

SCMC: An Efficient Scheme for Minimizing Energy in WSN using A Set Cover Approach

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Abstract

Wireless Sensor Networks (WSNs) are used in a wide variety of applications ranging from national security to environmental monitoring. Their wide use has addressed a major flaw among these networks, which is energy conservation. The mission is to have every target to be inside the sensing boundaries of one sensor at minimum. In this paper we propose an efficient Set Cover Min Cost (SCMC) approach to maximize WSN lifetime and minimize energy consumption by using a set cover method for creating clusters, and a min-cost flow method for routing. A linear programming (LP) formulation for such problem is presented. This formulation considers minimizing energy for all nodes in each set cover (cluster), and then minimizing routing energy between nodes and base station through intermediate nodes, namely cluster heads. To evaluate the performance of such scheme, extensive simulations with different scenarios are conducted. The results show that the set cover approach combined with the min-cost flow algorithm reduces energy consumption and increases lifetime and network throughput.

Keywords:

Set Cover, Min Cost Flow, Cluster, Optimization, Wireless sensor network, Routing

1. Introduction

Wireless Sensor Network (WSN) refers to a large number of spatially distributed autonomous nodes that organize themselves into a multi-hop wireless network for monitoring and recording the physical or environmental conditions such as battlefield surveillance, target tracking, security, environmental control, habitat monitoring, source localization, fire detection, oil and gas pumping and much more. (Fig 1).



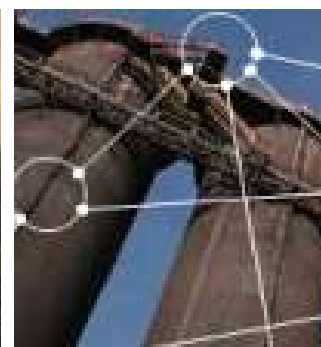
Structural Monitoring



Bio-Habitat Monitoring



Disaster Management



Industrial monitoring



Military surveillance



Home/building security

Figure.1 WSN applications

A WSN system consists of distributed nodes and a gateway that provides wireless connectivity back to the wired world (see Fig.2). They can be organized into three types of network topology as shown in Fig.3.



Figure.2 WSN Components, Gateway, and Distributed Nodes

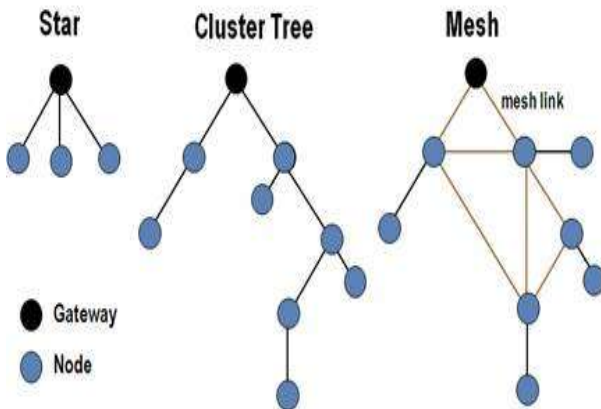


Figure.3 WSN Topology

Because they are usually deployed in harsh environmental scenarios, WSN nodes most of the time rely only on their battery, which has a finite capacity. For this reason, it is very important to extend the lifetime of sensor nodes without sacrificing their functionality. Thus, the study of minimizing energy consumption is very important in this situation.

In WSNs, all nodes share common sensing tasks covering some target areas. This implies that not all sensors that are deployed within the same target area are required to perform the sensing task during the whole system lifetime. Sensor nodes consume more energy when they are in the transmission mode (active) than being in sleeping mode (inactive). If all sensor nodes within a coverage target area are all active, a huge amount of energy will be consumed and wasted, and the data collected will be redundant. For this purpose, in the new approach, we propose to turn off some nodes within each target area (set cover/cluster) while conserving the system connectivity and without disrupting the overall system function. In this manner, we aim at expanding the WSN's lifetime and minimizing the energy consumption.

The key idea of this paper is to firstly create clusters based on a minimum set cover algorithm, where, within each cluster, an optimization objective function represented by a LP model is proposed. The solution of the proposed LP model will allow as many sensor nodes as possible to be turned off most of the time, subject to preserving the network connectivity and minimize the energy consumption within each cluster, thus in the whole WSN. Secondly, we minimize the energy of routing between cluster heads (CHs) to the base station using a min-cost flow algorithm. The remainder of the paper is organized as follows: Section 2 presents related work, while Section 3 presents network models and assumptions. Section 4 describes simulation results, and Section 5 concludes the paper.

2. Related Work

Three fundamental issues in WSN are: coverage, connectivity and battery lifetime [1], [2] and [3]. *Coverage* determines how well is an area monitored. *Connectivity* implies that each node or device should be connected so that the data is sent back to the base station (BS). Any heuristic needs to fulfil the requirement of Q-coverage and P-connectivity. *Q-coverage* means that every point in the area is monitored by at least 'q' sensors. *P-connectivity* refers to the number 'p' of disjoint paths between any two sensors. Authors in [4] proposed a heuristic method called QC-MCSC to maximize the network lifetime satisfying both requirements. It consists of three phases or layers where the output of one phase is the input of the other. The first phase is the *Coverage Phase*. The output of this phase is a set of sensors that cover all the target areas. *Connectivity and Redundancy Reduction Phase* takes the set of the first phase and applies BFS algorithm to find the shortest path for each sensor. In this phase, extra nodes will be added only if the network is not fully connected, and unnecessary nodes will

be removed. The output is a minimal connected set cover of nodes. Finally, the *Energy and Priority Updating Phase* determines the lifetime constant of each set cover from the second phase. The lifetime constant is the minimum lifetime available from sensors in a set cover. In this phase, if 'B' battery life of one node is less than 'E' - the energy needed for communicating and sensing - the node is removed from the set cover. Through simulation, the authors compared *QC-MCSC* with *TPICSC* [5] and the result shows that the former achieves a higher lifetime. Furthermore, the MATLAB simulations' results reveal that the proposed heuristic - *QC-MCSC* - is very close to the actual optimal

