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Performance evaluation of static and random distribution of nodes on energy consumption for wireless sensor networks

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Abstract
Energy consumption is one of the most important challenges for wireless sensor networks that need to be addressed. In addition to the proposed and developed many protocols in the data link layer and the network layer, cross- layer protocols have been designed to resolve energy consumption issues. Some of these protocols are valid for applications requiring a static distribution of nodes and others for applications requiring a random distribution of nodes. In this paper, we evaluate the effect of static and random distribution of nodes on slotted ALOHA based p-persistent CSMA MAC Protocol for data link layer, enhance energy conservation based on residual energy and distance (EECRED) for the network layer, and cross-layer design between the data link and the network layers (slotted ALOHA based p-persistent CSMA and EECRED) protocols. The MATLAB simulation program was used to evaluate the performance of the network. The results of the simulation show that there is no significant influence on energy consumption between a static distribution and random distribution. In general, the static distribution may be considered better than a random distribution since the static distribution of nodes ensures that each point in the area of interest is covered by a small number of sensors compared to the random distribution method, which requires a relatively large number of sensors to cover all areas of interest, in addition to not recognizing the position of the sensors and therefore it is difficult to replace the sensor when a malfunction occurs.

Keywords: Wireless sensor networks (WSNs), static distribution, random distribution, energy-efficient protocols, Slotted-ALOHA, P-Persistent CSMA, EECRED, cross-layer

1. Introduction

Nowadays, Wireless Sensor Networks (WSNs) have made life much easier by reducing people's efforts in various areas. WSNs consist of hundreds to thousands of sensors that used to sense the environment phenomena. The sensor nodes, which are the basic unit of the sensor network, consist of multiple functional units including a sensing unit that contains one or more kinds of sensors depending on the application such as pressure sensors, humidity sensors, temperature sensors, acoustic sensors, vibration sensors, etc. and the Analog to Digital Converter (ADC) used to convert analog signals generated by the sensor into a digital signal to process the measured information, a transceiver that is a wireless transmitter and a receiver that provides communication between the nodes, Micro-controller for processing sensed data, external memory for storing information, route information. The power unit is used to supply the sensor with energy because most of the sensor nodes are battery powered [1]. Sensors are tiny in size, low-cost, limited power, and battery-operated. Generally, WSNs have a lot of applications such as health care monitoring, precision agriculture, smart building, military, traffic control, vehicle tracking, animal tracking, security and surveillance. Depending on the application requirements, these sensors are manually or dynamically distributed, when the sensor senses an event, the sensing data is transmitted to nearby nodes or to the base station [2, 3].

There are many challenges facing wireless sensor networks such as harsh environmental conditions, self- management, hardware and software issues, heterogeneity, redundant data, data freshness, event-driven challenge, quality of service (QoS), deployment, operating system (OS), security, fault tolerance, localization, time synchronization, but the main challenge is that it is difficult to replace node's battery in inaccessible places [4]. This paper analyzes the impact of static and random distribution of nodes on the energy consumption of wireless sensor networks.

Due to the energy consumption problems of the wireless sensor networks, a number of protocols have been proposed in the data link and network layers to reduce energy consumption and prolong the lifetime of the network.

The authors of [5] suggested an Energy-efficient adaptive MAC protocol for mission-critical applications in WSN (ADMC-MAC) protocol to increase data delivery performance on the basis of traffic conditions, taking into account the size of the queue, and also to improve energy efficiency. Sabitri Poudel *et al*. [6] proposed an energy-efficient and fast MAC (EF-MAC) protocol in UWSNs for time-critical sensing applications to outperform the traditional MAC protocols in order to reduce communication delays energy consumption. Amanjot Singh Toor *et al*. produced in [7] a new hierarchical heterogeneous routing protocol for wireless sensor networks called Mobile Energy Aware Cluster Based Multi-hop (MEACBM) to increase the lifetime of the network, increase the throughput, provide more stable networks, and reduce the number of dead nodes. In [8], Mohammed Almazaideh and Janos Levendovszky presented novel energy-aware and reliable routing protocols in order to balance the energy of the wireless sensor network and increase the network lifetime.

The authors in [9] proposed Mobile Intelligent Fog Computing: An Energy-efficient Cross-layer-sensing Clustering Method (ECCM) to address the issue of energy hotspots or voids in WSNs in order to maximize the efficiency of data collection and enhance the performance of the network. Samira Yessad *et al*. in [10] designed a cross-layer protocol combined between the MAC layer and the network layer to extend the lifetime of the wireless sensor networks through balancing the consumption of energy in the routing task.

More information and details on the energy-efficient MAC layer protocols, network layer protocols, and cross- layer protocols can be found in [11-19].

This paper analyzes the effect of static and random distribution of nodes on the slotted ALOHA based on p-persistent CSMA MAC protocol proposed in [20], enhance energy conservation based on residual energy and distance (EECRED) proposed in [21], and the cross- layer protocol in proposed in [22].

