Audio node characteristics

Sensing range of the *omni*-directional audio sensor is based on the well-known Elfe's function [33]. In this model the sensor cannot detect an event if the sensor-to-event distance (x) is greater than the audio sensing range, R_{sa}. However, the detection probability for an audio is an exponential decay function when sensor-to-event distance lies between the audio threshold range, R_{tha} and R_{sa}. We define the audio threshold range where probability of target detection is *one*. The sensor characteristic is determined by two sensor technology parameters λ and μ which are positive constants as shown in Eq. (1). We now define the sensing parameters along with their typical values for a rotational video node.

$$P(x) = \begin{cases} 1 & \text{if} \quad x \le R_{tha} \\ e^{-\lambda(x-R_{tha})^{\mu}} & \text{if} \quad R_{tha} < x \le R_{sa} \\ 0 & \text{if} \quad R_{sa} < x \end{cases} \quad (1)$$

3.1.2 Rotational video node characteristics

Compared to the traditional sensors, a rotational video (RV) is highly directional in nature. Figure 3 illustrates the sensing coverage of RV with rotation or motility capability associated with a video node. The sensing coverage is temporal coverage at two discrete units of time. For the ease of explanation, we define the following terms.

3.1.2.1 Sensing range The sensing range of a video node is the area covered by AOB points in the initial condition or by A′OB′ after rotation. We will refer *FOV* or the *sensing range* approximated as an isosceles triangle as shown in Fig. 3. The *sensing radius* (R_s) is given by the maximum depth along the *working direction* of a node.

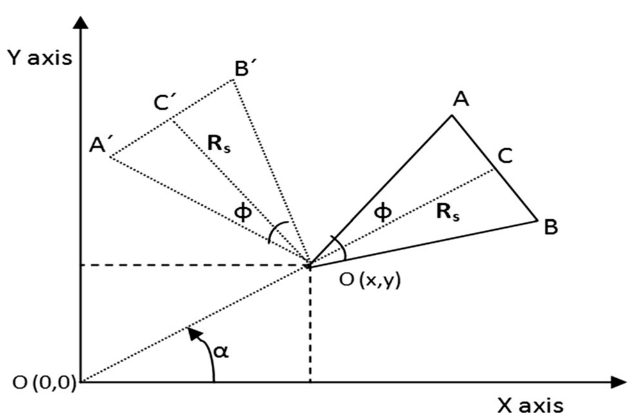


Fig. 3 Plot of rotational video (R&D) sensing coverage model for initial and final orientation of the node

3.1.2.2 Working direction ($\vec{v}$) is defined as the direction in which sensor faces with respect to its azimuth (α)

3.1.2.3 Conflict and non-conflict direction Given a set D(α) for a video node and some events in the sensing range of *RV,* if a video node requires different *working directions* in order to cover multiple events then these directions are termed as *conflict* direction. Otherwise, if the video node covers one or more events without rotation then the working direction is termed as *non- conflict* direction [11].

3.1.2.4 Position of a node A video node is represented in two-dimensional coordinate system as O. A video node is now represented with the tuple as:

$$(O, R_s, \vec{v}, \alpha)$$

The *working direction* of a static video (*SV*) node is fixed throughout its lifetime. However, *working direction* of the *RV* sensor may change with respect to time and will provide temporal coverage with the help of a servo mechanism attached to a node [34]. For the sake of simplicity we considered a two-dimensional model that can be easily extended to a three-dimensional scenario. Figure 4 presents the effect of the *sensing radius* and *working direction* of an *RV* node. As the *sensing radius* increases from 40 to 60 m there is an increase in the *coverage of RoI*. Again, with the change in the *working direction,* a node leads to *temporal* coverage as shown in Fig. 4(c). However there is a trade-off between rotational energy and coverage parameters of a node.

3.1.3 Energy consumption model

The energy consumption of a wireless multimedia sensor node is mainly due to its sensing, data processing, and communication activities [35, 36]. All of the three components can be either in *active* state or power saving *sleep* state. In this paper, we ignore energy consumption whenever a component switches from one state to the other. Table 1 presents the typical energy costs incurred by the components of a sensor node under various operational states. For the sake of simplicity we also consider two operational states: *active* and *sleep* state. In the *active* state, the processor and the sensor are in *active* state. However in the *sleep* state, the energy consumption is neglected as the value of it is significantly low.

The transceiver energy consumption depends upon the operational states, data size, and the distance between the nodes. Similar to the earlier case the energy consumption of the transceiver in the *sleep* state is also neglected due to its very low value. The *active* states for transceiver is further divided into *transmit*, *receive*, and *idle* mode. We assume that a transceiver in *active* state is either in *transmit* or *receive* mode, otherwise it is in *sleep* state. We also assume that

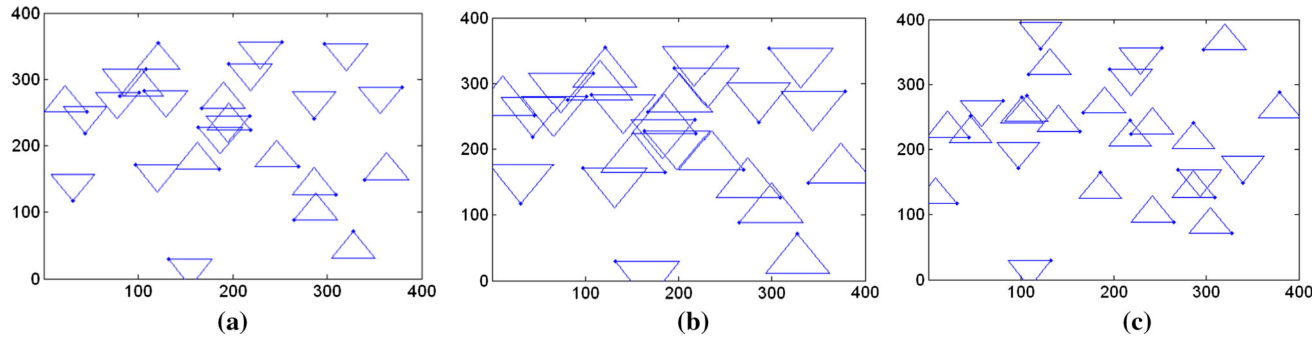


Fig. 4 *FOV* of RV with R_s **a** 40 m, **b** 60 m, **c** 40 m (with motility)

Table 1 Energy costs of a multimedia node

Component	Sensor	Mode	Power (mW)
Processor	Audio	*Active*	21.6
	Video		970
Sensor	Audio	*Active*	20
	Video		90
Transceiver energy parameters			
E_{elec}: 50nJ/bit		ε_{amp}: 100 pJ/bit/m^2	
Rotational energy parameters[a]			
0.3 J per 60 degree or *one* sector degree panning			

[a] Adapted from [34]

a low-power radio known as *wake-up radio* monitors the radio channel and wakes up the sensor node on demand basis. The most commonly used energy consumption model for a transceiver is the first order radio model. In order to transmit *k* bits of message from a sender to a receiver over a distance of d meters we know that:

$$E_{trans}(k, d) = E_{elec} \times k + \varepsilon_{amp} \times d^2 \quad \text{and} \\ E_{rec}(k) = E_{elec} \times k \tag{2}$$

where E_{trans} (k, d) is the energy consumption function for the transmitter, E_{elec} is the energy consumption of the transmitter circuitry and ε_{amp} is the energy consumption of an amplifier circuitry. Similarly in order to receive *k* bits of a message from the sender, the energy consumption function for the receiver is given by $E_{rec}(k)$. Typical values of E_{elec} = 50 nJ/bit is same for both transmitter and receiver circuitry as shown in Table 1.