A difficulty that faces researchers when they want to expand the coverage time span is how to distribute the sensors into separate independent subdivisions known as Disjoint Set Covers (DSC). This problem is identified as having an NP-hard complexity. Many researches use the Boolean sensing model to solve such problem. However authors in [6] proposed an approach to strengthen WSN coverage reliability while utilizing the maximum number of DSCs. They tried to solve two conflicting problems at once; thereby making the problem set a multi-objective one. To meet the requirement of staying active for long periods, the authors proposed to alternate nodes between idle and active states through something called 'wake-up scheduling' of the sensors. The objective is to achieve a WSN system, which can actively sense its predefined targets almost all the time. With the implementation of this method, only a single disjoint set is active with the others in sleep mode (in a specific interval), which is an energy conservation scheme. When the active set goes out of power, another set is scheduled to be in active state. Therefore, with this approach, the more DSCs that there are, the better it is for the entire system to stay on power.

Authors in [7] proposed another approach to keep the entire system of sensors active, by only a few active sensors at an instance. These sensors are expected to autonomously function in unattended environments for prolonged periods of time. Devices used in these networks have a limited amount of energy. So, the problem is to increase the lifespan of these WSNs while consuming power from these sensors which have a limited source of energy. While other papers study a uniform set of nodes to achieve the above objective, this paper investigates a set of nodes possessing an adjustable radius, which could be altered to increase or decrease the sensing area. There are several techniques for power saving and they could be categorized into two main ones.

- 1) Alternating nodes between sleep and active modes.
- 2) Regulating the sensing range of the nodes.

Many papers only solve the problem of WSN lifetimes by selecting a single approach. However, this paper uses both 1 and 2. The way that both approaches could be implemented at once is by setting up the minimum-sensing radius for each sensor in active state. This reduces the active node's density thereby reducing useless MAC layer interference, which would otherwise consume lots of power. Authors in [8] addressed the problem of target coverage, where the objective is to have the maximum number of targets monitored before the sensors run out of energy, where the network lifetime is defined as the amount of time each target is covered by one or more sensors. To extend the network lifetime, authors proposed an approach to calculate the maximum number of disjoint sensor covers. Recall that the problem of disjoint set covers aims at finding the nearest most favorable solution for the problem. They proposed a heuristic greedy algorithm using three parameters: 1) the set covers, 2) the number of targets and 3) the number of sensors. The proposed approach finds the cover sets to maximize the network lifetime of a WSN in polynomial time. They showed that it gives a local maximum solution due to its heuristic search. Authors in [9] proposed a greedy set cover algorithm that selects the minimum number of sensors that are disseminated into disjoint and non-disjoint sets with the necessity that every set cover completely fulfills the scope of all targets. They stated that the proposed algorithm is an improvement of the classical greedy set cover algorithm, and its approximation ratio is verified to be not worse than $\log(m)$. Through simulations, they showed that their algorithm performs well over some other ones found in literature.

Redundancy plays an important role in maintaining the reliability of a wireless sensor network (WSN) by handling unforeseen failures and boosting the accuracy of calculated computations due to the infeasibility of replacing the sensors. Due to the infeasibility, prolonging the network lifetime to ensure measurements are taken for as long as possible is another desired trait. The Location-Unaware Coverage (LUC) algorithm [10] addresses finding the balance between efficient redundancy and network lifetime. The LUC algorithm determines whether a sensory node will either be actively receiving measurements or sleeping to preserve its energy. To carry this out, each sensor node determines its neighbours and their relative distance in a two-hop neighbourhood. LUC carries out a series of geometric and heuristic tests to determine the 'strength' of nodes with the weaker ones put to sleep initially. The stronger nodes possess a higher reliability hence are kept active for a longer duration. The LUC algorithm has two protocols namely Iterative LUC (LUC-I) and Probabilistic LUC (LUC-P) that determine whether nodes will be set as active or in sleep mode through a series of hops. The protocols bring about low operating costs and may greatly minimize the number of nodes that are active. Upon

completion of the protocols, all nodes will be assigned either to sleep or active mode; all active nodes will cover the complete target area and the WSN lifetime and reliability are improved.

Authors in [11] studied the importance of complete coverage of the target area and full connectivity of the WSN for data collection. They proposed an algorithm for ensuring that both conditions are met for conserving energy and extending the lifetime of the WSN. It relies on a distributed response procedure planned to locate the routes between the sensors and sinks. The procedure allows for several routes to be discovered leading from a sink to individual sensors. Depending on the set of routes, a minimum distance path (MDP) greedy algorithm is derived from resolving the maximum set cover (MSC) issue with the goal of locating the highest possible set covers. The MDP-MSC algorithm works with the concept of choosing the sensors possessing the shortest distance to the building set cover to unite into the contemporary set cover after every single process. In the algorithm, the discovered routes, which are determined by the maximum number of routes per cover, influence the choice of sensors that are added to the set cover. Finding the optimum value of the maximum number of routes per cover greatly influences the results of the algorithm hence sufficient tests must be carried out initially. The authors stated that the optimum value of the maximum number of routes per cover, as well as the level of density of the sensors within the target area, impact the performance and control of transmission overhead in the WSN. Based on simulation and experimental analysis using MDP-MSC, a number of set covers received a noticeable growth by 13% and 21% versus Greedy - MSC and HA-MDS algorithm. MDP-MSC did not just outperform Greedy - MSC and HA-MDS, it also had the lowest time complexity between them. This new algorithm has achieved a balanced consumption of energy and less computational time.