The remainder of the paper is summarized as follows: Section 2 describes the energy model of the system. The network model and simulation results are discussed and evaluated in Section 3. Section 4 concludes the paper.

2. Energy Model

The radio model used in the wireless sensors to transmit (*k* bits) of data over distance (*d*) is explained in Fig. 1. In general, the amount of energy consumed depends on the size of the packet and the distance, an increase in the size or distance of the packet leads to an increase in energy consumption. Equation (1) is used to measure the amount of energy needed by the source for sending a packet to the destination, and equation (2) is used to measure the amount of energy that the destination consumes when receiving a packet from the source [23].

$$E_{TX}(k,d) = \begin{cases} E_{elec} \times k + \varepsilon_{fs} \times k \times d^2 & , d < d_0 \\ E_{elec} \times k + \varepsilon_{amp} \times k \times d^4 & , d \geq d_0 \end{cases} \quad (1)$$

$$E_{RX}(k,d) = E_{elec} \times k \quad (2)$$

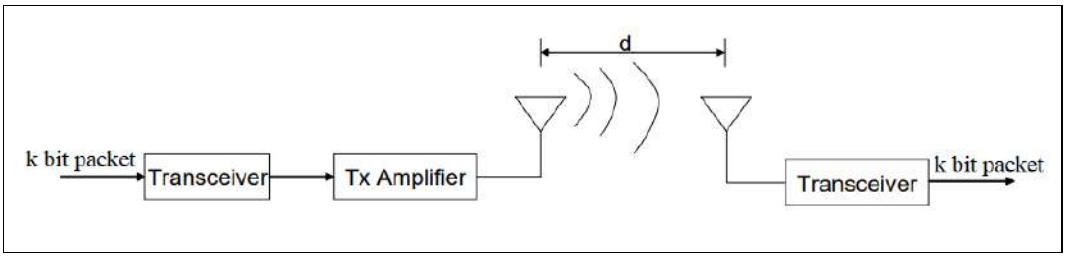

Fig 1: WSN energy model

Where:

E_{TX}/E_{RX}: is the energy consumed to transmit/receive *k* bits of data.

E_{elec}: is the energy consumed in the modulation.

$\varepsilon_{fs}, \varepsilon_{amp}$: is the energy consumed in the amplification.

k: number of bits.

d: is the distance between transmitter and receiver.

3. Network model and simulation results

In order to analyze the effect of static and random node propagation on wireless sensor networks, three separate scenarios were conducted and the network performance was calculated using the number of alive nodes, the amount of energy consumption, the stability of the network, and the lifetime of the network in each round. There are two types of sensor nodes deployed, Normal Node (NN) and Cluster Head (CH). The sensor area consists of 8 CHs and 72 NNs. The main responsibility of the normal nodes is to sense the event and send it to the cluster head. The cluster head, in turn, aggregates and processes the data for normal nodes and transmits it to the Base Station (BS) located at the center of the sensing field. Each normal node follows the flowcharts in [20-22] in order to transmit the sensed data to the cluster head and to transmit the aggregated data from cluster heads to the base station at each round. Table I gives the parameters of the simulation.

1. First Scenario

The impact of static and random distribution of nodes on slotted ALOHA based p-persistent CSMA MAC protocol [20] is analyzed in this scenario. The network model in Fig. 2 was used to evaluate the simulation results of the static MAC protocol where eighty nodes are distributed manually, while the network model in Fig. 3 was used to evaluate the simulation results of the random MAC protocol where eighty nodes are randomly distributed. The difference between the static distribution and the random distribution has been shown in Fig. 4, Fig. 5, Fig. 6, and Fig.7. The results of the simulation show that there is a slight change and that the random distribution gives better results compared to the static distribution, which means that in the case of random distribution the nodes are distributed close to the CHs, the distance is shortened, therefore the energy consumption is reduced and the network life is increased.

Table 1: Simulation parameters

Parameters	1st Scenario [20]	2nd Scenario [21]	3rd Scenario [22]
Area of sensor field	100 x 100 m^2	100 x 100 m^2	100 x 100 m^2
Base station position	(50,50)	(50,50)	(50,50)
Number of nodes	80	80	80
Number of CH	8	8	8
Number of NN	72	72	72
Initial energy	E_{CH}= 0.1J, E_{NN}= 2J	1J	0.1J
Data aggregation energy	-	5pJ/bit	5pJ/bit
ε_{amp}	100pJ/bit/m2	100pJ/bit/m2	100pJ/bit/m2
E_{elec}	50nJ/bit	50nJ/bit	50nJ/bit
Packet size	500 bytes	250bytes	250 bytes