3.2 Event detection

In our work we have categorized events as *nominal* or *critical*. A *critical* event requires to be handled in a *low-delay* mode upon its detection by a node. We assume that each event has a designated sensing attribute and each multimedia node stores a lookup table to assign priority to an event. Depending on the specified sensing attribute of an event, the event can be handled in a *low-delay* or in an *energy-efficient* manner. In our work we have adopted two phase event detection process where the audio node detects an acoustic nature of an event and passes on the information to the base station with the help of a connected network. The base station then activates the rotational video nodes to cover the event. Let us now consider a scenario where two events with different priorities are detected by the audio nodes. On detection the audio node first sends an ALARM message to the base station and based on the priority of an event the audio and rotational video node selects multiple routes in order to attend the event. Moreover, both the type of events (*nominal* or *critical)* may have a varying level of coverage parameter to be satisfied.

3.3 Problem formulation

We assume that a base station (BS) is placed as a centre node in a deterministic manner and is responsible for obtaining the network topology during the network initialization. The BS also coordinates among the multimedia nodes and computes an energy saving scheme. Now, as soon as a *critical* event occurs in the network, the audio nodes detect it and send an ALARM message to the BS so that a route, based on the event, can be selected from its source to the sink. Therefore, we formulate our problem statement as follows:

Given a set of discrete events with priority whose occurrence is random in terms of location and time, these events are to be monitored by a set of audio and rotatable video sensors. The problem is to propose a strategy for critical event surveillance such that the two divergent parameters energy consumption and communication delay of the network is optimized while preserving its coverage and connectivity.

4 Proposed algorithm

In this section, we first elaborate the topology formation phase of our two tier sensor network architecture and then discuss our Weighted Shortest Path Tree (*WSPT*) approach.

We then present the base station and multimedia algorithms for our event surveillance strategy. Further, we present two *ILP* formulations and two heuristics algorithms for optimization of energy in the two tier sensor network presented in Sect. 3.

4.1 Topology formation

Multipath routing establishes multiple paths from source to sink node for transmission of data. These multiple routes differ in terms of energy consumption and hop delay. We propose Infrastructure-*based WSPT* where construction of multiple paths is done during initialization phase. First we take a look at the topology formation with the help of cost function and Weighted Shortest Path Tree (*WSPT*). The audio and video nodes soon after deployment are put into an initialization mode. These randomly placed audio and video sensors send their co-ordinates to the base station so that the two-tier architecture is in place. Our cost function for weighted edge in *WSPT* takes path delay and path energy consumption into account which is discussed next.

4.1.1 Case I: edge delay metric

We assume path delay as a function of the number of hops and average node degree along the path. This can be explained with a simple scenario: A high average node degree along a path leads to higher end-to-end path delay. This is due to the fact that data transmission delay increases for a high degree node. Again if the hop counts along the path is more, it requires more time for data transmission along the path. Let $d(u)$ and $d(v)$ denote the node degree of the nodes u and v respectively. Again let $h(u)$ and $h(v)$ denote hop count of nodes u and v from the sink respectively. The hop count is computed based on shortest path tree from the sink node. A *max* function selects an appropriate edge during the path construction phase. The function *max* returns the maximum of two values that are supplied as its arguments. Thus $max(h(u), h(v))$ returns $h(u)$ if hopcount of the node u is greater than $h(v)$. Similarly, we denote $max(d(u), d(v))$ as the maximum of the two degrees for the node u and v respectively. We know that *Eccentricity* of the sink (v_0) is the maximum number of hops between the sink and any other vertex in the network. Therefore, the edge delay δ_{uv} for the two nodes u and v can now be computed as

$$\delta_{uv} = \frac{\max(\mathrm{h(u), h(v)})}{\epsilon(v_0)} \times \frac{\max(\mathrm{d(u), d(v)})}{\Delta} \tag{3}$$

where $\epsilon(v_0)$ eccentricity of sink node, Δ maximum node degree.

4.1.2 Case II: energy metric

Energy is directly proportional to the power of the distance between two nodes. We represent the edge cost $\Psi(u,v)$ as the transmission energy consumption between u and v nodes. Let Φ be the maximum path energy consumption of some edge in the network. We omit the reception energy for the sake of convenience. Let us further assume that e_{uv} is the normalized energy of an edge between the nodes u and v in the network. Therefore we have,

$$e_{uv} = \frac{\psi(u,v)}{\Phi} \tag{4}$$

In Eq. (5) we define a cost metric as the function of two components, delay and energy between any two pairs of connected nodes. The weights w_1 and w_2 are adjusted to obtain the desired *WSPT* constructed from the well-known shortest path algorithm available in the literature.

$$c_{uv} = w_1 \times \delta_{uv} + w_2 \times e_{uv} \tag{5}$$

4.2 Tree construction

Let us assume the (v_1, v_2, … v_n) be the sensor nodes and let v_0 be the sink node. For the sake of simplicity we assume that the transmission range (R_c) of each node is same for the entire set. Each edge is assigned a cost c_{uv} for a given node set of u and v pair of nodes. We now present the WSPT (Weighted Shortest Path Tree) algorithm which is based on Dijkstra's algorithm. Because Dijkstra's algorithm always chooses the closest vertex, we say that it uses a greedy strategy. WSPT is constructed in which edge weights are computed using Eq. (5). WSPT is constructed with base station as the source node and all nodes in set as the destination nodes. Figure 5(a) and (b) illustrates *WSPT* under low path delays and low path energy consumption along the paths. In order to maintain the optimal *WSPT* periodic tree, construction or adaptive approaches available in the literature can be used [37].

