# Centroid Energy-Based Sleep Scheduling Design in Dense Wireless Sensor Networks using Evolutionary Algorithms

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**Summary**
A wireless sensor network (WSN) contains hundreds or even thousands of small sensor nodes constructed in the welfare environment. Due to the resource constraints, energy is an important issue in a WSN. Therefore, increasing the network lifetime through the energy conservation with implementing different protocols and algorithms is desirable. Applying the different sleep scheduling algorithms in densely deployed WSN leads to an efficient energy conservation. Most introduced WSNs' sleep scheduling algorithms operate based on the local approach regardless of the other important network parameters. In this paper, regarding the most important WSN's parameters, a centroid energy-based sleep scheduling algorithm (CESS) using evolutionary algorithms is proposed. The results demonstrate the CESS-GA performance is more successful in providing the maximum network coverage, reducing the efficient data redundancy and utilizing a minimum number of living sensors in comparison with that of the CESS-ICA and CESS-PSO. Using 28.3% of living sensors with the highest residual battery and efficient data redundancy reduction, the maximum coverage of the network is obtained. Due to the lack of any similar research, to check the accuracy of the proposed method, its output is applied on the LEACH and SEP (CESS-LEATCH and CESS-SEP), two different homogeneous and heterogeneous algorithms, as an initiation phase input. The network lifetime is increased significantly five times as much, and the maximum network coverage is obtained without any change in routines of the LEACH and SEP algorithms.

***Key words:***
*Sleep scheduling, wireless sensor network, LEACH, SEP, energy conservation.*

## 1. Introduction

Based on improvements in different branches of science and technologies, self-organizing, tiny, lightweight, smart and cheap sensors with capabilities of sensing, local data processing and short range communicating were created [1]. A powerful network which contains hundreds or even potentially thousands of sensors in a critical and spatially polluted environment to capture different physical phenomena such as temperature, sound, pressure and etc. is named Wireless Sensor Network (WSN) [2]. Locations and physical positions of sensors are not predefined or predetermined. Mostly, they are spatially deployed, randomly and densely in the majority of the remote field of interest to sense and collect data from the surrounded conditions and send to the base station (BS) directly or via some intermediate nodes [3].

The WSNs are applied in many practical applications. Generally, the monitoring and tracking applications are two main WSNs classifications. In the beginning, the WSNs were created to use in many military applications including battlefield monitoring, while today they are used in many industrial, health care, environmental, oceanic, agricultural, residential, foresting, mobile target tracking, nuclear refactoring, fire detecting and etc. applications to monitor and control different processes and physical phenomena. In addition to energy constraints, topology control, network coverage, time synchronization, localization, collected data fusion, robust and optimal routing are some other open issues in the WSNs design [4].

In previous decades, energy optimization has been the most important challenging issue in the topology design. To interact with an application domain and surrounding neighbors, the sensor nodes are powered with small, fixed and irreplaceable batteries. A sensor consumes energy for different functions such as gathering, processing, fusing and wireless transmitting data to the BS. Due to the conditions of the application area, recharging or exchanging batteries is very difficult or even impossible after sensors deployment [5].

Mostly, they are densely deployed in the field of interest, because if any node dies, the nearest neighbor is activated to prevent any network operation failure. Therefore, using energy conservation mechanisms, the network lifetime may increase for a few months or even years. Moreover, in the WSNs, lack of power consumption control mechanisms may lead to draining batteries very fast. Every node can be alive until the power source is available, and when the battery is drained, the node dies. Moreover, to minimize energy consumption and lifetime extension, applying all energy and power control mechanisms and techniques to efficiently use finite node resources is essential [6].

Each sensor node contains a transducer, microcomputer, transceiver and power source for communication. The sensing, A/D convertor, power supply, memory, processing and radio transmitter are different units of a

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wireless sensor node. The sensing unit includes some sensors to guarantee the interaction with surroundings. The processing unit is responsible for overall controlling such as collected data preprocessing, ensuring communication links and so on. The radio unit consists of a short range radio transmitter to keep the data link connection with others [7].

Inside a node, the most amount of energy is used in radio transmission unit to exchange the gathered data from the environment. Therefore, short range with multi-hop transmission is preferred to long distance communication. To this end, communication nodes should be located closely to each other. Unlike wireless networks which use point to point connections, the sensors use broadcast messaging using electronic signals due to the large number of sensors, data overloading and disability to identify all neighbors. In most WSNs, regarding the applications, every sensor node may involve data aggregation. After some primarily local data fusion, the produced data is transmitted to the next hop periodically [8-9].

In WSNs design, in addition to the other network characteristics, network topology plays an important role in energy conservation. Based on constructed network topology, a sensor node can operate with different functions; for example in a hierarchy architecture, a sensor may operate with cluster head (CH), ordinary or even sleeping modes. In the sleeping mode, different idle units are switched off or on to minimize the network energy consumption [10].

Every sleep scheduling algorithm may employ several mechanisms and techniques to control the power of sensors. They mainly focus on the radio unit performance with the rotation of status on or off. Moreover, designing a high performance sleep scheduling became an important part of dens WSNs topologies to increase network efficiency and flexibility. Therefore, using a sleep scheduling algorithm is a way for controlling the power effectively to reduce energy consumption of nodes. Different methods and algorithms are presented for sleep scheduling which reduce nodes' activation periods for energy conservation [11].

If some other important parameters such as the network's coverage, selection of nodes with maximum available battery, minimum redundancy of collected data, and etc. are taken into consideration in the WSNs topology design, then the sleep scheduling algorithms problem turns into a NP-Complete problem. To solve an NP-Complete problem and find an optimized solution, using evolutionary algorithms is proposed. The Meta-Heuristic algorithms utilize computational methods and operations and repeat random primary solutions to find out the rather optimal solution to any NP-Complete problem [12].

In this paper, different evolutionary algorithms are applied to design a centroid energy-based sleep scheduling algorithm (CESS) to select a minimum number of active sensors with the highest residual power resource, max network coverage and minimum redundancy of collected data. To check the accuracy and analyze the output of proposed algorithm, this algorithm is applied on the Low-Energy Adaptive Clustering Hierarchy (LEACH) [13] and Stable Election Protocol (SEP) [14] algorithms due to the lack of any previous researches.

The rest of this paper is organized as follows: section 2 deals with the WSNs topology, section 3 deals with the sleep scheduling algorithms, section 4 deals with evolutionary algorithms, section 5 deals the proposed method, section 6 deals with results discussion, and the last section concludes the paper.

## 2. The WSNs Topology

To find a better understanding of different sleep scheduling algorithms operation, it seems necessary to find a brief review of the WSNs topology, radio communication unit and the reasons of wastage of energy in the data communication.