Authors in [12] proposed a distributed lifetime coverage optimization (DiLCO) protocol to preserve coverage as well as boost the WSN lifetime. The protocol begins by applying a divide and conquer algorithm to split the target location into smaller regions known as sub-locations, then it is concurrently carried out in every single sub-location. Assumptions are made that the partitioning of the sub-locations is carried out in a regular manner and the sensors are set uniformly in each sub-location. The periodic DiLCO protocol possesses four stages in each period, namely information exchange, leader election, decision, and sensing. Every period possesses a single cover set handling the sensing operation. Cyclic scheduling boosts the reliability of the WSN against sensor failures. Sensors without sufficient power to successfully carry out a period or those that fail before the decision phase is completed are not included in the scheduling procedure. If a sensor fails

after being chosen, the quality is only reduced for the duration of the period as another functioning sensor is selected in the next period.

Two types of packets are used when carrying out the DiLCO protocol: info, and Active/Sleep packets. Info packets are transmitted from a sensor to all others within the same sub-location to give information. Active/Sleep packets are transmitted by the leader to the other sensors within the same sub-location to notify them to set their status to either Active or Sleep in the sensing stage. The challenges faced in implementing the DiLCO protocol lie in selecting the most appropriate leader in every single sub location and the most suitable collection of active sensors to ascertain a high standard in coverage.

Authors in [13] studied the optimization problem of network sensors distribution. They considered it as a multi objective optimization problem. They proposed an efficient cover set selection (ECSS) which is an improved version of the non dominated sorting genetic algorithm (NSGA-II) [14]. The goal of the proposed scheme is to maintain the full coverage by using fewer sensors. They highlighted that more active sensors means more coverage, however, it provides less lifetime and vice versa. The authors concluded that the ECSS algorithm had advantages such as; resetting all sensors' statuses with a one-time approach. It can also be made flexible by providing it with parameters such the requested field coverage and the model.

Finding the maximum number of coverage sets of sensors was the study of [15]. Authors used two centralized algorithms and one localized algorithm. The two centralized algorithms deal with how the sensors are added to make a connected cover. "Connected" means that a node is on the transmission of another node. The localized algorithm is used for the local nodes' communication. All three algorithms are only done once during the initialization phase. They concluded that keeping one coverage set active in a round robin fashion will extensively reduce the energy consumption.

Authors in [16] proposed a scheme to choose the smallest possible number of nodes that will cover the critical targets by using a cost function which is called the Critical Control Factor. This function mapped into 3 loops: sensor availability check (will add cover sets), uncovered target check (populated the added cover sets with sensors) and sensor applicability check (sorting the nodes and choosing the top scoring node). The main benefits of this proposed solution are that it is flexible, has low complexity and a short execution time. At the end, authors concluded that there are two solutions for node deployment: static and dynamic. In the static method, the proposed algorithm

performs better than other approaches in terms of execution time and showed near-optimal results in the generated coverage sets. The dynamic method on the other hand gave better results but exhibited a longer execution time.

Authors in [17] studied how well thought out energy management and scheduling for the sensors can affect the lifetime expectancy of sensor nodes. They proposed to compute maximum set covers by presenting two heuristics. At each step, they selected a critical target and then the heuristics would select the sensor with the most contributions. They suggested scheduling the nodes' activities so that every sensor is alternating between states.

The authors in [18] proposed to use LEACH with the Fuzzy Inference System (FIS) based on Mamdani's method [19] to select cluster heads and to extend the lifetime of WSNs. FIS consists of a fuzzifier, an inference engine and a defuzzifier. The proposed model uses three parameters: distance to coordinator, energy, and density. IF-THEN rules are used to calculate the chance for a sensor node to become a cluster head. The chance value is obtained by defuzzification which aggregates the results of each rule. Then, the node chooses the maximum of the chances and compares it to a specific threshold value. If it is less than the threshold then it becomes the cluster head. Experimental studies are done to compute LEACH [20] and LEACH-FL which show that using LEACH-FL increased network lifetime two times more than using LEACH.

3. Models and Assumptions

3.1 Network Model:

A wireless sensor network is composed of a set of battery-powered sensors and a sink. The latter is connected to the power source, thus we pay no attention to the energy consumption of the sink in this paper. The communication between sensors is done through wireless links if they are within range of each other, otherwise they can communicate with each other through other intermediate sensors. Thus, a WSN can be modelled as unit disk graph [21] and [22] $G=(V, E)$ where V is the set of all nodes including the sink and $E \subseteq V \times V$ is a set of possible communication links. We assume our graph is connected.

$S = \{s_1, s_2, \dots, s_N\}$ represents a collection of N sensor nodes that are distributed randomly in a two-dimensional plane (Fig.4) to monitor a set of target nodes $T = \{t_1, t_2, \dots, t_M\}$.

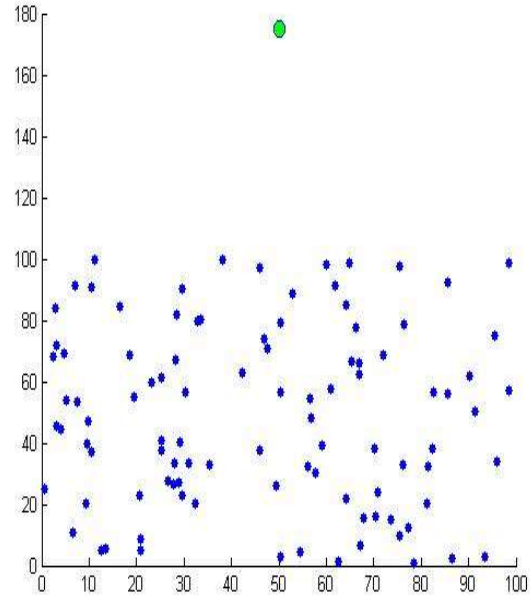


Figure.4 WSN nodes Distribution

Given two nodes s_1 and s_2 (one of them should be a sensor); they are connected by an edge $(s_1, s_2) \in E$, if the first sensor is within the sensing coverage range of the second sensor. Thus, two nodes s_1 and s_2 can communicate with each other (there is an edge between them) if $\|d(s_1, s_2)\| \leq 1$, where $\|d(s_1, s_2)\|$ is the Euclidean distance between s_1 and s_2 .