4.3 Algorithm for base station

The base station (BS) is a powerful node with high computational power and sufficient energy resources. BS coordinates with the audio and video tier nodes to detect any event that may happen within the coverage area of the network. The algorithm works in two phases. The first phase is the initialization phase for construction of video and audio tier *WSPT*. In order to construct the video tier *WSPT,* some audio nodes may be utilized as relay nodes. Rest of the dense audio deployment nodes forms a connected audio tier *WSPT*. The second phase is the waiting phase till an ALARM is received from the audio nodes. Upon reception of an ALARM by the base station, only a subset of the nodes' set are sent the notification to collect data containing information. Notification is based on some optimization criteria (ILP or heuristics) and can be computed during initialization phase. We give the pseudo code for Algorithm 1 that should run at the base station with complexity of O(|N|), where N is the total number of multimedia nodes.

4.4 Algorithm for multimedia node

Algorithm 2 discusses the pseudo-code which is run by the multimedia nodes with constant time complexity. We assume that a multimedia node is equipped with a low power wake-up device and changes state from *sleep* to *active* during its lifetime. The authors in [38] discuss a low power wake up radio to put the node from *sleep* to *active* state for effective radio communication. Similarly the authors in [34] propose a framework in which low energy consumption devices activates high energy consumption devices.

```
Base_Station_Algo ( )
{
/*initialize*/
/*receive location from audio nodes */
/*receive location and orientation from video nodes */
/*construct weighted tree using (5) */
/* send path information to all nodes */
while (1) do
    wait for event ();
    if (event = = ALARM) then
        select the audio node(s) based on event
        select the video node(s) based on event
        send the event notification to the selected audio node
        send the event notification to the selected video node
    end
    if (event = = DATA) then
        receive sensing data from selected audio and video nodes
    end
end
}
```

Algorithm 1: Base_Station_Algo( )

```
Multimedia_Node_Algo ( )
{
/*initialize*/
/*send coordinates and orientation to BS*/
/*wait for path information from BS*/
/*store path information in look up table*/
while (1) do
    wait for event ();
    if (node= = AUDIO) then
        if (event = = ALARM) then
            send ALARM to the BS
            wait for notification
            if (event = = NOTIFICATION) then
                send DATA to the BS
            end
            if (event==TIMEOUT) then
                sleep
            end
        end
    end
    if (node= = VIDEO) then
        if (event = = NOTIFICATION) then
            Adjust direction of the sensor if required
            send the DATA to the BS
        end
    end
end
}
```

Algorithm 2: Multimedia_Node_Algo( )

4.4.1 State diagram

Figure 6(a) and (b) illustrates state transition diagram for audio and video nodes respectively. As shown in the figure, the video sensor is in *active* state only if the NOTIFICATION is received by the BS along the *WSPT*. Further, only a subset of video sensors is put into *active* state. The nodes then enter into DATA gathering state for transmission of DATA.

4.5 ILP formulations

We present an *ILP* model whose sole goal is energy optimization for the audio and video tier nodes. We assume that the events those are generated in the network are transmitted quickly to the base station via multiple paths. The *ILP* formulation helps us to optimize the number of paths required for the data transmission. Figures 7 and 8 illustrates the critical surveillance scenario for audio and video traffic via multiple paths.

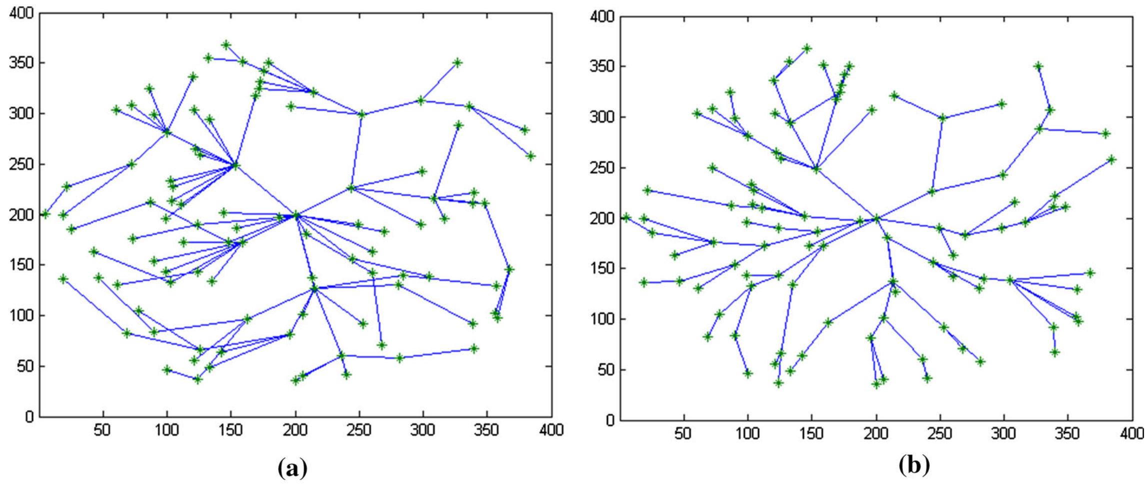


Fig. 5 *WSPT* with $R_c = 75$ m, 100 nodes, sink is located at (200, 200). **a** ($w_1 = 1, w_2 = 0$), **b** ($w_1 = 0, w_2 = 1$)

4.5.1 Minimum energy consumption for audio tier (MEAT) network

We formulate the minimum power consumption problem as *ILP* problem which aims to minimize the audio traffic energy consumption under the condition of audio coverage preservation. We also formulate the minimum sum of rotational and transmission for video sensors. In our work, an event is covered by k (where $k \geq 1$) or more audio sensors.

4.5.2 Decision variables

We define a decision variable X_i, which is a *0–1* variable such that X_i equals *one* if the audio sensor transmits its data to the base station. X_i equals *zero* if the audio sensor does not transmit its data to the base station. The objective function is given by

$$P_1X_1 + P_2X_2 + \cdots + P_nX_n \quad (6)$$

where P_i is the total path energy consumption for an audio traffic generated at the ith audio sensor node and sent to the base station. The above objective function minimizes the total energy consumption for transmission of audio data to the base station subject to the coverage constrains:

$$X_1 + X_2 + \cdots + X_n \geq k \quad (7)$$

Here k is the required degree-of-coverage for each discrete event. This constraint requires that for each event the required degree of audio coverage satisfies.

4.5.3 Minimum energy consumption for video tier (MEVT)

We formulate the minimum power consumption as *ILP* problem which aims to minimize the sum of video traffic and rotational energy consumption under the condition of video coverage preservation. Multiple camera view coverage is the required quality of service parameter and needs to be preserved. In our work, an event is covered by k' or more video sensors ($k' \geq 1$) from different directions thus providing multiple camera view coverage [8].