Every network including WSNs has a topology, which determines the way different devices on the network are arranged, and how they communicate with each other. It provides knowledge about the connections and logical relationships among the sensors. Different network topologies have different effects on the properties such as the reliability, energy consumption, latency, etc. of a network. The WSNs topologies can be evaluated according to different parameters such as implementation and maintenance costs, fault tolerance, scalability, communication cost, security and interferences and extension capability, etc. [15].

The WSNs topologies may be classified into tree based, cluster based and hybrid topologies. Mostly, in the tree based architecture, a super node (sink) is the root node of the WSN. A super node gathers, processes and analyzes the sensors queries (includes the collected data) to monitor and control the different physical phenomena continuously. In the WSNs with tree architecture, data flows from every leaf node to a super node via some interface nodes (aggregator nodes). After processing received gathered data from the subset nodes, a super node adds its own monitored data. In hierarchy approach, members of every cluster transmit the collected data to their own CHs for further processes. Depending on the designed hierarchy topology, a CH transmits the collected data to the sink node directly or via the next CHs, which are close to it. A hybrid topology uses the combination of both, the tree and cluster based architectures simultaneously [16].

In a WSNs topology, the sensors consume energy to gather, process, fuse and transmit data to the BS. The radio transmitter unit consumes the most amount of energy in the network lifespan. Also, the WSNs can have access to a limited number of non-overlapping radio channels. Therefore, it is very difficult or impossible to assign a different radio channel to every node. The sensors transmit the gathered data to the next hop through the wireless radio channel. The transmission of a sensor's redundant collected data leads to the wastage of energy, and the sensor node requires additional power supply for redundant data transmission. Hence, through using data fusion mechanisms and eliminating the redundant gathered data, the number of packets which should be transmitted will be optimized [17].

To communicate with other nodes, a sensor may use broadcast, convergecast, and local gossip communication patterns. Mostly, the BS or a super node (sink) prefers to use a broadcast pattern to transmit any query or controlling packets for all sensors to query-process a node when any WSNs topology change or update of the whole system is required. To send and transmit a massage to all, a node can broadcast it. The convergecast communication pattern is used when a group of specified sensor nodes needs to transmit some gathered data to a sensor node (destination node) which could be a CH, a data fusion center, or a BS [18].

Sometimes, a node requires short distance communication to transmit some information to the neighbor nodes, which are located inside the radio communication range. Therefore, it uses local communication (local gossip) pattern. In the cluster based architecture, the CHs communicate with all their assigned members or a subset of neighbors using a type of communication pattern named multicast communication pattern.

Reducing energy wastage in the radio communication unit leads to incrementing network lifetime and efficiency of the WSN topology. The data packets collision, idle listening, overhearing, redundant data packet transmission and over-emitting are some reasons of energy wastage in the transmission unit. When a sensor receives more than one data packet simultaneously, the data packet collision will occur. All the data packets which cause the data packet collision have to be discarded. Retransmissions of these data packets are required, which increases the network energy consumption.

Transmitting, receiving, idling and sleeping are four different radio unit statuses. The major source of energy waste is the idle listening which occurs when a node listens to an ideal channel in order to receive the possible traffic. When there is no data to transmit, the radio can be turned off instead of going idle to conserve a considerable energy amount; because when the radio is idle, it listens to the channel and uses the same energy as transmitting state. With frequent changes of the radio status, the node consumes more energy for the initializing step.

Overhearing the channel is another reason of energy wastage that happens when a sensor node receives packets of other destinations. Transmission of redundant data packet to the next destination is one more factor of energy wastage in the WSNs. When the destination is not ready to receive any packet, the over-emitting occurs. Consideration and optimization of the above energy wastage factors leads to designing an efficient WSNs topology. Depending on the type of the network topology, a sensor node may operate in a different duty modes such as super cluster head, cluster head, ordinary sensor, sleep and etc. over the network lifetime [19].

## 3. The Sleep Scheduling Algorithms

To reduce energy consumption of the radio transmission unit, different sleep scheduling algorithms are proposed. A sleep scheduling algorithm tries to maximize the radio communication unit efficiency through switching different redundant units of the sensors off or keeping them active with the lowest energy consumption. They employ several mechanisms and techniques to control the power of different sensor operations. Most wireless and ad-hoc sleep scheduling algorithms concentrate on the sensors energy consumption reduction, management of the performance of the radio unit and bandwidth with the rotation of its status on or off. Therefore, designing and applying WSNs optimal protocols (including a sleep scheduling algorithm) to control energy consumption of exchanging data among sensor nodes are necessary.

Regarding the basic principles of sleep scheduling algorithms, a node is permitted to send and receive data packets when the destination node is active and ready to communicate. Therefore, before starting to send data, the sender node broadcasts a message to make the destination nodes standby to receive the data packets. Although using a sleep scheduling algorithm in a network topology improves the network lifetime, it may increase the message broadcasting delay as well. In addition to the sleep scheduling, increasing the network scale may lead to increasing the delay time of the message broadcasting, too. Moreover, to design an efficient sleep scheduling algorithm, minimizing the network energy consumption and message broadcasting delay simultaneously is unavoidable [20].

Sleep scheduling can be categorized into centroid and distributed sleep scheduling algorithms. Due to the lack of any previous researches for centroid sleep scheduling, the literature review of this paper concentrates only on the distributed sleep scheduling algorithms proposed for wireless sensor networks. Only a few proposed WSNs topologies centroid designed take the sleeping mode into account as an operation mode of a sensor using evolutionary algorithms. No particular parameter was defined and mentioned in the evolution function to measure the performance and efficiency of sleeping mode. Also, in the result discussions, no figure or table considered and explained the influence of the sleep scheduling algorithm on the different designed network topology parameters such as coverage, connectivity, data redundancy and etc. [21].

The Medium Access Control (MAC) protocol is introduced being used in the second layer of the OSI model (data link layer). Using a mechanism to address and access the communication channel, the MAC provides the possibility of several nodes to communicate with a shared medium simultaneously. In the WSNs, the MAC is an important protocol to avoid packet collisions when some nodes want to transmit any data at the same time. This protocol puts the sensors in small function duty to reduce throughput and increase the latency of event reporting, while in addition to energy conservation, the latency and throughput are very important in some WSNs applications [22].

Scheduling the primary packets is based on gathered data from all connection links. Also, in the MAC protocol, messaging for global coordination results in scheduling delay. Because of the difficulty or impossibility of exchanging or recharging low-powered batteries used in the sensor nodes, the MAC protocols should efficiently minimize nodes energy consumption. Flexibility and adaptability to the different network changes which should be easily accommodated in the WSNs including the network size, nodes density, topology, etc. are another important characteristics of the MAC protocols. This attribute is called the WSNs scalability. The network fairness, latency, throughput and bandwidth utilization are some other important specifications of the MAC protocols. These protocols should avoid and minimize the consumed energy caused by the collision of data packets, idle listening, overhearing, redundant data packet transmission and over-emitting factors as well.