Each sensor node $s_i \in S$, can operate into a number of sensing ranges $r_1, r_2, \dots, r_p$ where each r_k consumes energy e_k , $1 \leq k \leq P$. The initial energy of each sensor node is E . A sensing node $s_i \in S$ can cover a target $t_i \in T$ using sensing range r_k if the Euclidean distance $d(s_i, t_i)$ is less than or equal to r_k , denoted as $t_j \rightarrow s_i$. Then, we define the target subset $T_i = \{t_j \mid t_j \rightarrow s_i, 1 \leq j \leq m\}$ as the target set of the sensor s_i .

We assume that at regular time intervals, the information sensed by a network node has a fixed unit size of b bits that can be stored at the sensor in a buffer of infinite capacity modeled as FIFO. We also assume that the channel bandwidth for all links is W /bps and all transmitted packets have a unit size of b bits. Only one packet can be transmitted in each time slot t that is defined as $t=b/W$ seconds. Time division multiple access (TDMA) is used at the media access control (MAC) layer.

3.2 Clusters creation:

In this paper our purpose is to extend the network lifetime as much as possible and minimize the energy consumption by keeping the amount of traffic to a minimum and by scheduling nodes to monitor a set of targets continuously in turn. For these reasons a set of clusters are constructed. Many studies have adopted the creation of clusters in WSN [23-25], however few of them considered the use of a set cover algorithm. In this study we consider the construction of a minimum set cover $C = \{C_i\}$, $1 \leq i \leq K$ to create clusters. The problem can be described formally as follows:

3.2.1 Set cover definition and creation:

The set cover problem is one of Karp's 21 NP-complete problems shown to be NP-complete in 1972 [26-28]. The set cover optimization has many applications in different areas [29] including manufacturing, service planning, location problems, network security and multiple sequence alignments for computational [30], [31], [32] and [33].

Given a set of elements (called the universe) and a collection S of m sets whose union equals the universe, the set cover problem is to identify the smallest sub-collection of S whose union equals the universe.

In our paper we adopt the following approach: we use a greedy set cover algorithm [34] to choose which cover a sensor node will belong to. In this approach, we define a finite set $S = \{S_1, S_2, S_3, \dots, S_m\}$, corresponding to the areas to be monitored, a collection $\{S_j\}_{j=1}^n$ of subsets of S , where each S_j represents a sensor and contains the areas that sensor monitors from S , and a positive integer $k \geq 2$. The goal is to find a partition G of the subsets into k covers $c_1, \dots, c_k$ where each cover is a set of subsets, such that

$$N(G) = \sum_{i=1}^k |\cup_{S_j \in c_i} S_j| \text{ is minimized.}$$

The heuristic used in our paper consists of greedily picking sets from S . The set $S_j \in S$ that contains the most number of uncovered vertices is picked at each step. We repeat the process until all vertices are covered. Fig.5 shows the results of running the greedy algorithm in Matlab, and the following is the corresponding pseudo-code:

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1-  $U \leftarrow X$  //  $U$  is the set of uncovered elements

2-  $S' \leftarrow \emptyset$  //  $S'$  is the current set cover

3- While  $U \neq \emptyset$  Do

4-   Pick  $S_j \in S$  such that  $|S_j \cap U|$  is maximized

5-    $S' \leftarrow S' \cup S_j$ 

6-    $U \leftarrow U - S_j$ 

7- end

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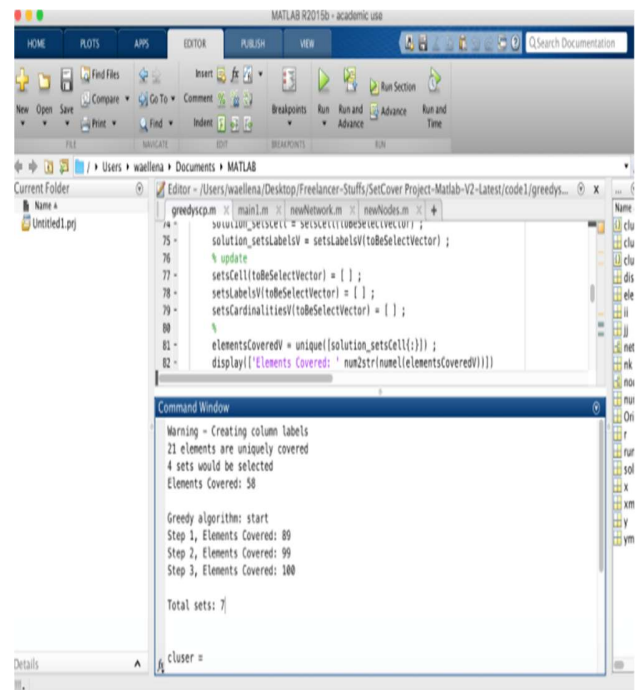


Figure.5 Greedy set cover in MATLAB

Once the set covers (clusters) are constructed, some sensor nodes become cluster heads and collect all traffic from their respective cluster. The cluster head aggregates the collected data and then sends it to its base station. When using clustering, the workload on the cluster head is thus larger than for non-cluster heads. Thus, we elect two cluster heads within each cluster that have the highest energy among nodes, and they interchange their role on a round robin fashion during their lifetime in order to distribute the extra workload and energy consumption evenly between them.

3.3 Energy Consumption Model:

The energy consumption model adopted in this paper is based on the proposed model in [35] which has been used by many researchers [36-41]. In this model, it is assumed the transmitter dissipates energy to run the radio electronics and the power amplifier and the receiver dissipates energy to run the radio electronics as shown in Fig.6.