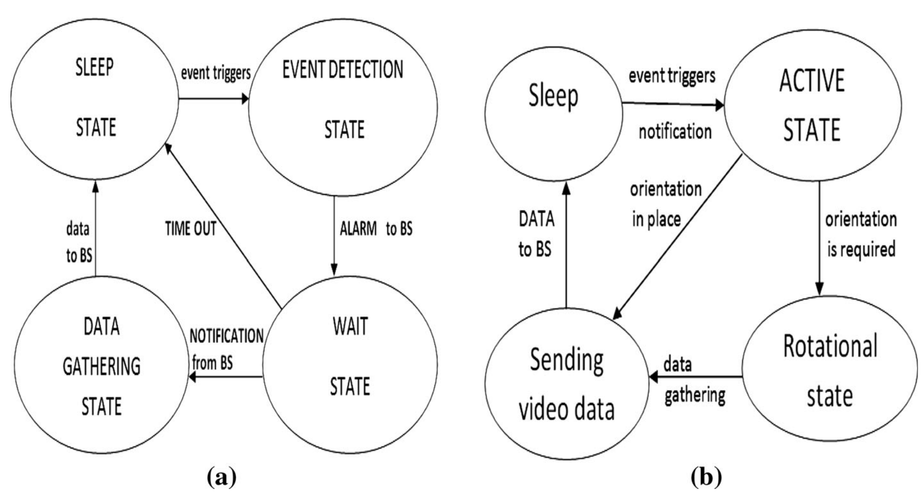


Fig. 6 State transition diagram for **a** audio, **b** video nodes

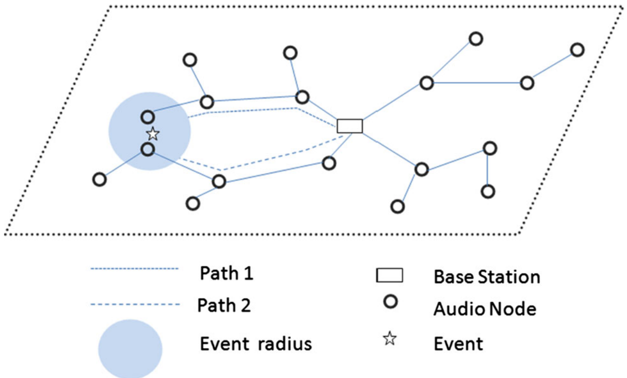


Fig. 7 Audio traffic transmitted to BS

4.5.4 Decision variables

We define a decision variable for a video sensor node:

$$X^{v}_{d_{i,f}} = \begin{cases} 1, & \text{if sensor v having i and f as initial and final orientations.} \\ 0, & \text{otherwise.} \end{cases}$$

where $d_{i,f} \in D(\alpha)$ such that $D(\alpha)$ is the set of possible orientations for a video node. The objective function is given by the following equation that minimizes the following expression while satisfying a set of constraints and requirements. Thus the objective function is

$$\sum_{\{v \in V_v\}} \sum_{\{d_{i,f} \in D\}} X^{v}_{d_{i,f}} (P_{d_{i,f}} + P_v) \quad (8)$$

where $(P_{d_{i,f}} + P_v)$ is the sum of rotational energy consumption and the total transmission energy along the W*SPT* for a video traffic generated at the *v*th video sensor node and sent to the base station. The above objective function minimizes the total energy consumption for transmission of video data to the base station subject to the coverage constrains:

$$\sum_{\{d_{i,f} \in D\}} X^{v}_{d_{i,f}} \leq 1, \forall v \in V_v \quad (9)$$

and

$$\sum_{\{v \in V_v\}} \sum_{\{d_{i,f} \in D\}} X^{v}_{d_{i,f}} \Theta^{v}_{d_{i,f}} \geq k' \quad (10)$$

$$\Theta^{v}_{d_{i,f}} = \begin{cases} 1, & \text{if coverage matrix covers the event.} \\ 0, & \text{if coverage matrix cannot cover the event.} \end{cases}$$

Equation (9) guarantees that at any particular instance of time each video sensor can have only one initial and one final orientation.

In Eq. (10) k' is the required degree-of-coverage for each discrete event. This constraint requires that for each event the required degree of multiple camera view coverage satisfies.

Both *MEAT* and *MEVT* can further take the advantage in case of dense node deployment. This is due to the fact that several paths from a source to a sink node result in such dense deployment scenarios. The variables required by *MEAT* and *MEVT* are of the order of (|N|) and (|N| × |D|) respectively.

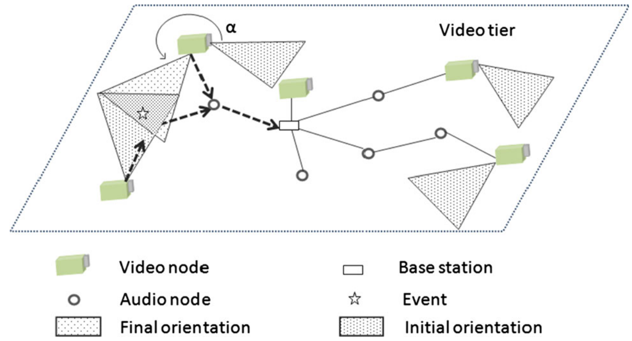


Fig. 8 Video traffic transmitted to BS

4.6 *Greedy* and *DCSEG* algorithm

In this section we propose two approaches namely, *Greedy* and *DCSEG* which are inspired from *DCS-Greedy* [11] and we find them suitable for large-scale sensor deployment. Here we use a policy called the pivot-policy to select an event where the selected event (e*) is covered by a minimum number of sensors. Even though the selected event may be covered by a number of sensors, we select the sensors (s*) those consume the minimum energy in terms of path energy consumption, processor energy consumption, and/or rotational energy (applicable for video sensors). Here the greedy heuristic algorithm selects the local optimal choice.

```
Input: event_list, sensor_list
Greedy algorithm
{
select the event e* according to pivot policy;
select the minimum energy sensor s* covering e*;
mark the event e* as covered by s* (s*, e*);
event_list ⟵ event_list − {e*};
remove all the events e′ covered by s*; (s*, e′);
sensor_list ⟵ sensor_list − {s*};
remove the sensors with no event coverage;
if ( sensor_list != empty ) then
 | goto start;
else
 | stop
end
}
Output: sensor to event assignment list
```