Avoidance of data packet-lost through exchanging the duration and increasing the operational throughput with dynamic scheduling are some of the advantages and difficulties in the network traffic control, and data packet-lost in meta-network are some of the disadvantages of using the MAC protocol in the WSNs. During recent decades, different MAC protocols such as the Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) and some contention-based MAC protocols including Sensor-MAC (SMAC), Timeout-MAC (TMAC), Dynamic-MAC (DMAC), Synchronized Sensor MAC (SSMAC) and etc. have been proposed for the WSNs [23].

To become suited for the WSNs energy efficiency, some needed changes are identified in the conventional MAC protocols. Regarding the same usage of energy in the transmission and idle states during non-availability of data, switching the transmitter off is desirable. To minimize idle channel listening, the SMAC protocol proposes periodical synchronized functioning cycle.

Every node synchronizes itself with the neighbors to switch to active or sleep states sequentially shown in figure 1. This process is energy efficient and decreases the latency of gathered data. The SMAC protocol is one of the best contention based MAC protocols (IEEE 802.11 MAC), which is specially designed for the WSNs to adopt the different WSNs factors to reduce energy consumption of different units of the sensors. If the node does not identify any sensing event, it operates in the idle listening mode for a long period of time. Consequently, in the idle listening mode, a sensor consumes the same amount of energy as the transmission mode. Moreover, operating the nodes in the idle listening mode is not favorable [24]. To reduce energy consumption of idle listening mode, the SMAC protocol switches the nodes' operating mode from the listening to the sleeping mode after a certain period of time consequently.

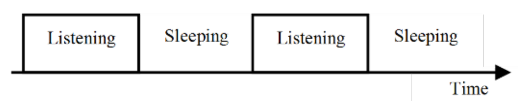


Fig. 1 Periodic listen and sleep over the time.

In the sleeping mode, the radio communication unit is switched off. In fact, periodical nodes' sleep leads to conserving more energy. To start listening to the channel by the nodes, every node uses a self-timer to wake up and start listening. In WSNs, a frame is a full cycle of listening and sleeping mode. To abstain data packet collision, the SMAC protocol uses the synchronizing method. Through proposing the continual and fixed operation periods, sleep and active modes, the SMAC tries to reduce the energy consumption. When the data traffic is dynamic, the fixed and predetermined sleep and active scheduling decreases the protocol performance and efficiency. In case of a lower rate of packets, energy is wasted in the idle listening mode; it leads to non-optimality of the SMAC protocol. Collision avoidance during message broadcasting and minimizing the delay and energy utilization are some advantages, while the difficulty of reducing communication delay during message broadcasting and latency maintenance are some disadvantages of these algorithms [25].

Adaptive modification of active and sleep scheduling based on the flow of traffic prediction to increase energy conservation and delay reduction leads to an extension protocol of SMAC named Timeout-MAC (TMAC) protocol. Compared with the SMAC protocol, the TMAC protocol reduces sensor's idle listening (inactive) time through the variable message length transmission. The sensors wake up and communicate to the other nodes periodically using ACK, CTS and RTS layout to avoid packet collision and achieve the robust and reliable communication.

The active time, buffer space and total frame time (bound with delay demands) are important parameters of the SMAC protocol. Basically, the active time depends on the packets rate transmission. As long as transmission of total packets of the sensors is possible, the value of the sleep time should be minimized. In case of non-event occurrence in the application area (idle listening time), much energy is wasted by the SMAC protocol, while the TMAC protocol reduces the energy consumption via the time frame's duty cycle modifications. Moreover, during the idle listening time, the TMAC protocol solution is more optimal compared with the SMAC protocol. In the TMAC protocol, the early sleeping problem influences the performance and throughput of the protocol efficiently. When a destination node switches to sleep mode and the source node still has some packets to transmit, the early sleep problem will occur [26].

TDMA sleep scheduling algorithms divide duty time of every node into two slots, in one of which the radio is turned on, and sending and receiving data are done, and in the other slot, the data exchange is impossible as the radio is switched off. In another approach, to decrease radio collisions, a specific slot time is allocated to every connection. Therefore, more slot times than the WSN's need are created. It increases the delay time and reduces the optimized channel utilizations.

The creation of collision-less data link connections is a NP-complete problem, and to solve this problem, many approximate algorithms are proposed. However, if any sensor node uses TDMA sleep scheduling, it may start its activity with a huge number of connections with its neighbors. Increasing the sensors' life time and data packet-lost minimization during sleep time is an advantage, while a surplus of real-time slot demand, increasing the delay time, reducing the optimal usage of channel and data redundancy are some TDMA method disadvantages [27].

To solve the delay problem created by the sensor nodes sleeping, the DMAC protocol is proposed that modifies the staggering problem in the sleep scheduling algorithms. For a fragment of data, it divides a sensor's duty cycle frame into the send, receive sleep time periods respectively.

Sending and receiving data packets are defined in a time period. Based on the node schedule, every node begins to transmit the data from the lower layer to the upper layer ready to receive the sent data. Moreover, to solve this problem and the possibility of continual multi-hop data forwarding, the DMAC protocol proposes an effective and energy efficient active-sleep mechanism to transmit data with low-latency through the multi-hop among the sensor nodes consequently. Also, in the WSNs, the range of the overhearing is bound. As a result, the problem of data forwarding interrupts the incidental adjusted duty cycle.

A subdivision of slots is assigned to every sensor node, thus the multipath data communication became possible, and the data latency is reduced. Moreover, compared with other active-sleep algorithms, the data latency of the DMAC protocol is better. This protocol is useful for such network applications in which the data latency is crucial. To avoid the data collision, the DMAC protocol did not employ any method for avoiding the collision. In the DMAC protocol, the data collision will happen if some sensors want to send some data packets to the same destination sensors through the same schedule [28].

## 4. Evolutionary Algorithms

The evolutionary algorithm (EA) is an evolutionary computational subset used to search and find an optimal solution in the solution scope. They inspire different biological evolution mechanisms such as natural selection, reproduction, mutation and symbiosis. Every creature that is more compatible with the natural parameters has a higher chance to survive. As non-compatible, other creatures are eliminated, even though they might be very good. Self-repetition or the desire for immortality is the main motivation inside all creatures. Mutation occurs due to some random or nonrandom parameters causing non-programed changes. Mostly, the result of these non-programed changes is unpleasant, but sometimes a limited percentage of the mutation results are desirable. Symbiosis may improve the generation like dogs and cats more clever than other biotypes since they have lived with humans [29].