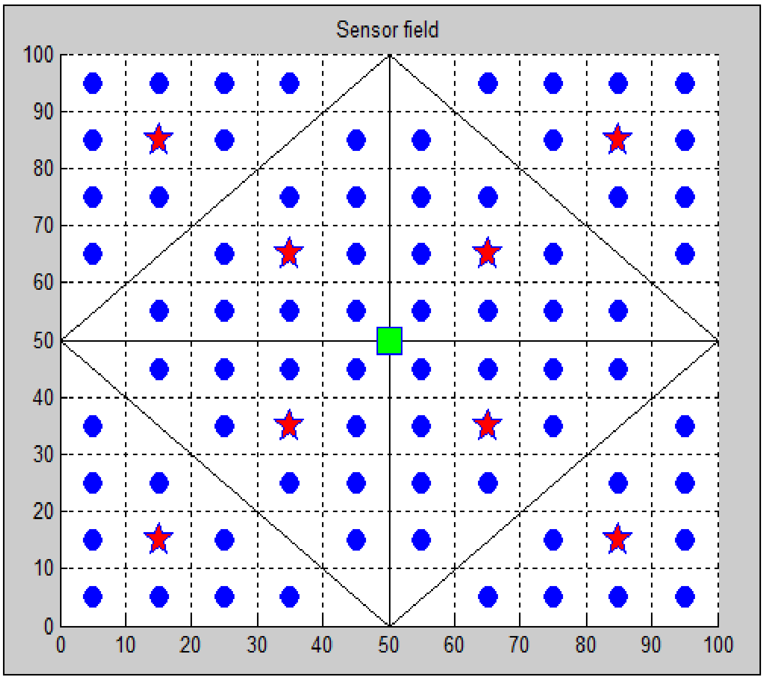

Fig 2: Sensor scope of the static distribution

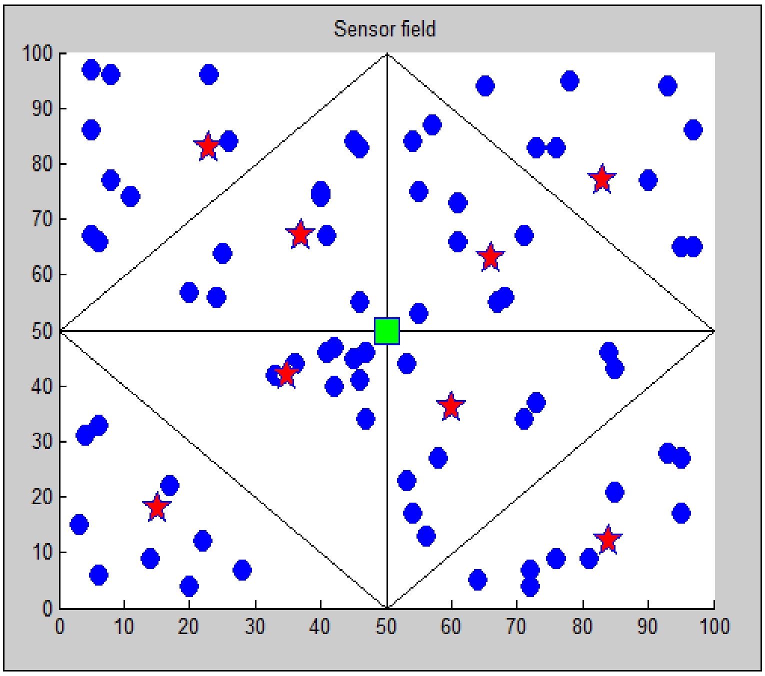

Fig 3: Sensor scope of the random distribution for first scenario

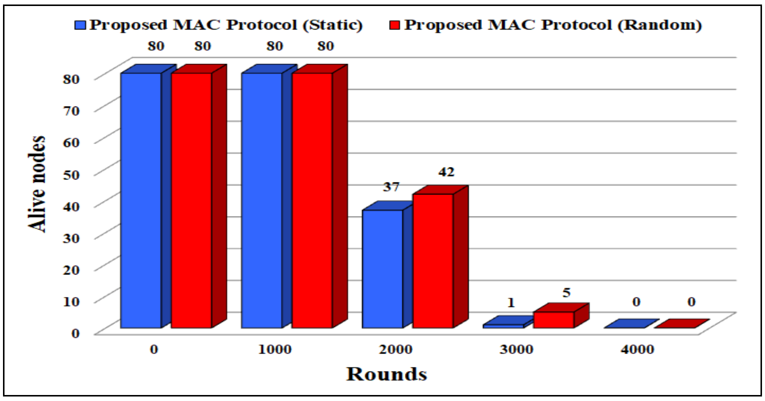

Fig 4: Number of alive nodes over time in the proposed MAC protocol using static and random distribution