Algorithm 3: Greedy algorithm

Input: event_list, sensor_list: (conflict, non-conflict)
DCSEG algorithm
{
select the event e* according to pivot policy;
select the non-conflict minimum energy sensor s* covering e*;
mark the event e* as covered by s* (s*, e*);
event_list ⟵ event_list − $\{e^*\}$;
remove all the events e' covered by s*; (s^*, e');
non-conflict_list ⟵ non-conflict_list − $\{s^*\}$;
remove the sensors with no event coverage;
if (non-conflict_list ! = empty) **then**
| goto start;
else
| goto next step;
end
select the event e** according to the pivot policy. select the conflict minimum energy sensor s** covering e**;
if (conflict_list ! = empty) **then**
| goto next step;
else
| stop;
end
remove all the working directions of s** except current.
mark this sensor as non-conflict sensor;
goto start;
}
Output: sensor to event assignment list

Algorithm 4: DCSEG algorithm

Our second algorithm *DCSEG* selects an event according to a pivot policy similar to *DCS-Greedy*. However the algorithm selects the sensor in order to cover an appropriate event according to minimum energy requirement among the candidate nodes. In *DCSEG* approach the sensors are divided into two parts: *conflict* sensor direction and *non-conflict* sensor directions similar to [11]. Algorithm 3 and Algorithm 4 provides the description of *greedy* and *DCSEG* algorithms. We represent |*N*| and |*T*| as the total number of multimedia sensors and number of events respectively. Both *Greedy* and *DCSEG* have time complexity of O((|T| + |N| log|N|) |T|). Line 1 requires O(|T|) in order to select an event. Line 2 requires O(|N| log|N|). Further, the total complexity of the algorithm is bounded by the outer loop by O(|T|).

5 Performance evaluation

In this section, we present the simulation results that has been obtained using our proposed approach. The network in each scenario is modelled using our custom simulator written in C over Linux platform. Intel Core i5 processor with 8 MB RAM is used for this work. ILP optimization tool CPLEX has been used for implementation of the ILP model. The other algorithms are implemented with the help our custom built simulator. We conduct extensive simulations to study the impact of various performance metrics.

5.1 Weighted shortest path tree (WSPT)

WSPT is a weighted tree with edge weight calculated using to Eq. (5). We know that the tree topology is fundamentally determined by the transmission range (R_c) of nodes and their distribution over 2-D plane. Again, for a given number of audio and video nodes with identical distribution and same R_c, both will produce similar *WSPT*. Here we only present weighted tree for the video tier. The two parameters delay (δ_{uv}) and energy consumption (e_{uv}) are normalized in the range of [0, 1]. These two parameters are assigned weights w_1 and w_2 respectively. We now plot the tree construction while varying various parameters one at a time so that the effect of a parameter reflects well.

The deployment field is of dimensions 800 × 800 square meters with a radius of 400 m. The location of BS is (400, 400). The transmission range for the node is fixed at 200 m. Figure 9 illustrates the energy efficient and low-delay links for a *WSPT*. Observing the Figs. 9a–c, we find that as weights w_1 increases and w_2 decreases in the range of [0, 1] and [1, 0] respectively, the characteristics for the tree changes significantly. Figure 9a is an energy efficient tree with an average path energy consumption of 71.790 mJ and average path count of 3.64 hops. However in Fig. 9c, the average path energy consumption is 98.742 mJ and the average path count is 1.92 hops. Therefore the results show that the tree in Fig. 9.c can be used as low-delay tree whereas Fig. 9a can be used for as an energy efficient topology. The tree in Fig. 9b presents a middle approach with average path energy consumption and average path delay as 86.824 J and 1.94 respectively.

We also investigate the effect of random and Gaussian node distribution over average energy consumption and hop count for the tree. For a given number of 50 nodes we observe that the average energy consumption and average hop count is always lower for Gaussian distribution as compared to a random distribution of nodes. This is due to the fact that in Gaussian distribution, nodes tend to cluster around the sink. However, from the coverage point of view, this leads to a low coverage of boundary events for Gaussian distribution of nodes.

We now plot the average path energy consumption and average hop delay per path for different types of trees. The parameter settings of weights are varied for a given scenario. The number of video nodes is varied from 50 to 400 in steps of 50 video nodes. We take two transmission ranges as 75 and 100 m respectively. Figures 10 and 11 plots the two metrics for various parameters settings.

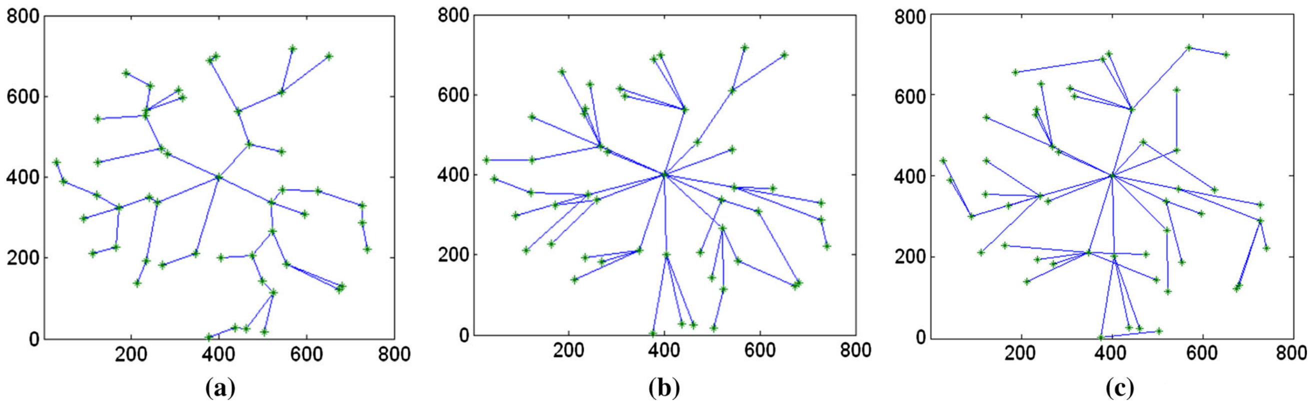


Fig. 9 Plot of tree topology versus weights (w_1, w_2). **a** (0, 1), **b** (0.5, 0.5), **c** (1, 0)