### 4.1 Genetic Algorithm

By inspiring different natural phenomena, many evolutionary algorithms such as genetic algorithm (GA), ant colony optimization algorithm (ACO), imperialist competition algorithm, artificial bee colony algorithm (ABC) and particle swarm optimization (PSO) are introduced. Originally, most EAs are designed to solve continuous, and few algorithms are able to solve discrete or integer problems. With some manipulations, a continuous algorithm is able to solve an integer or discrete problem. As a sleep scheduling algorithm design regarding different network parameters and criteria is a discrete NP-Complete problem, the GA, ICA and PSO algorithms are used to study and find an active sensor arrangement with the highest performance. Prior to describing the used EAs, some other important concepts in optimization should be discussed briefly [30].

Optimization is based on objective function values, in other words, those parameters of the problem optimized in the objective function. In some algorithms, the objective function should be maximized named fitness or profit functions, and in others this function should be minimized named cost or error function. For example, generally for the objective function definition in the GA, the fitness, and in the ICA, the cost functions are used. When a condition is met, the evolutionary algorithm should be terminated. Arriving to an acceptable level of solution, passing a certain period of time or iteration and passing a certain period of time and iteration without any observation of improvement in the result are three different classifications of an algorithm termination. From the beginning of 1950s, lots of efforts were made to simulate evolutionary phenomena in the computer system. Undoubtedly, the GA is the famous evolutionary and meta-heuristics algorithm, and studying the different concepts of the GA leads to better understanding other EAs.

The GA is a special EA, introduced by Mr. John Holland and his colleagues in 1970s. In this algorithm, the parameters are coded and represented by genes. A chromosome is a predefined collection of genes. In every generation, a subset of chromosomes find the chance to reproduce themselves named parent chromosomes and the produced chromosomes named children chromosomes. The GA deals with a population of individuals, where each individual is a potential solution represented as a chromosome. Each population evolves through a number of generations. Representing and encoding parameters in the GA can be done in different ways such as binary, decimal or any other bases. To evaluate each member (chromosome) of the population, a fitness or cost function is applied in every generation [31].

The creation of random population solution; the evolution of random population solution; the selection of parent chromosomes to apply crossover and create the children population; a subset selection of population to apply and create mutated population; merging and ranking after the evaluation of the children population, mutated and parent populations; creating a new generation through selecting *n* chromosomes from the merged population are different steps of the GA algorithm.

Regarding the criteria of the EAs, different selection methods are proposed such as randomness, competency or competition based methods. The random method is not suitable because some members with an equal chance are selected blindly and randomly. In the competency method, members are selected based on fitness, cost or rank values such as the roulette wheel selection. In the competition based selection like the tournament selection, first *m* member of the population with an equal probability are selected. Then, the best member is selected among them as a result of competition. As a result, the roulette wheel selection method is more common and famous.

In the crossover step, based on the fitness or cost values, the total number ($n_c$) of even chromosomes (parents) with selection pressure, $P_c$ ($0 \le P_c \le 1$) are selected for recombination from which children are created, calculated by Eq. (1).

$$n_c = 2 \times \left\lceil \frac{P_c \times n_{pop}}{2} \right\rceil \qquad (1)$$

The total number ($n_c$) should be an integer and even number as in crossing over the minimum two chromosomes are required. Different crossover methods such as one parent to multi-parent, even with different genders in which two similar cognate chromosomes cannot be crossed, are defined. The crossover can be applied using single-point, double-point or uniform methods. Better chromosomes have higher chances of being carried on to the next generation, and any member of the old population may not be selected in the new generation. Mostly, the size of children population is lower than the size of parent population.

In single-point method, a pair of chromosomes is cut form a point, and only the last parts will be exchanged. Therefore, with $n_{var}$ variables, $n_{var}$-1 crossing points will be created. In the double-point method, a pair of chromosome is cut from two random points, $P_1$ and $P_2$. By crossing two points, the different solutions (children chromosomes) with a better diversity are created. In the uniform crossover method, the pair of chromosomes exchanges genes from *n* different points where $n \in \{1, 2, .., n_{var} - 1\}$. Compared with the uniform crossover method, the single-point and double-point crossover methods have better exploitation, while the uniform crossover has better exploration. Using a hybrid method increases the GA efficiency. Figure … illustrates different crossover methods [32].

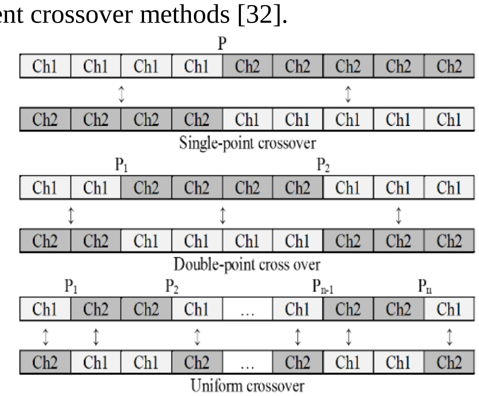


Fig. 2 The different crossover methods.

To prevent premature convergence to local optimal, a mutation operator is used. Also, it increases the exploration ability of the GA. In the mutation phase, if a generated random number between 0 and 1 is greater than $P_m$ (mutation probability), then the mutation will be applied on a subset of genes of the chromosome, otherwise, nothing will happen to it. In binary codding, a special state of decimal codding, 0 value is changed to 1 and vice-versa, while in decimal codding, the value of gene will be exchanged with a generated random value between $X_{min}$ and $X_{max}$.

### 4.2 Imperialist Competition Algorithm

The ICA, introduced in 2007, is a new paradigm in optimization algorithm and intelligence systems. Using social, political and cultural processes to create an optimization algorithm was unique. In the ICA, first a random population of countries with different characteristics are generated. Those countries with better quality and more power, decide to colonize other weaker countries to establish an imperialism [33].

In fact, an intra-empire competition is responsible for improving problem solution, while the main competition occurs among different imperialists. Assimilation, imperialistic competition and revolution are the based and important concepts of the ICA. In colonialism process, an imperialist imposes a set of policies on the colonized society with some changes to assimilate the target society to the dominant culture. Based on the same manner, every colony moves toward its empire. Those policies are named assimilation policies. The colony movement may be done in one, two or more directions. The direct movement is not desirable, though.

Sometimes, the colonized countries are not satisfied with their situations, and they decide to experiment a completely different policy. Therefore, they go through fundamental changes or a revolution. In other words, the revolution takes place in some countries’ dimensions randomly, which is similar to the mutation in the GA. The target of revolution is increasing the search power of algorithm to create new solutions in the domain scope as the empire might be located in an undesirable position of the domain scope [34].