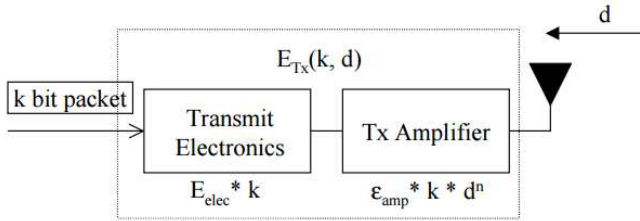


Figure.6 Radio energy Dissipation Model

The power attenuation is dependent on the distance between the transmitter and the receiver. For relatively short distances, the propagation loss can be modelled as inversely proportional to d^2 whereas, for longer distances, the propagation loss can be modelled as inversely proportional to d^4 . Power control can be used to invert this loss by setting the power amplifier to ensure a certain power at the receiver. Thus, to calculate transmission cost (*joule/bit*) and receiving cost (*joule/bit*) for a message of k -bit size, from sensor node i (transmitter : T_x) to sensor node j (receiver R_x) over a distance d_{ij} (Euclidian-Distance), where the energy consumption at node i comprises operating radio electronics and amplifiers, while at node j , it involves only radio electronics, the following equations are used

Transmission cost:

$$E_{TX}(k, d) = k * E_{TX-elec} + E_{TX-amp}(k, d) = k * E_{TX-elec} + k * d^2 * E_{amp};$$

Receiving cost:

$$E_{RX}(k, d) = k * E_{RX-elec};$$

Where E_{elec} is the energy dissipation of the radio in order to run the transmitter and receiver circuitry, and E_{amp} is the transmit amplifier.

Typical values used in this paper during simulation are:

$E_{elec}=50\text{nJ/bit}$, $E_{amp}=100\text{pJ/bit/m}^2$, $d^2=500$, and the packet size $k=2000$ bits [39].

If we consider that node i wants to transmit an amount of data (f_{ij}) to node j , the energy consumption (Joules) at node i will be:

$$E_{TX,i} = \sum_{j=1}^n (E_{TX,ij} * f_{ij})$$

On the other hand, if node j wants to send an amount of data (f_{ji}) to node i , the energy consumption (Joules) at node i will be:

$$E_{RX,i} = E_{RX} \sum_{j=1}^n f_{ji},$$

Thus, total energy consumed at node i will be:

$$E_{consu,i} = E_{TX,i} + E_{RX,i}$$

3.4 Energy Optimization:

Once the clusters are created, our objective is to minimize the energy consumption when routing data to the base station. First we minimize energy consumption within each cluster, and then we minimize routing energy consumption.

3.4.1 Minimizing energy consumption in clusters:

The objective of using a SET K-COVER approach to construct clusters in WSN is to increase the energy efficiency of WSNs. Because a single area in a WSN may be covered by multiple sensors due to the ad hoc nature of sensor placement, topological constraints, or perhaps to compensate for the short lifetime of a sensor by placing multiple sensors close together. Therefore, in an effort to increase the longevity of the network and conserve battery power, it is beneficial to activate groups of sensors in rounds, so that the battery life of a sensor is not wasted on areas that are already monitored by other sensors. In addition, certain batteries last up to twice as long when used in short bursts as opposed to continuously. Therefore, activating a sensor only once every k time units can extend the lifetime of its battery. For the active nodes inside a cluster, an energy cost e_i , is associated to a sensor node x_i each time the latter sends a message to the cluster head (CH).

Thus, the energy consumption for a cluster can be formulated as a linear programming optimization problem where:

$$\text{Minimize } \sum_{i=1}^k x_i * e_i, \text{ k is the number of active nodes inside the cluster} \quad (1)$$

St:

$$e_i \leq E_{\text{init}}, \text{ where } E_{\text{init}} \text{ is the initial energy of node } x_i \quad (2)$$

$$x_i = \begin{cases} 1 & \text{if active} \\ 0 & \text{if inactive} \end{cases} \quad (3)$$

$$\sum_1^k e_i \leq E_{\text{clust}}, \text{ where } E_{\text{clust}} \text{ is the initial cluster total energy of all nodes} \quad (4)$$

Output: vector $X = (x_1, x_2, \dots, x_n)$ for nodes active and inactive.

3.4.2 Routing Energy Optimization:

It is to note that to achieve the effective collection of the data, WSNs must meet two requirements. One is the full coverage of the targets. The other is the complete connectivity of the network. The full coverage refers to the sensors that can monitor all targets, and the complete connectivity means that the data originated from the monitoring targets can reach a base station through the multi-hop wireless communication using a minimum energy path.

3.4.2.1 Minimum Energy path Model:

In order to minimize the energy consumption between any sensor nodes, we use a min-cost flow algorithm [42]. The Wireless Sensor Network used in this paper is modelled as a directed graph $G(V, E)$, where V represents the set of sensor nodes and E the set of edges.

Each edge $(u, v) \in E$ is associated with a cost $c(u, v)$ which represents the energy consumption when there is a flow f_{ij} going out from u to v , a capacity constraint u_{ij} expressed in number of packets per unit time, and a supplies/demands d_{ij} .

The cost of a flow $f(u, v)$. $c(u, v)$.

The objective is to deliver all the data generated by sensor nodes to base station with minimum energy consumption and without exceeding the link capacities.

ure

The problem can be formulated as follows:

Minimizes the total cost of the flow over all edges:

$$\sum_{(u,v) \in E} f(u, v) \cdot c(u, v) \quad (5)$$

St:

$$f(u, v) \leq c(u, v) \quad \forall (u, v) \in E \quad (6)$$

$$f(u, v) = -f(v, u) \quad (7)$$

$$\sum_{w \in V} f(u, w) = 0 \text{ for all } u \neq s, t \quad (8)$$

$$\sum_{w \in V} f(v, w) - \sum_{w \in V} f(w, v) = d \quad (9)$$

Where (6) represents the capacity constraint, (7) the skew symmetry, (8) the flow conservation and (9) the required flow.

The above problem can be converted into a minimum-cost circulation problem [43] and can be solved efficiently using well-known min-cost flow algorithms [44-46]. In this research we adopt a network simplex method [47] as it is considered the most practical algorithm [48]. Fig.7 shows a sample of a sensor network where s_1 is the source and s_6 is the destination. The flow capacities and demand are shown on the graph.