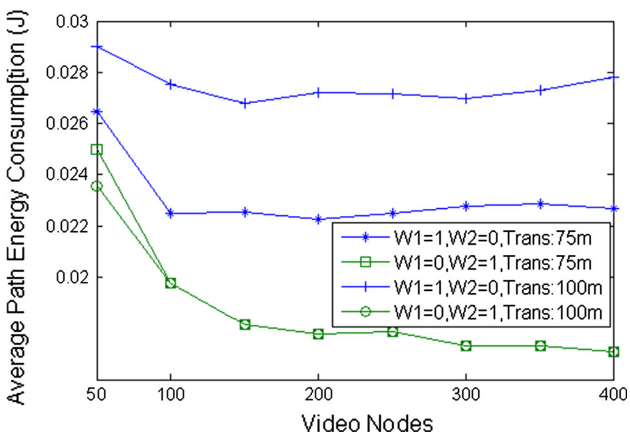


Fig. 10 Plot of average path energy

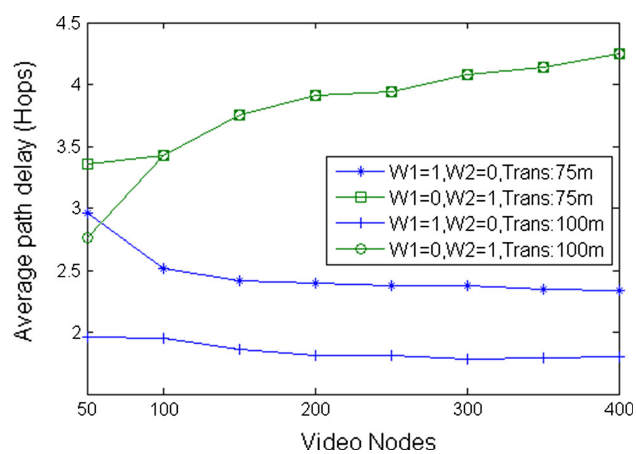


Fig. 11 Plot of average path delay (hops)

As shown in Fig. 10, for energy efficient tree the average path energy consumption is significantly less as compared to low delay tree. With an increase in transmission radius, more number of paths are available which in turn leads to more energy efficient paths. However for delay efficient trees, energy is not the prime concern as reflected in Fig. 10. Figure 11 plots the average path delay in terms of hops for various settings. As is evident from the figure the low delay trees leads to a less average hops per path. This is not true for energy efficient trees where energy is a primary concern. We also observe from the Fig. 11 that an increase in transmission range increases the degree of connectivity. This leads to more available options for transmission during the process of tree construction which in turn leads to lower values for delay paths.

5.2 Coverage by multimedia nodes

The simulation parameters used in this section are taken from Table 2. Audio and video nodes are fixed as 100 and 200 nodes respectively. We now take various scenarios for static video (SV) and rotational video (RV). In both of these cases we take two values of the working distance as 40 and 60 m respectively. Figure 12(a) and (b) presents the event coverage for video and audio nodes respectively. Rotational videos show enhanced coverage as compared to static videos. This is due to the fact that coverage area is more for a rotational video node than for a static video node. However, this comes at the expense of the motility energy required by a node. We also investigate the multiple coverage scenario of an event by audio and video nodes. We observe that such scenarios are only useful in cases of dense deployment of nodes.

We now plot the audio coverage of events. For the first scenario the range is fixed as 40 m whereas for the second scenario the range is fixed as 80 m respectively. The uncertainty range for the two scenarios is kept as 25 and 50 m respectively. The successful detection of an event depends upon the audio and video coverage and the scheduling scheme. Due to poor audio coverage the event

Table 2 Simulation parameters used in the paper

Plane characteristics	
Deployment plane (m^2):	400 *400, 800 *800
Deployment type:	Circular
Deployment radius:	200, 400
Node deployment	
Audio:	Random (omnidirectional)
Video:	Random (rotational and directional)
Events:	Random
Number of audio nodes:	200
Number of video nodes:	100
Events:	{50, 100… 500}
Video packet size:	19.2 Kbps
Audio packet size:	128 bps
Optimization	*ILP,* Greedy
w_1, w_2:	{0, 1}{0, 1}
Connected network:	*WSPT*
Communication range:	75 m
Audio characteristics	
λ:	0.9
μ:	0.1
R_{tha}:	50 m
R_{sa}:	80 m
Thres:	0.9
Detection model:	ELFES
Video characteristics	
Working distance:	100 m
Horizontal and vertical angle:	60°
Azimuth angle:	{0°, 60°,120°, 180°, 240°, 300°}
Elevation angle:	{0°}
Detection model:	Boolean
Rotational energy (J/sector):	0.3 J
Base station	
Location:	(200, 200), (400, 400)

may remain undetected by the audio nodes where the video nodes are not informed about the occurrence of an event even if they are capable of covering the event. One of the solutions to detect an event with a higher probability is to deploy a large number of nodes over the region of interest (*ROI*). However this leads to an increase in the overall network energy consumption.

Figure 13(a) and (b) presents the coverage of the video nodes for sparse and dense video nodes. The number of video nodes selected for sparse and dense deployment is 25 and 100 nodes respectively. Similarly the area coverage of sparse and dense audio nodes is shown in Fig. 14(a) and (b) respectively.

5.3 Energy reduction with MEAT and MEVT

In this section we evaluate our two optimization scheme: *MEAT* and *MEVT*. We evaluate the number of active visual and audio nodes and then measure the network energy consumption. We also investigate the effect of our protocol in prolonging the network lifetime. As is evident from Table 1, energy consumption of a video node is significantly higher compared to an audio node. Thus activation of the video node on demand basis leads to an energy efficient coverage.

In Fig. 15 we plot the number of audio and video nodes with and without ILP. We see that both *MEAT* and *MEVT* reduce the number of audio and video nodes substantially. We observe that without optimization the number of nodes is significantly higher. This is because in this case all nodes covering the events transfer data to the sink. However M*EAT* and *MEVT* select nodes based upon coverage requirement and therefore requires minimum path length and processor energy. However the video nodes follow an additional requirement of minimum rotational energy.

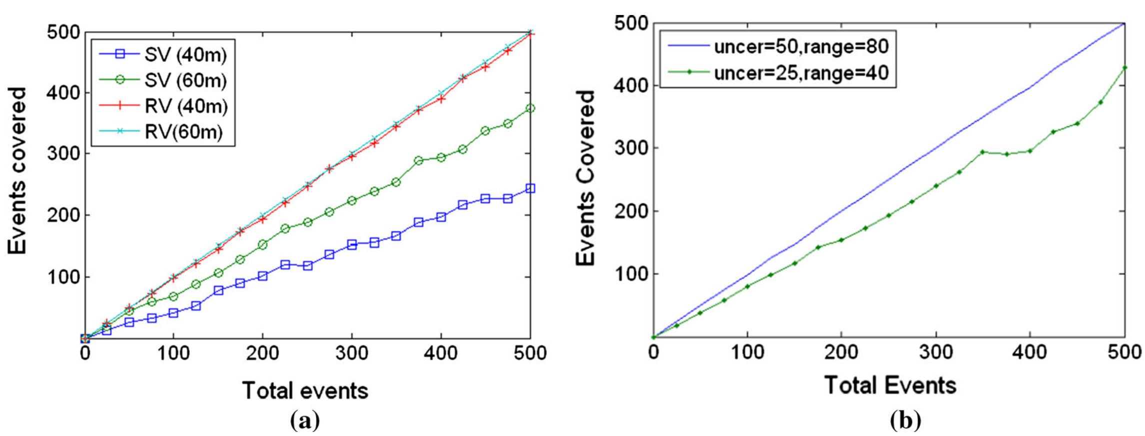


Fig. 12 **a** Plot of event coverage by video, **b** plot of event coverage by audio