Comparing colonies with their corresponding imperialists, evaluating imperialists based on the objective function, eliminating the weakest colony from the weakest imperialist and assigning it to any other imperialist randomly, converting the colony-less imperialist to a colony and assigning it to any other imperialist randomly and reporting the best imperialist are some of other ICA steps [35].

### 4.3 Particle Swarm Optimization algorithm

The Particle swarm optimization (PSO), introduced in 1995, was originally defined to solve continuous problems. However, with some algorithm modifications, it can be used for the discrete problems. The basic idea was to use the powerful social models which do not require special social abilities. It other words, the ordinary people of a society should be able to create an artificial society using swarm artificial rules.

It is proposed to create some living creatures named particles and distribute them across the search space. In the PSO, every particle has five characteristics such as position, objective function, velocity, the best experienced position and the objective function value of the best experienced position. Every particle calculates the value of objective function regarding its own position in the search space. It selects a movement’s direction based on a combination of the present local and the best previous positions of itself in addition to the information of the best global position of particles. The velocity vector is tangent to the movement vector. After a collective movements of particles, one step of the PSO is done. The algorithm’s steps will repeat until it meets a termination condition [36]. The PSO is used in different types of applications such as different kinds of optimizations, modeling and controlling, signal processing and pattern recognition, system management of power production and distribution, designing and optimizing communication network and so on. Creating and evaluating the initial population, finding and recording the best local and global experienced positions, updating the velocity and position of particles, exiting algorithm if the termination algorithm is met, otherwise, repeating from the step two; are different steps of a PSO algorithm [37].

### 4.4 Evaluation Function

The most important part of an optimization problem is the evaluation function obtained from the conversion of the different object parameters which are supposed to be optimized. Defining an objective function to evaluate a set of produced solutions is the most important part of any EA. The fitness or cost function evaluates every chromosome by a numeric value that specifies its quality. The higher or lower the quality of chromosomes (as answer to the problem), the higher the chance of the chromosome to be selected in the next generation.

To extend the network lifetime and prevent any network failure, the sensors are densely deployed inside or very close to the field of interest based on the hardware limitations of the nodes. It leads to increasing the total network data redundancy and energy consumption. The high performance sleep scheduling algorithm can reduce data redundancy. In the CESS, to calculate the data redundancy of the WSN, a data redundancy matrix (DRM) is defined according to Eq. (2).

$$\text{DRM} = \begin{bmatrix} a_{11} & a_{12} & & a_{1m} \\ a_{21} & a_{22} & & a_{2m} \\ & & & \\ a_{n1} & a_{n2} & & a_{nm} \end{bmatrix}_{m\times n} \quad (2)$$

To calculate the data redundancy, the application domain with m×n (m2) is split to a grid area based on the sensing radius (Rsen = 1m). It is assumed that in all junctions (per 1 m2), an event is present. Therefore, totally, m×n event points in the application area are created (Fig. 3). Every DRM matrix's element determines how many sensor nodes report the same event. Ideally, an event should be reported only by one sensor node, but it is assumed that two sensor nodes are permitted to report an identical event. The values of DRM matrix are the most important parameters in the evaluation function. The proposed method tries to find an optimal value for these parameters. Consequently, the average of data redundancy per sensor in the network (DR) is calculated by Eq. (3).

$$\text{DR}=\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\text{DRM}}{\sum_{i=1}^{k}\text{active sensors}} \quad \text{where } a_{ij} \geq 3 \ \& \ a_{ij} \leq 0 \qquad (3)$$

The network coverage is the most effective parameter on the network efficiency and performance.

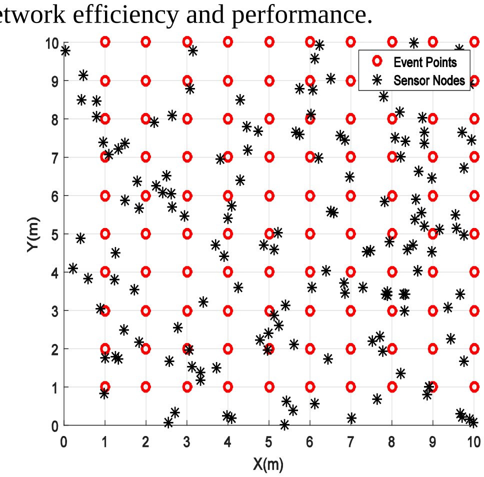


Fig. 3 The event points and the deployed sensor nodes in the application area.

To switch the status of some sensors off, it damages the network performance extremely regardless of their influence on the network coverage and connectivity. To calculate the network coverage, similar to the data redundancy calculation, the application area is split into grids again. To be covered, every junction point should at least have access to a sensor, otherwise, it becomes an uncovered point. Therefore, to calculate the total network coverage, similar to the DRM, a binary matrix is defined named the network coverage matrix (NCM). It is almost the same matrix as DRM, but the NCM element value range is different; min value is zero and max value is one. Moreover, the coverage percentage is calculated by Eq. (4).

$$\text{NC}=\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\text{NCM}}{\sum_{i=1}^{m\times n}\text{grid points}} \qquad (4)$$

Also, the uncovered percentage may be obtained by Eq. (5).

$$\text{UNC}=100-\text{NC} \qquad (5)$$

Although, the DR is used to calculate the average of data redundancy per sensor, it is not able to calculate the distance of sensor nodes, which are close or away from each other based on the sensing distance. To calculate neighbors' overlapping, the same matrix as the DR is mostly defined called the distance matrix (DM). The elements of DM determine the sensor nodes' sensing overlapping calculated by Eq. (6).

$$c_{ij} = 2R_{sen}^{\ 2}\cos^{-1}\left(\frac{d}{2R_{sen}}\right) - \frac{1}{2}d\sqrt{4R_{sen}^{\ 2} - d^2} \qquad (6)$$

Where the d is the distance of two sensor nodes located in equal or less than Rsen. Therefore, the average neighbor distance (ND) is calculated by Eq. (7).

$$\text{ND} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}c_{ij}}{\sum_{i=1}^{k}\text{active sensors}} \qquad (7)$$

Another objective function parameter is the residual battery power (RBP) of sensor nodes. It is assumed that m out of n number of sensor nodes switch the operation mode to the sleep mode in every round. If the total residual battery power of sleep sensor is minimized, as a result, the residual battery power of active sensors will be maximized. If the residual battery power (RBP) of active and sleep nodes are presented by ARBP and SRBP, consequently, the ratio of ARBP to SRBP presented by RRBP is obtained using Eq. (8).

$$\text{RRPB}=\frac{Avg\left(\sum_{i=1}^{m}ARBP_i\right)}{Avg\left(\sum_{i=1}^{n}\text{SRBP}_i\right)} \qquad (8)$$

The RRBP value should always be more than one, otherwise, unsuitable sensor nodes are selected to be operated in the active mode in that round. Regarding the above parameters, the cost function is calculated by Eq. (9).

$$\text{Cost fun.} = w_1 \times DR + w_2 \times UNC + w_3 \times ND + w_4 \times RRPB \qquad (9)$$

Where the w1, w2, w3, w4 are the different weights of parameters in the cost function and are obtained by trial and error experiments.