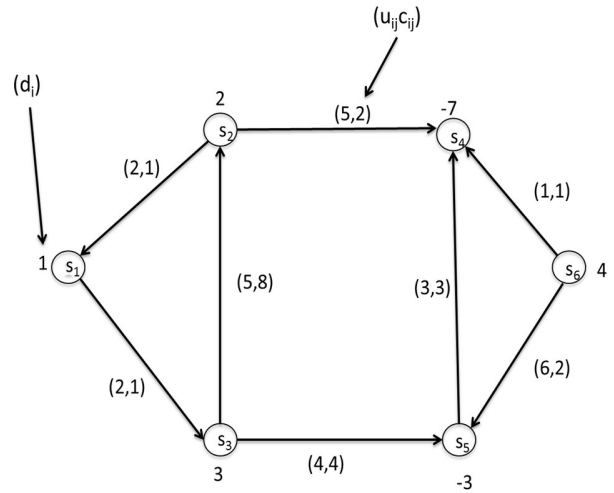


Figure.7 WSN graph representation

The corresponding network simplex LP is as follows, where x_{ij} = Number of units shipped from node i to j using arc $i-j$:

$$\text{Min } z = x_{13} + 2x_{21} + 2x_{24} + 8x_{32} + 4x_{35} + 3x_{54} + x_{64} + 2x_{65}$$

$$\text{Node } s_1: x_{13} - x_{21} = 1$$

$$\text{Node } s_2: x_{21} + x_{24} - x_{32} = 2$$

$$\text{Node } s_3: -x_{13} + x_{32} + x_{35} = 3$$

$$\text{Node } s_4: -x_{24} - x_{54} - x_{64} = -7$$

$$\text{Node } s_5: -x_{35} + x_{54} - x_{65} = -3$$

$$\text{Node } s_6: x_{64} + x_{65} = 4$$

$$x_{13} \leq 2 \quad x_{21} \leq 2 \quad x_{24} \leq 5 \quad x_{32} \leq 5 \quad x_{35} \leq 4 \quad x_{54} \leq 3 \quad x_{64} \leq 1 \quad x_{65} \leq 6$$

4. Simulation Results

To assess our model, we compare it to two other models: MO-SCP [49] and MDP-MSC [50]

For this purpose, a simulation was conducted using a variable number of sensor nodes (100, 200, 300, 400) deployed randomly in an area 1500 x 1500 m². The base station is at the centre of the field (Fig.8).

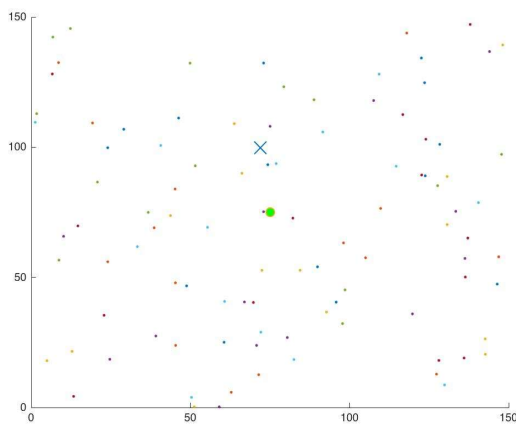


Figure.8 Nodes Distribution

Parameters used in simulation are similar to those used in [51], and are shown in Table 1.

Table.1 Simulation parameters

Parameters	Value
Initial energy E_0	0.5 J
Transmitting and receiving energy E_{elec}	5 nJ/bit
Amplification energy for short distance E_f	10 pJ/bit/m ²
Amplification energy for long distance E_{amp}	0.013 pJ/bit/m ⁴
Packet size	200 bits
Operating frequency	2.4 GHz
Initial energy of sensor	61,560 J
Transmit power	32 mW
Reference distance	3 m
Path loss exponent	4
SNR	2 dB

The greedy set cover algorithm is run on for a number of nodes $N=100, 200, 300$ and 400 . Table 2 shows the number of set covers (clusters) created for each N .

Table.2 Set covers number created by Greedy algorithm

Number of nodes	Number of clusters
100	7
200	8
300	7
400	8

In the first experiment as shown in Fig.9-14, we compare the number of dead nodes, active nodes for all three algorithms, MO-SCP, MDP-MSC and SCMC, where we vary the number of sensors from 100 to 400 with an increment of 100. The number of dead nodes results returned by SCMC shows that all nodes are dead after a round=9000, while in the other approaches, the network is dead after a round = 4000. This shows that the lifetime is expanded in SCMC with higher number of alive nodes. The results stand for other network's size ($N=200, 300, 400$). Network lifetime results returned by the heuristics are close and they increase with sensor density. When more sensors are deployed, more sensors cover each target, thus more set covers can be formed.

In the second experiments we calculate the throughput for all schemes with different variation of sensor

nodes from 100 to 400 with an increment of 100. We observe as shown in Fig.15-18, that SCMC outperforms over other algorithm in terms of higher number of throughput and packet received at base station, which is understandable as SCMC has a longer live time and it uses an optimized routing path compared to other algorithms.