Fig. 13 Video node FOV for **a** sparse, **b** dense deployment

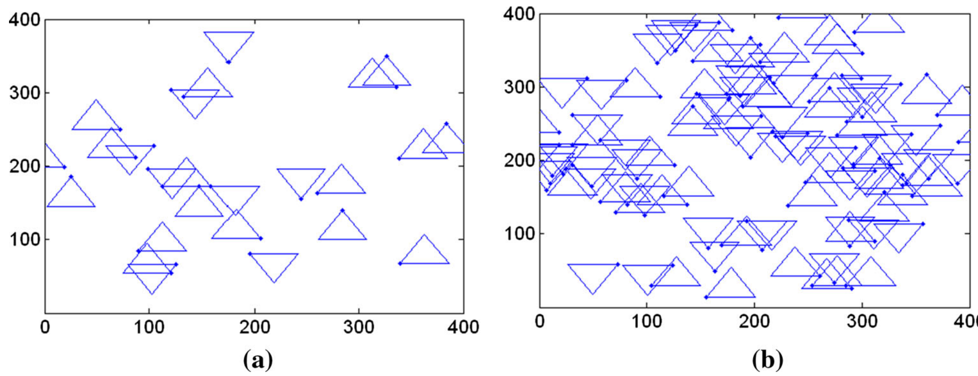


Fig. 14 Audio coverage for **a** sparse, **b** dense deployment

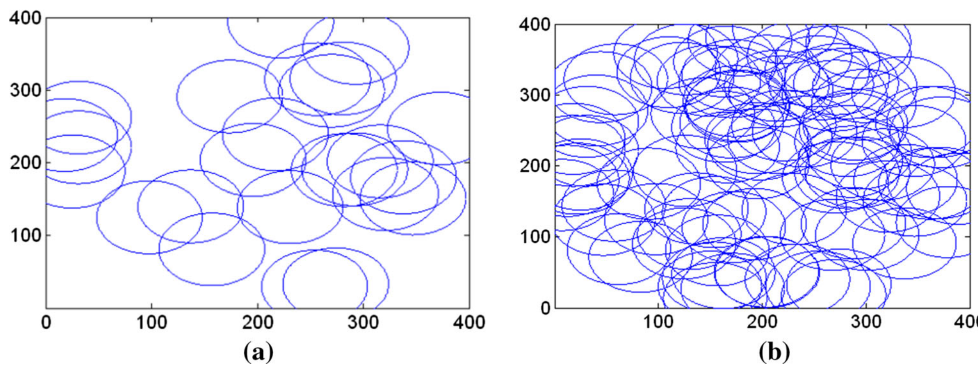


Figure 16 illustrates the scenario for the path energy consumption by *MEAT* and *MEVT* algorithm. Results show that the optimization reduces energy consumption of video nodes and leads to an increase in total residual energy of the network. This is due to the fact that only optimized route are selected for data transfer.

5.4 Detection of an event with *Greedy*, *DCSEG*, and *DCS-Greedy*

In this section we present the simulation results that compare our approach with existing protocols. Figure 17 presents the *greedy*, *DCSEG*, and *DCS-Greedy* approaches [11]. The event priority coverage or *degree-of-coverage* is fixed as *one (1)* for all the events. The gathered data is transmitted to the sink with the help of energy efficient *WSPT*. We take into account the amount of energy consumed by the nodes in sensing, rotation, and transmitting the gathered data to the sink. *DCSEG* and *DCS-greedy* approach works in two phases: In the first phase the *non-conflict* sensors which cover an event are selected followed by *conflict* sensors in the second phase. In both cases the event to be covered is determined by a pivot policy. In our *greedy* approach we keep the event selection criteria based on a pivot policy. However the greedy approach works in one phase only. Here the sensor selected for coverage requires minimum energy to carry out its operations.

Figure 17(a) and (b) illustrates the number of video and audio nodes required by the three approaches. The video node coverage is highly directional and are placed randomly over the area of coverage. This is reflected in Fig. 17(a) for all the three schemes. However, when comparing between the three approaches, we find that DCSG leads to higher number of the omni-directional audio nodes.

Figure 18(a) and (b) plots the average video energy per event for the three schemes and also for all the events without any optimization techniques. Results show that when DCSG is used the nodes consume more energy compared to the other schemes.