## 5. The Proposed Method

The simulation consists of two main phases. In the first step, the CESS algorithm is implemented through the different EAs such as the GA, ICA and PSO as a lack of any previous work for comparing the performance to check the accuracy and performance of it. These EAs are run to find the best evolutionary algorithm for the proposed method based on the different WSNs parameters. The following scenario discusses the different steps of the simulation method.

a. Initialize and deploy Sensor nodes to construct a WSN inside the field of interest.
b. Layer 1: Select M number of Active Sensor nodes randomly based on the network criteria using an EA in every Round.
c. Layer 2: Grouping M number of Active Sensors in *K*-Clusters using any Clustering Protocol.
d. Update the Sensors Batteries regarding the Clustering Protocol Characteristics and change the Status of any Died Sensor.
e. If the conditions are met, terminate the network otherwise Go to Step B.
f. End.

It selects some nodes out of living sensors to be active, and the rest of living sensors change their status to sleep mode in every round. Finding the optimization parameters which should be used in the objective function is very important. Selecting the minimum number of active sensors with the highest residual batteries to have the maximum network coverage and minimum data redundancy is the CESS algorithm issue.

In this simulation, it is assumed that sensor nodes are stationary and distributed randomly and uniformly in 10×10 m2 application area. The sensing radius is 1 m2. Therefore, the standard deployment density of the WSN is one sensor per square meter. Although in this simulation, 150 sensor nodes are used; so, deployment density is 1.5 of normal mode (Fig. 4).

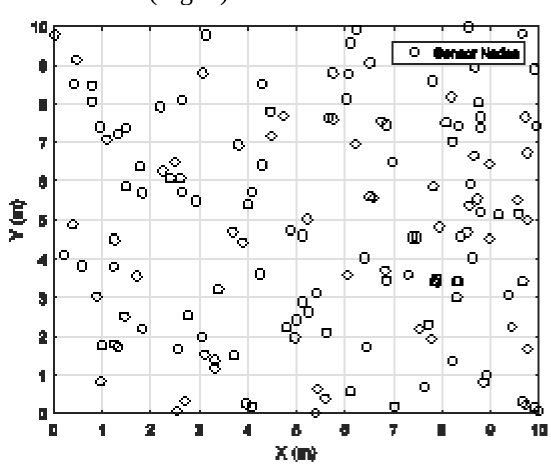


Fig. 4 Random Sensor nodes deployments in the field of interest.

In this scenario, on account of random deployment, the maximum network's coverage is 97% when all sensors operate in the active mode. To achieve 100% coverage, the sensor nodes should be deployed with the density of 2 to 2.5. The radio radius is fixed and all sensor nodes are able to communicate with BS (BS) which is located in the far distance. Also, the BS can communicate with all sensor nodes to send the required controlling messages.

To consider the residual battery of the sensors, a uniform random number from 0 to 1 is assigned to every sensor node. The total average of the residual battery charge is 0.48 J. Every sensor node can operate in sleep or active modes. Based on the protocol, an active sensor can operate in different modes such as super cluster head, normal cluster head or ordinary sensor node. The weighted parameters of the objective function in the GA, ICA and PSO are manipulated to achieve the max algorithms performance and find the best weighted values. The obtained values of parameters' weights are shown in table 1.

Table 1: The weight's values of objective function's parameters

| *EAs* | $W_1$ | $W_2$ | $W_3$ | $W_4$ |
|---|---|---|---|---|
| GA | 5 | 10 | 20 | 15 |
| ICA | 5 | 8 | 22 | 13 |
| PSO | 5 | 10 | 25 | 18 |

These results are obtained from running of the algorithms with 200 iterations. It should be mentioned that the final selection should be concluded based on all WSN parameters' results and priorities.

## 6. The Results Discussions

In the first part of this paper, the efficiency of the GA, ICA and PSO to solve a discrete NP-complete problem is compared based on different network parameters such as: no. of active sensors, average data redundancy per sensor, network coverage percentage, and average residual battery per sensor. Every WSNs topology would like to maximize the network performance, coverage, connectivity and conserve more energy using the minimum number of the active sensors. Therefore, an algorithm with a lower number of active sensors is favorable. Figure 5 illustrates the total number of active sensors for the CESS-GA, CESS-ICA and CESS-PSO algorithms.

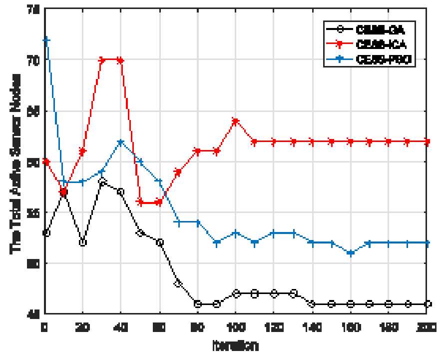


Fig. 5 Number of active sensors

During the primary rounds of the network, the total number of active sensors fluctuates sharply, while in the final rounds, it is converged. After 200 iterations, the CESS-GA ended with min number of 43 active sensors, while the CESS-PSO ended with 52 and the CESS-ICA ended with max number of 62 active sensor nodes. All algorithms converged after 110 iterations. Moreover, to employ the minimum number of active sensors, the CESS-GA is more efficient compared with the others.

The data redundancy is one of the most important parameters in the network energy wastage which increases the network traffic and reduces the network efficiency and lifetime. The main target of any sleep scheduling algorithm is to provide an ability for the network to operate with the maximum network performance through using a minimum number of the active sensors. Figure 6 shows the average of data redundancy per sensor.

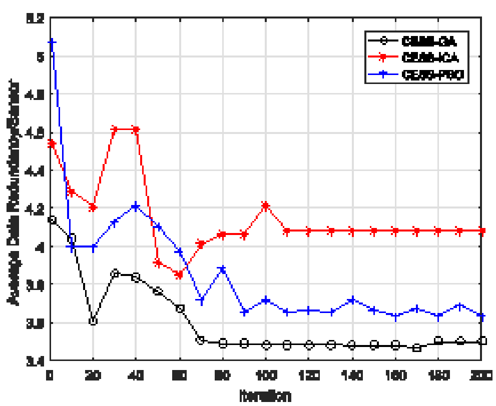


Fig. 6 Average of data redundancy per sensor

The CESS-GA recorded the min value, where the max value of data redundancy per sensor is obtained by the ICA algorithm. It means that compared with the others, the distance of the group of sensors, selected to act as the active sensors, form the neighbors is more satisfactory in the CESS-GA. Therefore, optimizing the number of error reporting leads to increasing the network robustness.