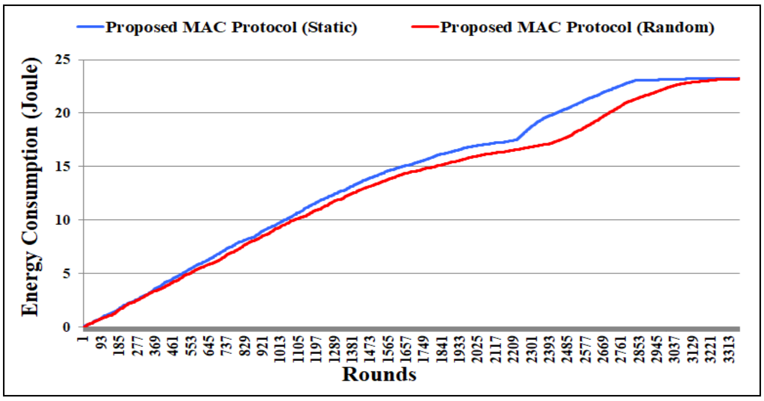

Fig 5: Energy consumption over time in the proposed MAC protocol using static and random distribution

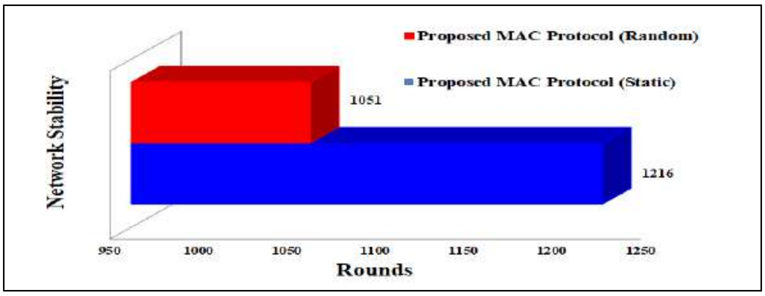

Fig 6: Network stability over time in the proposed MAC protocol using static and random distribution

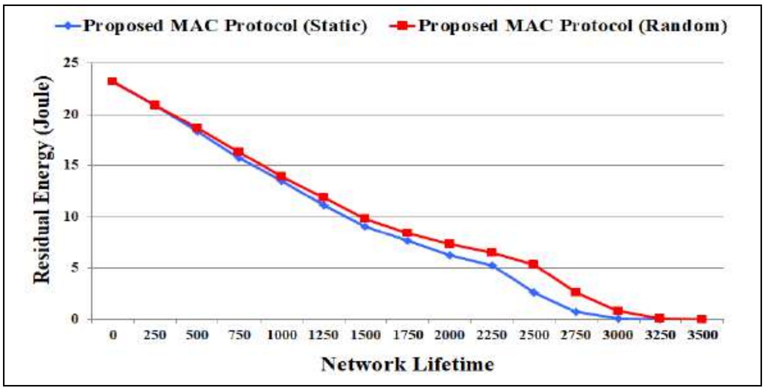

Fig 7: Network lifetime over time in the proposed MAC protocol using static and random distribution

Table 2. Summarizes the effect of both static and random distribution of nodes using slotted based on p- persistent CSMA MAC protocol.

2. Second Scenario

In this scenario, the proposed enhance energy conservation based on residual energy and distance (EECRED) [21] was implemented using the static and random distribution of nodes as shown in Fig. 2 and Fig. 8, respectively. Fig. 9, Fig.10, Fig.11 and Fig. 12 demonstrate the influence of the random distribution of nodes in the sensing area using the EECRED protocol. The results of the simulation showed that there is a negligible difference between a static distribution and random distribution. This negligible difference occurred as a result of a change in the location of the nodes, as the nodes lay close to each of them, as a result, the distance would be shortened and thus the energy consumption would be minimized.

Table 2: Summary of the results achieved in the first scenario

Metrics	Rounds	
	Static distribution	**Random distribution**
First node dead	1216	1051
Last node dead	3095	3368
Residual energy when the first node dead	11.39868 J	13.46432 J
Network lifetime	3095	3368