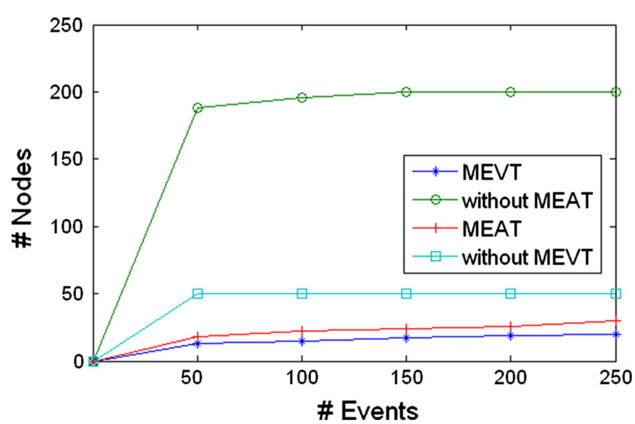


Fig. 15 Plot of number of nodes versus events

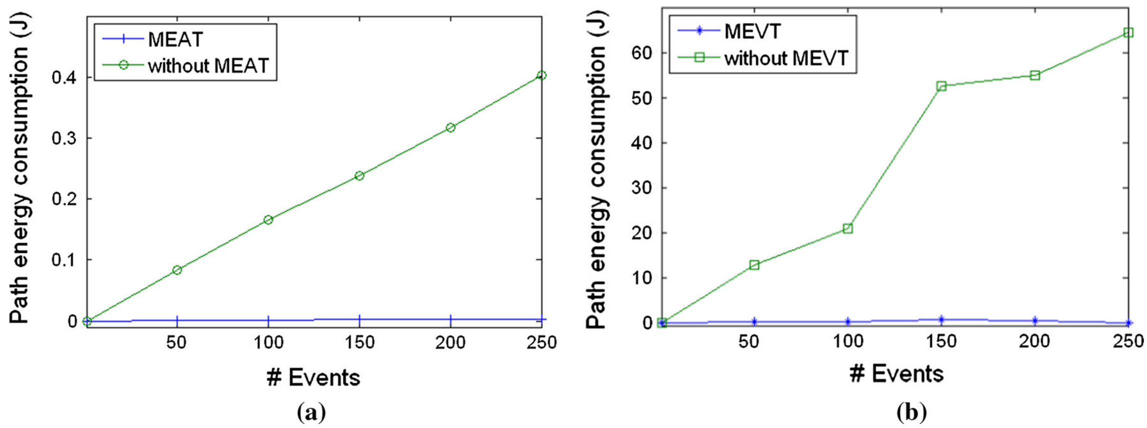


Fig. 16 Plot of path energy consumption of **a** audio, **b** video nodes

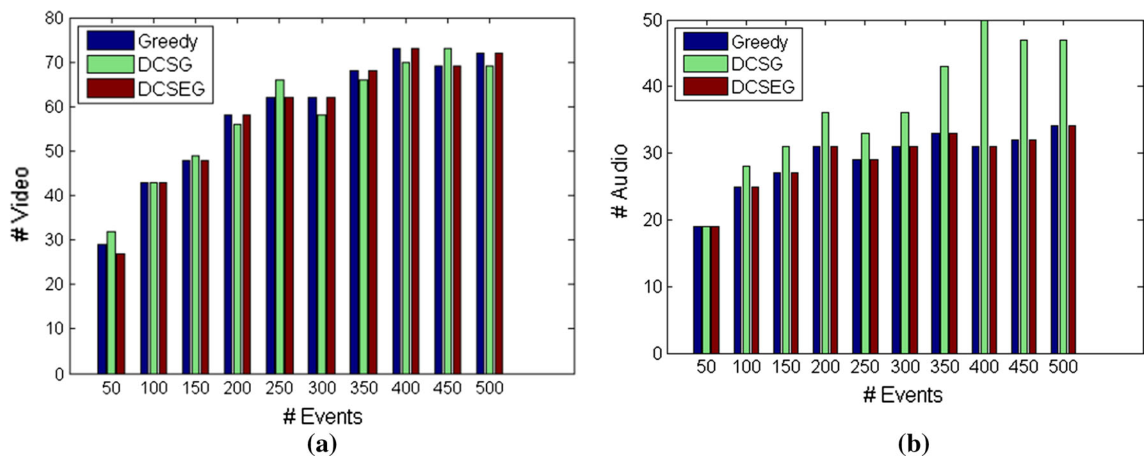


Fig. 17 Plot number of **a** video, **b** audio nodes versus events

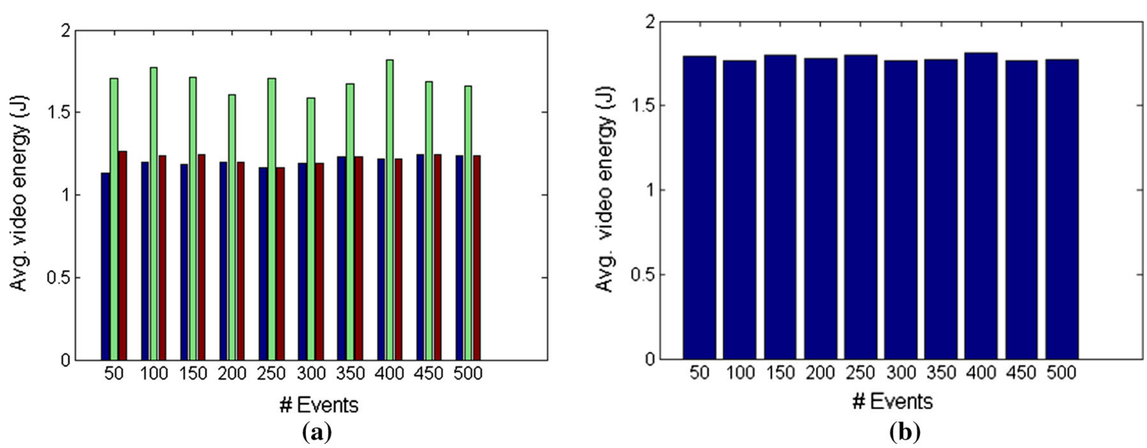
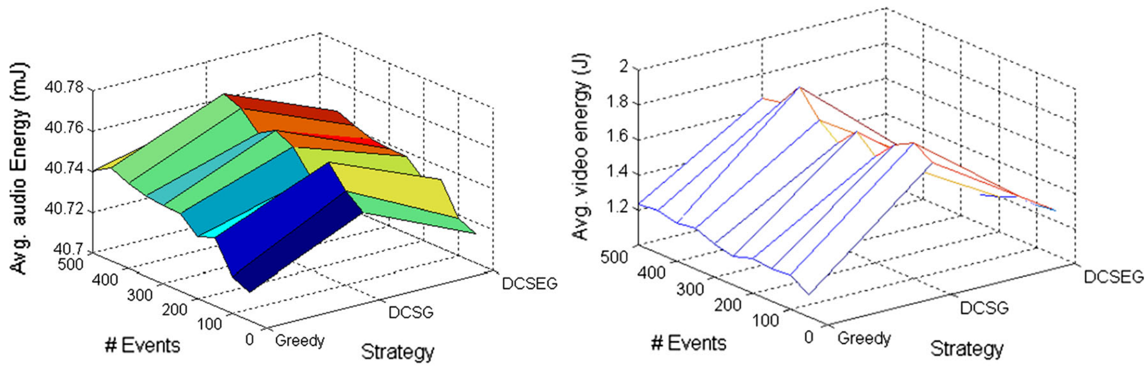


Fig. 18 Plot of Avg. video energy per event for **a** optimization, **b** without optimization



(a) (b)

Fig. 19 Plot of Avg. energy per event for **a** audio, **b** video nodes

Finally we plot the average audio and video energy consumption for all the three schemes in Figs. 19(a) and (b) respectively. Here too we observe that the DCS-greedy shows high energy consumption as compared to the other two schemes.

6 Conclusion and future scope of work

Multimedia sensors consumes large amount of energy in multimedia processing and transmission. Energy efficient design with temporal coverage and connectivity preserving is an important design parameter for such applications. In this paper, we propose an energy efficient strategy for *WMSN* based on coordinated information received from the audio nodes. An ALARM message is passed on to the base station through a non colliding path in a delay tolerant and energy-efficient manner. We formulate two energy minimization *ILPs* for audio and video tiers separately. We also propose two approaches, namely *greedy* and *DCSEG* for large scale sensor deployment. Simulation experiments performed with different performance metrics showed that our approaches reduce total energy consumption while maintaining the *QoS* parameter such as coverage and connectivity of the network. In future we plan to extend this study to three-dimensional wireless multimedia sensor networks with new scheduling schemes for audio nodes, and with varying degree of coverage and connectivity.

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