The main object of the constructing a WSN is to observe, monitor and control any physical phenomena, and it is expected that the sensors cover the whole application domain. As a result, the network coverage is another important parameter in a WSN, and the lack of sufficient network coverage leads to the network operation failure. In figure 7, although in the primary iterations, all evolutionary algorithms start with an undesirable subset of active nodes, which leads to increasing non-coverage percentage, after 100 iterations, the CESS-GA and CESS-ICA could achieve the maximum percentage of the network coverage. However, the CESS-GA and CESS-ICA are able to cover the whole application area, but the CESS-GA is more efficient as it employs a lower number of active sensors.

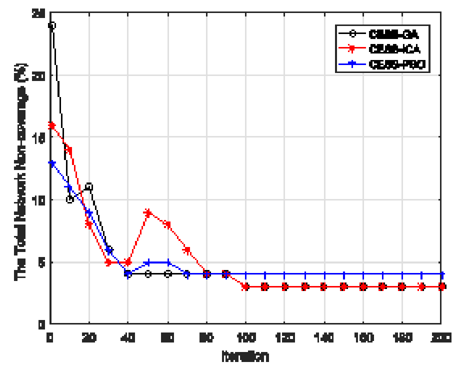


Fig. 7 Total non-coverage percent of the network

As already mentioned, the power resource is the most important parameter in the WSNs. When a sensor battery is drained, the node dies. Selecting any sensor with an insufficient residual battery may damage the whole network performance. If the unsuitable sensor is selected to act as a gateway, some or all the sensors may be disconnected by its failure. Therefore, selecting a subset of sensors with the highest residual battery by an effective algorithm seems necessary.

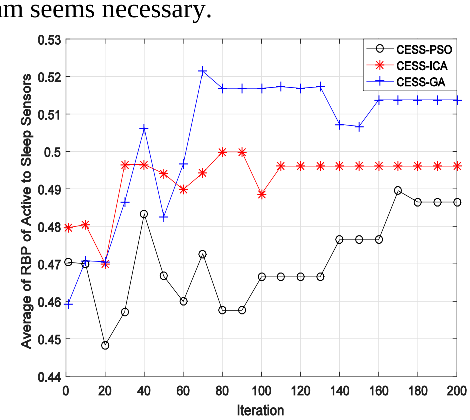


Fig. 8 The average of residual battery of active sensors to average of residual battery of sleep sensors.

The CESS-GA, CESS-ICA and CESS-PSO could select a subset of active sensors with a higher average of residual battery power (RBP). The CESS-GA could achieve the highest average around 0.515 compared with the other algorithms (Figure 8). It is concluded that compared with the others, the CESS-GA could satisfactory create a subset of nodes with the minimum number of active sensors and data redundancy and the max value of the coverage and residual battery power. Figure 9 shows the output of the proposed method, CESS-GA after 200 iterations. The selected nodes cover the whole application area with a reasonable distribution distance. Regarding the sensing radius ($R_s$), no very close nodes were selected. This output can be used as an input (initialization phase) for any clustering or routing algorithm.

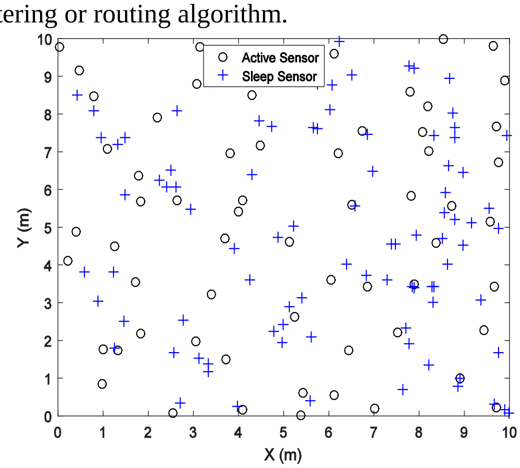


Fig. 9 The output of CESS through the GA.

Due to the lack of any similar research, in the second step of the result discussion, the CESS-GA output is used as input for the two different LEACH as homogeneous and SEP as heterogeneous called CESS-LEACH and CESS-SEP, clustering algorithms to examine the accuracy and performance of the proposed sleep scheduling method. The sensors' type is homogeneous in LEACH and CESS-LEACH and heterogeneous in SEP and CESS-LEACH without any routine algorithm modifications, and the network runs until 80% of sensors die.

A major part of a sensor energy is used for the radio communication. In the first radio model [13], it is assumed that the radio channel is symmetric such that the energy required to transmit a message from node A to node B is the same as the energy required to transmit a message from node B to node A. Data transmission energy consists of transmission ($E_{Tx}$) and receiving ($E_{Rx}$) energies. Thus, the total consumed energy to transfer a *k*-bit message over a distance *d* using the first radio model may be given by Eq. (10).

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$\Rightarrow E_{Tx}(k,d) = \begin{cases} k \times E_{elec} + k \times \varepsilon_{fs} \times d^2 & d < d_0 \\ k \times E_{elec} + k \times \varepsilon_{amp} \times d^4 & d \geq d_0 \end{cases} \quad (10)$$

where $d_0$ is a threshold distance defined as $d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$ , $E_{Tx\text{-}elec}$ is the energy spent by the transmit circuit, $E_{Tx\text{-}amp}$ is the energy-cost of the transmission amplifying circuit, $E_{Rx\text{-}elec}$ signifies the energy-cost of the receiving circuit, and $E_{elec}$ is the energy expense to transmit or receive 1-*bit* message by the transmitting or the receiving circuit. The energy spent in received data can be obtained by Eq. (11).

$$E_{Rx}(k,d) = (E_{Rx} + E_{BF}) \times k \quad (11)$$

where $E_{BF}$ is the beam forming energy. One has to minimize not only the transmission distances, but also the number of transmitting and receiving operations for each message. The energy consumption for data fusion is represented by Eq. (12).

$$E_{da-fus}(k,d) = k \times E_{da} \quad (12)$$

The total communication energy for a sensor node ($E_{CE\text{-}Sen}$) may be represented by Eq. (13).

$$E_{CE-Sen}(k,d) = E_{Tx}(k,d) + E_{Rx}(k,d) + E_{da-fus}(k,d) \quad (13)$$

Therefore, the total communication energy (*CE*) for the whole network communication can be represented by Eq. (14).

$$CE = \sum_{i=1}^{n} E_{CE-Sen_i}(k,d_i) \quad (14)$$

The termination condition of the WSN is related to the network coverage. It is assumed that should the total number of living sensors become less than 30 sensors (20% of the total sensors) or the current network coverage becomes less than 30% of the total network coverage, the WSN will not be meaningful and must be terminated.