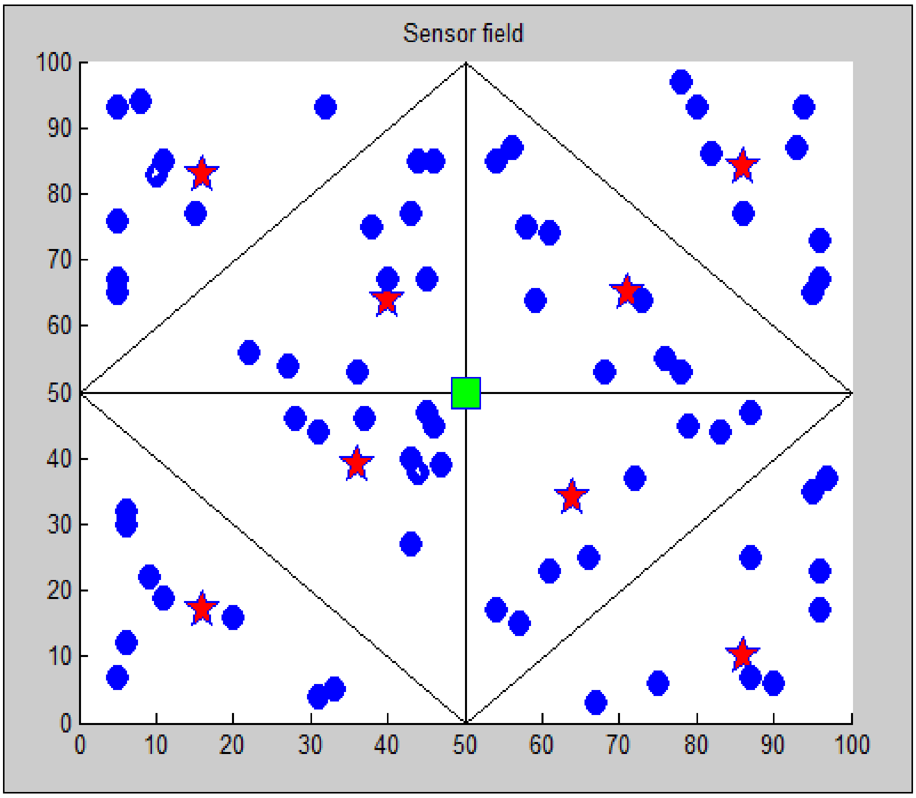

Fig 8: Sensor scope of the random distribution for second scenario

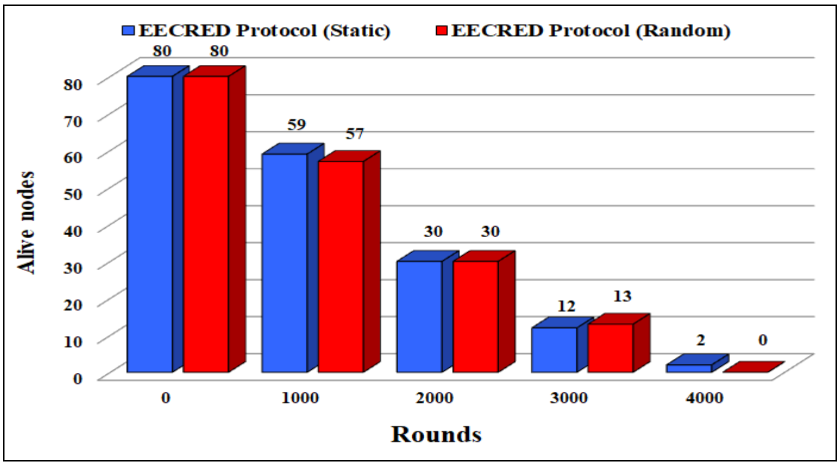

Fig 9: Number of alive nodes over time in the EECRED protocol using static and random distribution

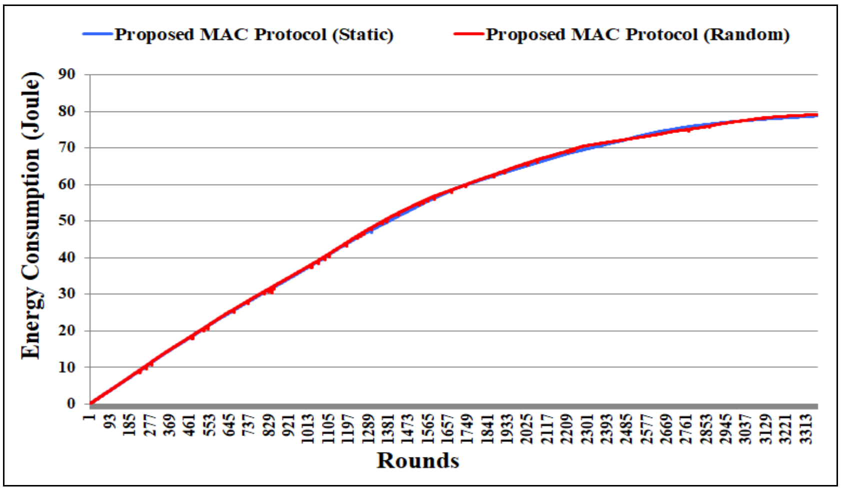

Fig 10: Energy consumption over time in the EECRED protocol using static and random distribution

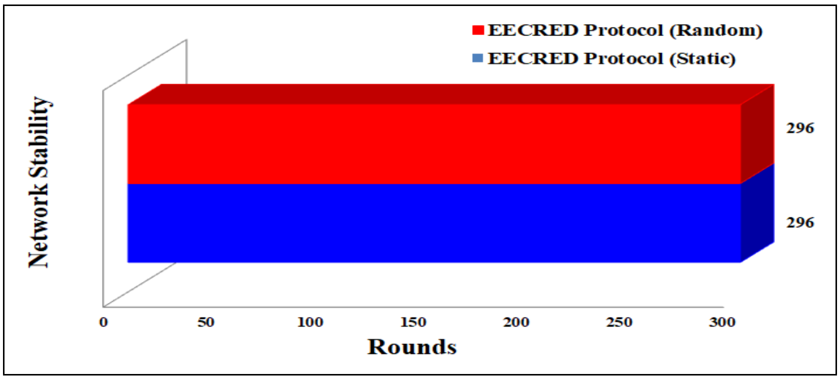

Fig 11: Network stability over time in the EECRED protocol using static and random distribution