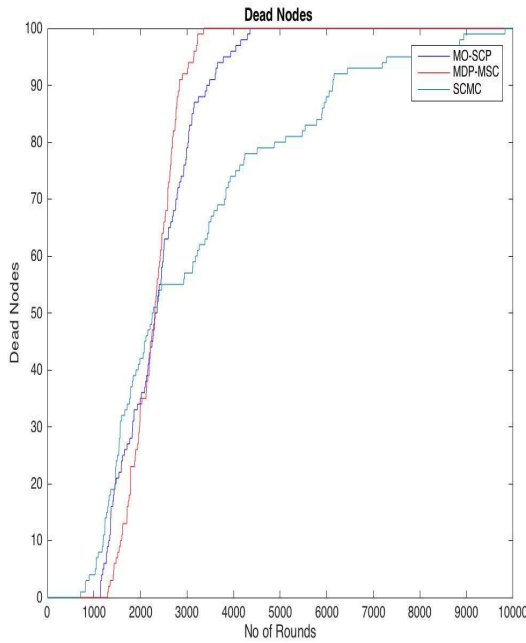


Figure.9: Dead nodes comparison of SCMC, MO-SCP, MDP-MSC. (Size = 100)

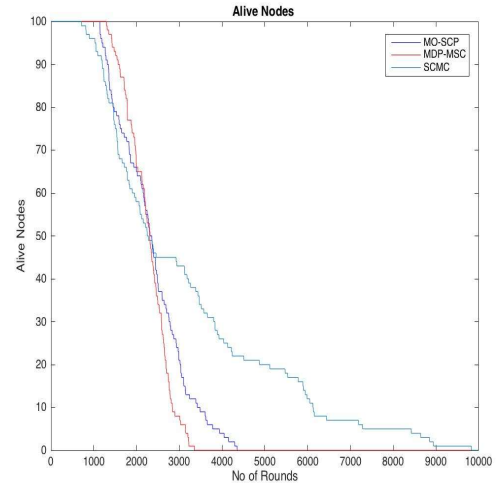


Figure.10: Active nodes comparison of SCMC, MO-SCP, MDP-MSC.

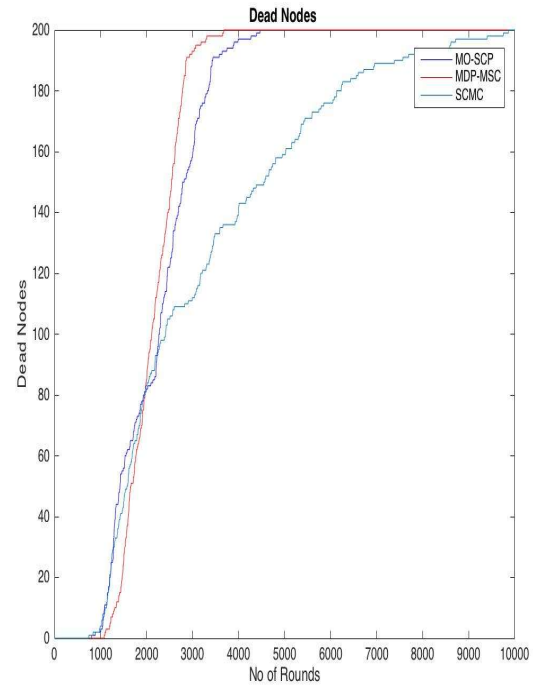


Figure.11: Dead nodes comparison of SCMC, MO-SCP, MDP-MSC (Size = 200)

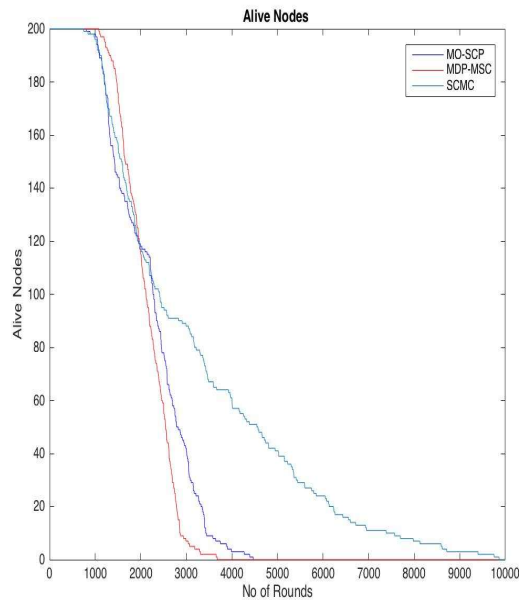


Figure.12: Actives nodes comparison of SMC, MO-SCP, MDP-MSC (Size =200)

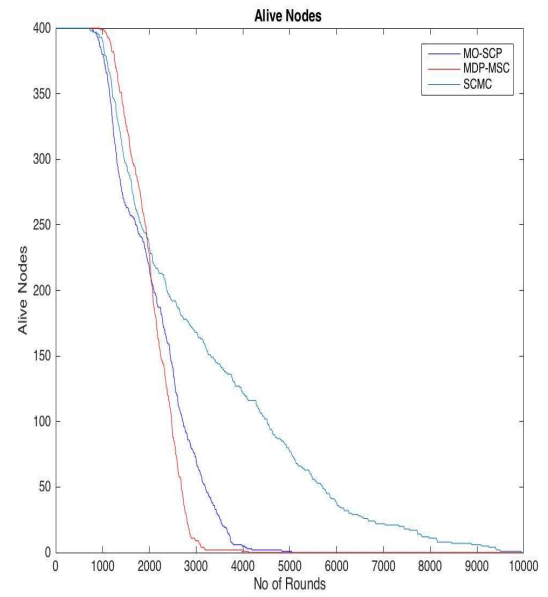


Figure.14: Actives nodes comparison of SMC, MO-SCP, MDP-MSC (Size =400)

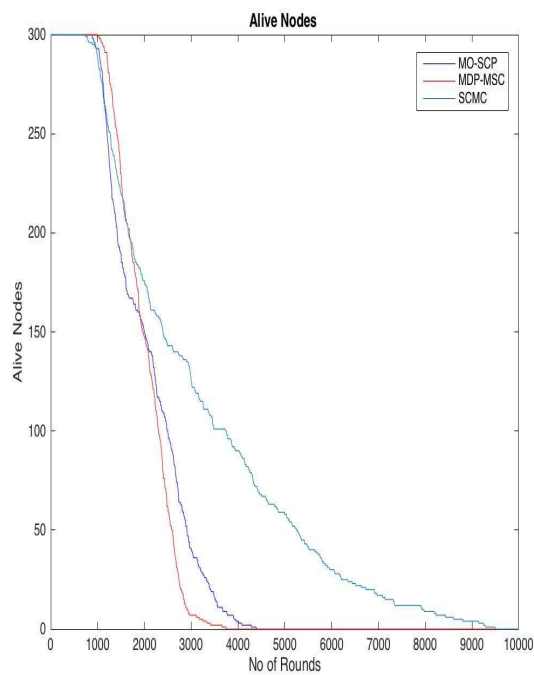


Figure.13: Actives nodes comparison of SMC, MO-SCP, MDP-MSC (Size =300)