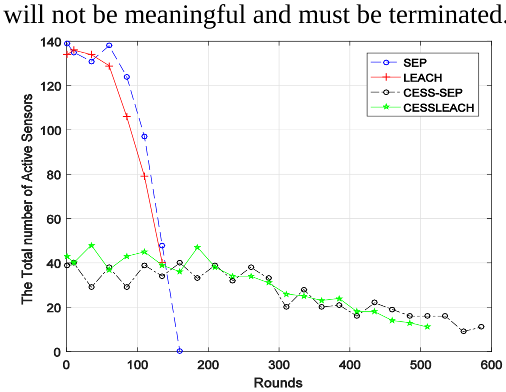


Fig. 10 Number of active sensors per round.

When two algorithms, the LEACH and SEP apply the CESS algorithm (proposed sleep schedule method), the

WSN is constructed with 29% of living sensor nodes, and it starts with 42 active sensors and stops after around 600 rounds, whereas the LEACH and SEP start with 138 normal sensors (without CHs) without the proposed algorithm, and it is terminated after 150 rounds. This process is shown in figure 10. Because of using 10% of the total advanced sensors in SEP algorithm, its efficiency is better than the LEACH algorithm.

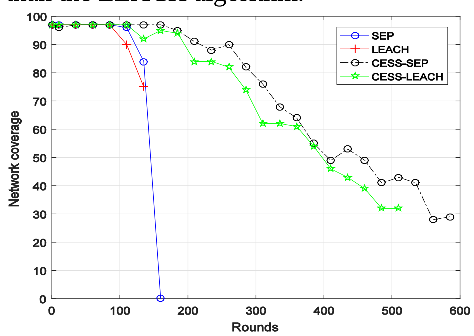


Fig. 11 The total network coverage per round.

Another important point is that applying the CESS on the LEATCH and SEP clustering algorithms (CESS-LEATCH, CESS-SEP), the network lifetime is increased 4 times as much as that obtained using LEACH and SEP without the proposed method.

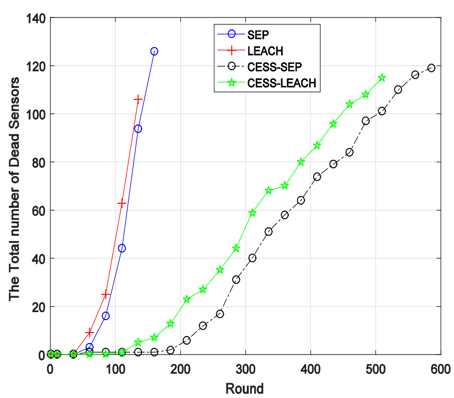


Fig. 12 The total number of dead sensors per round.

As for the network coverage issue, it is maximized with only 28.5% of living sensors through implementing the proposed method. Without the CESS algorithm, the network coverage decline is sharp in comparison with LEACH and SEP (figure 11).Figure 12 shows the total number of dead sensors per round. Through using the CESS algorithm, the WSN loses living sensors softly, while without applying the sleep scheduling, sensors die out very fast. It shows that the CEES's performance is better in heterogeneous than in homogeneous sensors.

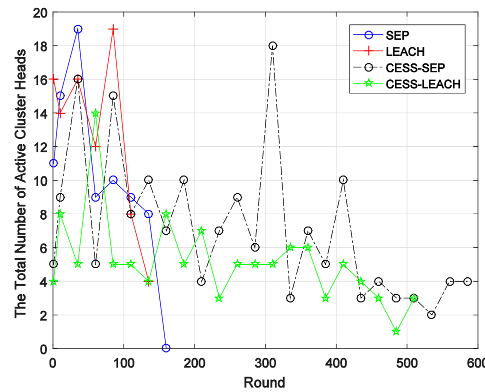


Fig. 13 The total number of active cluster heads per round.

The SEP and LEACH algorithms use almost an equal number of cluster heads, but when a sleep scheduling algorithm (CESS) is the CESS-SEP and CESS-LEACH, cluster's members are decreased, and the cluster heads should provide the service for a lower number of members (figure 13). Therefore, the total communicated packets inside and outside of the clusters are reduced, which leads to conserving more energy and extending the network lifetime shown in figure 14.

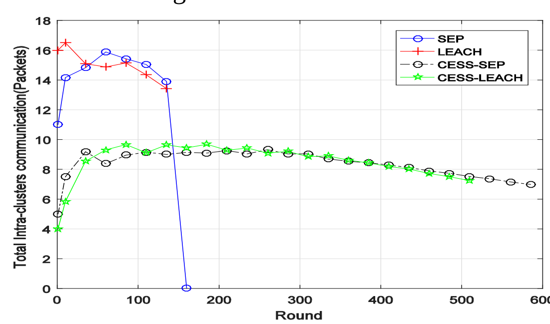


Fig. 14 The total intra-clusters communication (packets).

## 7. Conclusion

A WSN contains hundreds or even thousands of small sensor nodes constructed in the welfare environment. Due to the resource constraints, energy is an important issue in a WSN. Applying the different sleep scheduling algorithms in densely deployed sensors leads to an efficient energy conservation. In this paper, regarding the most important WSN's parameters, a centroid energy-based sleep scheduling algorithm (CESS), using evolutionary algorithms is proposed. These results are obtained from 200 iterations run by the algorithms, while all algorithms converged after 110 iterations. The performance of the CESS-GA in providing the maximum network coverage (97%), reducing the efficient data redundancy, utilizing the minimum number of living sensors with the maximum residual battery after 200 iterations is better in comparison with that of the CESS-ICA and CESS-PSO.

Due to the lack of any similar research, the CESS-GA's output is applied on the LEACH and SEP called CESS-LEATCH and CESS-SEP, input to check the accuracy of the proposed method without any changes in routines of the algorithms. It constructs the WSN with 42 out of 150 (29%) of living sensor nodes and terminates the network after around 600 rounds. Because of 10% of advanced sensors in CESS-SEP algorithm, its efficiency is better than that of CESS-LEACH algorithm. CESS-SEP and CESS-LEACH algorithms use almost an equal number of cluster heads but applying sleep scheduling algorithm, cluster's members are decreased, and cluster heads should provide the service for a lower number of members. Therefore, the total communicated packets inside and outside are reduced, which results in conserving more energy and extending the network lifetime, which is increased significantly five times as much, and the maximum network coverage is achieved.

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