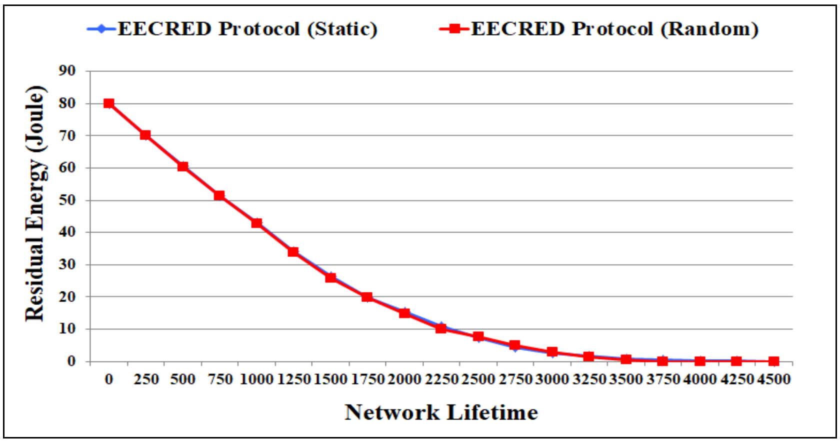

Fig 12: Network lifetime over time in EECRED protocol using static and random distribution

Table 3. Summarizes the effect of both static and random distribution of nodes using enhance energy conservation based on residual energy and distance (EECRED) routing protocol.

Third Scenario

A comparison was made in this scenario between the proposed cross-layer protocol in [22] using the static distribution of nodes as shown in Fig. 2 and the random distribution of nodes as shown in Fig. 13, Fig. 14, and Fig. 15. This scenario was repeated 3 times and the average was calculated to take into account the most possible random distribution of the sensors and to achieve reliable results. The results have shown that there is no significant difference between static distribution and random distribution. The proposed protocol can therefore be implemented in applications that require a static or random distribution of nodes. Fig. 16, Fig. 17, Fig. 18, and Fig. 19 show a comparison between static and random cross-layer in terms of the number of alive nodes, energy consumption, network stability, and network life.

Table 3: Summary of the results achieved in the second scenario

Metrics	Rounds	
	Static distribution	**Random distribution**
First node dead	296	296
Last node dead	4380	3757
Residual energy when the first node dead	68.23378 J	68.11879 J
Network lifetime	4380	3757

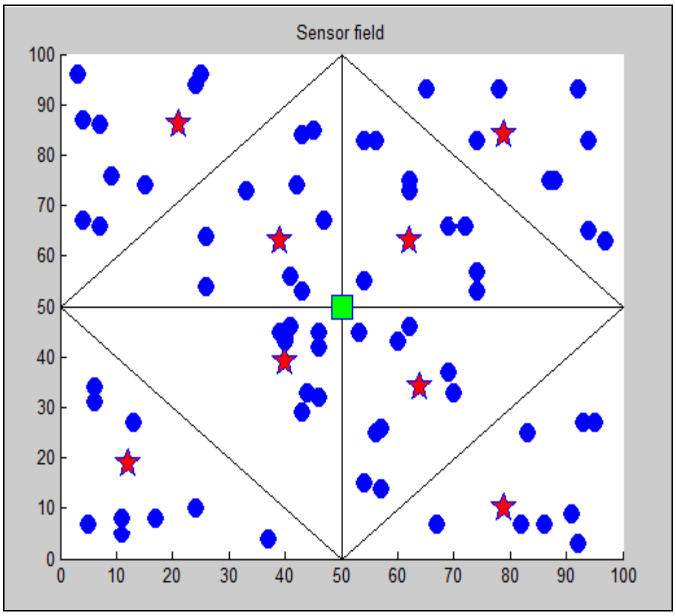

Fig 13: Sensor scope of the random distribution for third scenario (1st execution)

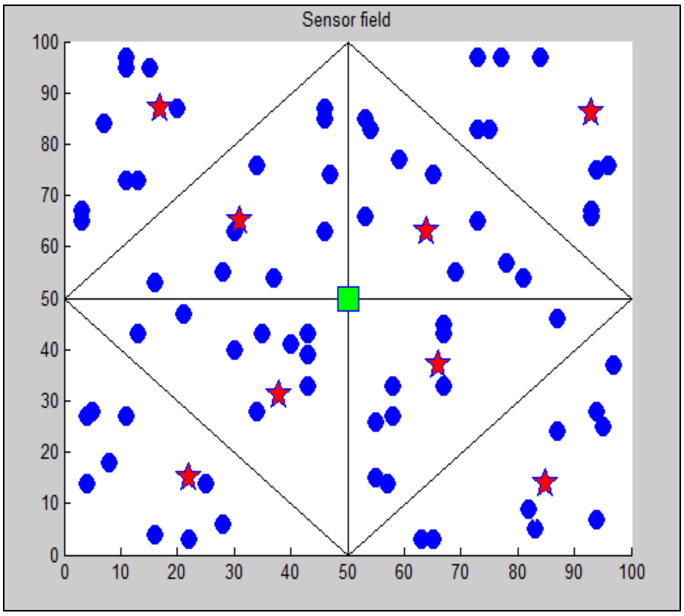

Fig 14: Sensor scope of the random distribution for third scenario (2nd execution)