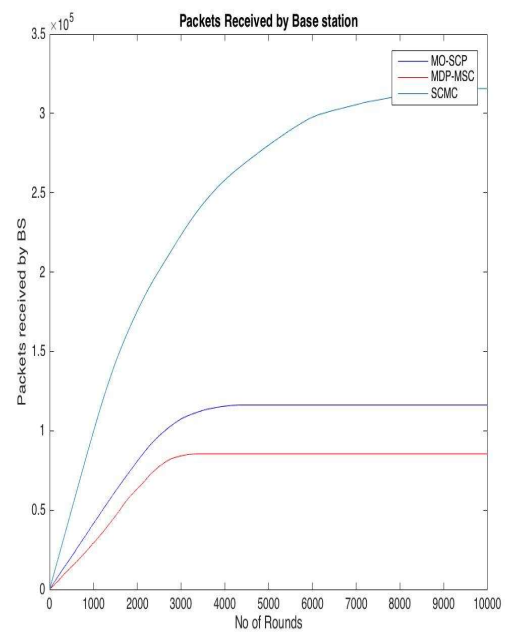


Figure.15: Throughput comparison of SMC, MO-SCP, MDP-MSC (Size =100)

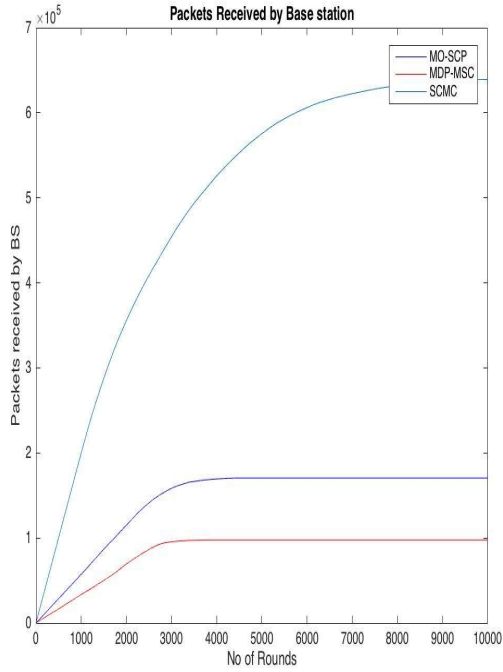


Fig.16: Throughput comparison of SCMC, MO-SCP, MDP-MSC (Size =200)

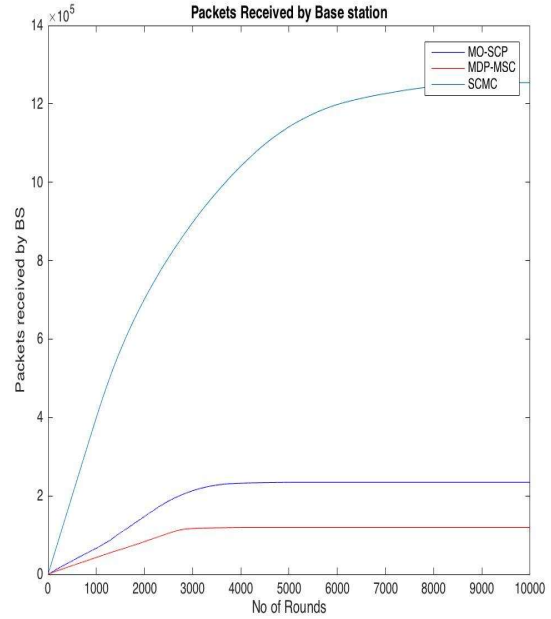


Figure.18: Throughput comparison of SCMC, MO-SCP, MDP-MSC (Size =400)

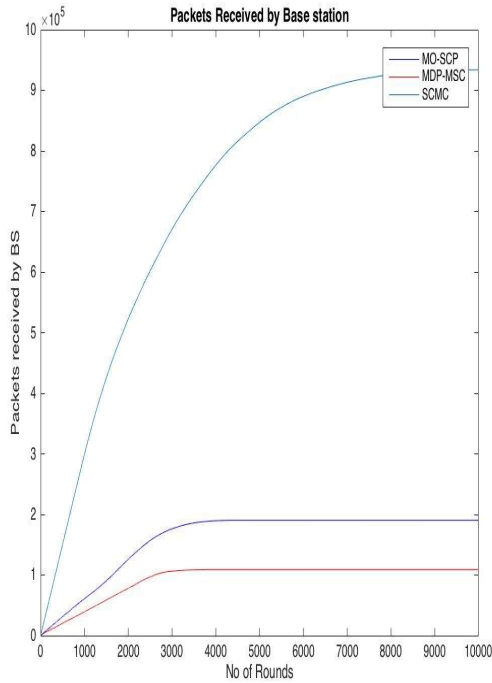


Figure.17: Throughput comparison of SCMC, MO-SCP, MDP-MSC (Size =300)

5. Conclusion

Minimizing the energy consumption and maximizing WSN lifetime have been studied extensively. In this research, we used a minimum set cover approach to determine the number of clusters needed, and then we proposed an efficient scheme that uses min-cost flow to send packets from any sensor node to the base station. Using LP, optimization models have been proposed for both min-cost flow and minimizing energy consumption in a cluster. Simulation results showed that the proposed scheme outperforms MO-SCP and MDP-MSC in terms of WSN lifetime and throughput. As a future project, we propose to apply our approach in many base station scenarios. Additionally, the use of a multi-objective optimization model will be of great interest.

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