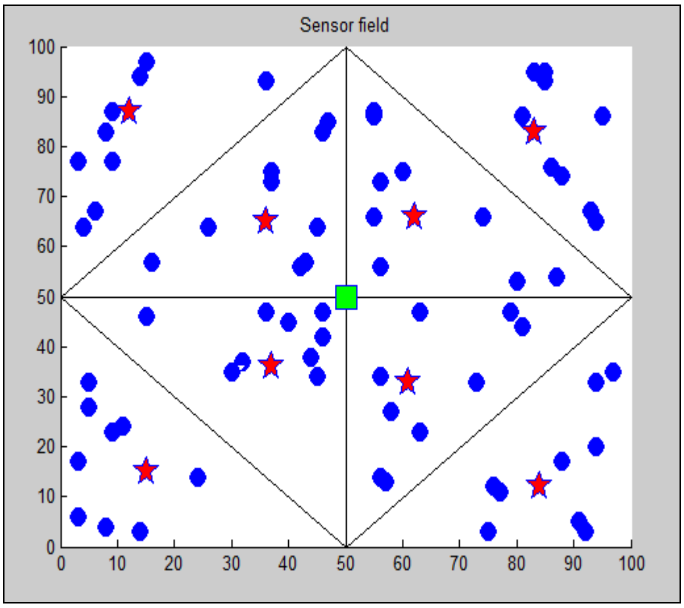

Fig 15: Sensor scope of the random distribution for third scenario (3rd execution)

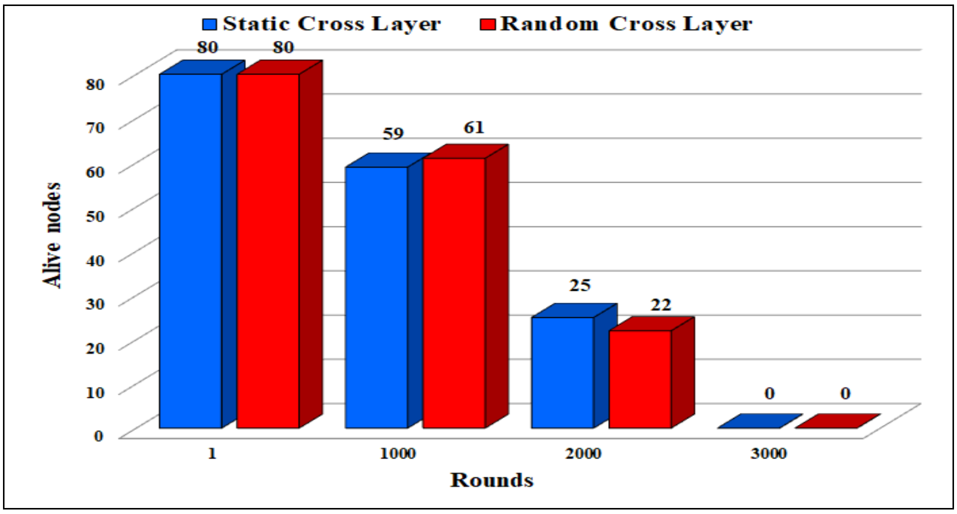

Fig 16: Number of alive nodes over time in the proposed cross-layer protocol using static and random distribution

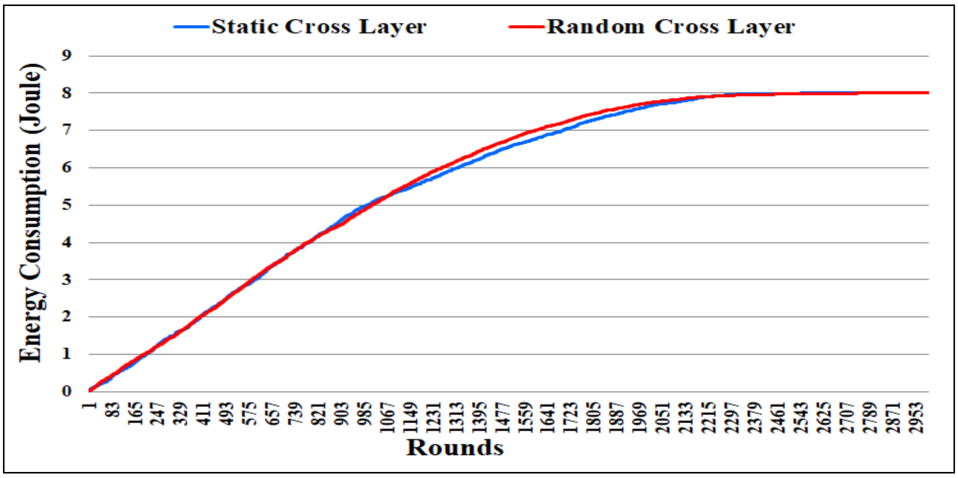

Fig 17: Energy consumption over time in the proposed cross-layer protocol using static and random distribution

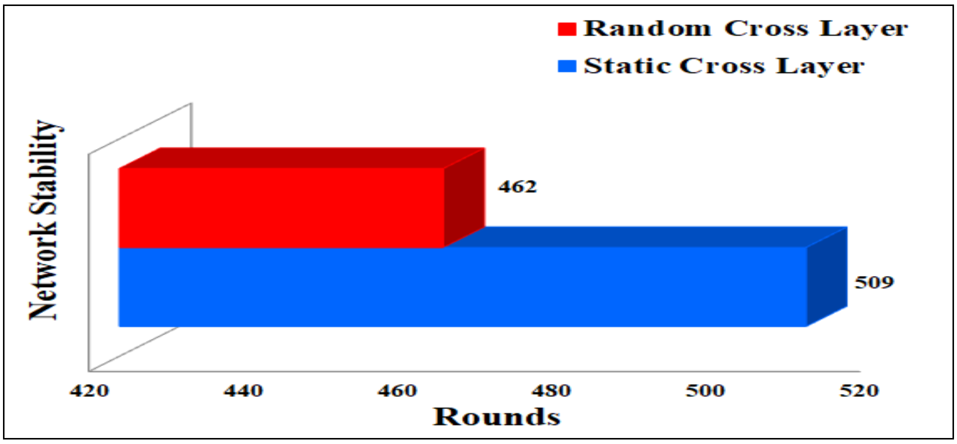

Fig 18: Network stability over time in the proposed cross-layer protocol using static and random distribution

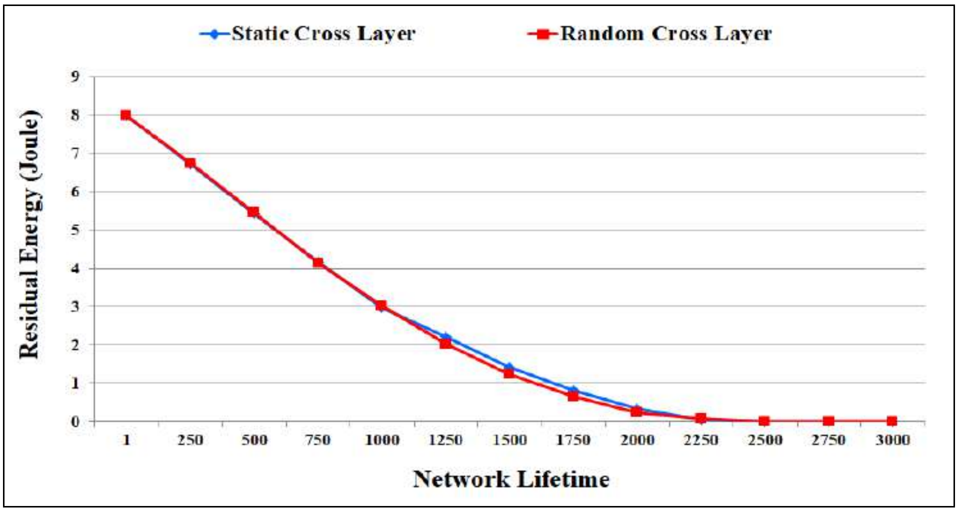

Fig 19: Network lifetime over time in the proposed cross-layer protocol using static and random distribution

Table 4. Summarizes the effect of both static and random distribution of nodes using the proposed cross - layer protocol.

Table 4: Summary of the results achieved in the third scenario

Metrics	Rounds	
	Static distribution	**Random distribution**
First node dead	509	462
Last node dead	2542	2661
Residual energy when the first node dead	5.390225 J	5.686253 J
Network lifetime	2542	2661

The above results have shown that there is no significant difference between the static distribution and the random distribution of the nodes in general. It can be considered that the static distribution is better than the random distribution because the static distribution of nodes ensures that each point in the area of interest is covered by a small number of sensors compared to the random distribution method, which requires a relatively large number of sensors to cover all areas of interest (hardware cost), in addition to not realizing the position of the sensors and therefore it is difficult to replace the sensor when a malfunction occurs.

4. Conclusion

The issue of energy consumption is one of the most critical issues facing wireless sensor networks. This paper analyzes the effect of the static and random distribution of nodes on energy consumption in wireless sensor networks. The analysis shows that the static distribution does not differ greatly from the random distribution. The static distribution is better than the random distribution since there are a small number of sensors required for the static distribution to cover the monitoring area and because of an awareness of the sensor position the sensor can be easily replaced when a malfunction occurred.

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