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Energy-Efficient Mobile-Sink Sojourn Location Optimization Scheme for Consumer Home Networks

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ABSTRACT With the fast development of wireless communication and semiconductor devices, home networking has gained considerable attention in the past few years. In Wireless Sensor Networks (WSNs), Sensing coverage is known as one of the most important standards in evaluating the performance of WSNs. The sensor nodes may have failures due to energy depletion during their service life which leads to incomplete coverage of the sensing area and coverage holes in the network which results in reducing the network performance. Therefore, designing an energy-efficient solution to prevent the coverage holes is vital. Employing Mobile Sink (MS) is a popular technique to enhance the energy efficiency of the network. Furthermore, sojourn location optimization is one of the main design issues of mobility based schemes. However, to the best of our knowledge, most of existing sojourn location optimization-based schemes are specially designed for homogeneous networks and much less attention has been devoted to optimizing this parameter in heterogeneous networks. Therefore, the aim behind this paper is to optimize the sojourn location of MS in a heterogeneous home network, which results in improving the coverage time and the performance of the network. Based on the experimental results, the scheme proposed in this paper remarkably improves the balanced energy consumption, which leads to enhanced network lifetime and performance.

INDEX TERMS Coverage time, home network, mobile sink, sojourn location, energy efficiency.

I. INTRODUCTION

A home network contains a set of internet-connected consumer electronic devices called sensors which sense and transmit the different types of data throughout the networks environment (Figure 1). Wireless Sensor Networks (WSNs) are suitable for the home network environment due to their inherent nature containing the features of infrastructure-less, fault-tolerance and self-organizing. Generally, WSN consists of several sensor nodes which can sense, process, and transmit the data packets to a Base Station (BS) or sink node via single- or multi-hop data transmission manner. WSNs are used in many home applications include sleeping/living pattern detection, fall detection, home automation, and home healthcare [1].

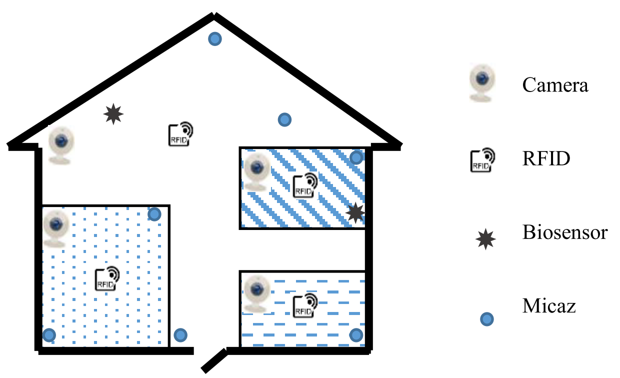

FIGURE 1. Smart home network.

In the home networks, the consumer sensor nodes are usually equipped with irreplaceable and limited batteries [2], therefore, designing the energy-efficient algorithms to enhance the network lifetime and energy conservation of

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the network is very important [3], [4]. In the most of home networks, where are small in size, due to the short distance between the network components, direct data transmission is utilized to transfer the sensed data from consumer devices to the BS, which results in unbalanced energy consumption of the devices. This is because in single-hop communication, the nodes placed farther from sink deplete their power earlier than other ones, which leads to defective coverage of the sensing area of the sensor nodes and appearing coverage holes in the network area [28].

Sink node, which can be dynamic or static, plays the most important role in the network since it is the only gateway between users and network. Mobile Sink (MS) was recently used as a solution to enhance the performance of the WSNs [26], [27]. MS are usually equipped with unlimited batteries and powerful computational tools. In the home networks, a sink node can be attached to a Robovac (Robotic Vacuum) or a simple robot.

One of the major issues for designing the mobility-based schemes is to optimize the sojourn positions of the MS. Sojourn locations are the set of positions, where MS stays to collect the data from sensor nodes. Selecting the proper sojourn locations of MS is one of the primary issues in MS based strategies, which is performed for different purposes such as balancing the energy consumption [30], [31], maximizing the network lifetime [32], [33], guaranteeing the connectivity and coverage [21], and improving the energy conservation of the network [34].

In recent decades, various MS based routing protocols attempt to optimize the sojourn positions of MS aiming at enhancing the balanced energy consumption throughout the network [25], [29]. However, most of them attempt to prevent the energy holes appeared in the multi-hop communication model and much less attention has been assigned to solve coverage holes. It is appeared in the single-hop communication model due to imbalanced power depletion of nodes and. Besides, the majority of previous sojourn location optimization-based schemes aim to balance the energy consumption of homogeneous nodes, but, most of the home networks consist of a set of heterogeneous consumer devices such as camera, Micaz, biosensors that differ from each other in terms of energy consumption and initial energy of the battery. Moreover, there is very little work that prevents appearing the coverage holes in the network and most of the previous schemes attempt to detect and solve the coverage holes which are costly and time-consuming. Therefore, an energy-efficient algorithm need to be introduced to balance the energy depletion time of heterogeneous sensor nodes, which leads to preventing appearing coverage holes and results in enhanced performance and coverage time of the network. For this purpose, in this paper, an Energy-efficient Mobile-sink Sojourn Location Optimization (EMSLO) scheme is proposed to balance the energy depletion time of consumer devices utilized in the home network environment which leads to enhanced coverage time and improved network performance. The main contributions of this paper can be summarized as follows:

1. The sojourn locations of MS is optimized to prevent coverage holes which stems from unbalanced energy depletion time of sensor nodes in single-hop data transmission manner.
2. Unlike previous schemes, the network consists of a set of heterogeneous consumer devices such as camera, Micaz, biosensors that differ from each other in terms of energy consumption and initial energy of the battery.
3. Furthermore, unlike the most of previous works which focus on detection and solving the coverage holes, the proposed scheme attempt to prevent the appearance of the coverage holes in the network, which leads to reduce the network overhead.

The remainder of the paper is organized as follows: Section II explains the related coverage hole avoiding based schemes and sojourn location of MS optimization-based Schemes. The system model is given in section III. The EMSLO algorithm is presented in section IV. Finally, section V and VI give numerical results and conclusion, respectively.

II. RELATED WORK

A. COVERAGE HOLE AVOIDING BASED SCHEMES

In the last decades, several schemes have been proposed to detect and overcome the coverage holes in the network. In [9], an optimized Bidding-based coverage improvement algorithm is proposed, which is able to detect the coverage holes after deploying the sensor nodes. Moreover, sensing radius of nodes are effectively adjusted based on the Delaunay triangulation to cover the coverage holes area. Likewise, if necessary, the mobile nodes will be employed to cover the uncovered area and reduce the overlapping between the sensing ranges of nodes. Khedr *et al.* [10] proposed a distributed coverage hole detection and recovery scheme, where nodes collaborate to detect and predict the coverage holes. In addition, they employed mobile nodes to achieve full coverage in the network.

In [11], a computational geometry approach based scheme is proposed to discover the coverage holes in a post-deployment scenario by considering only one and two-hop neighbors of each node. A Delaunay triangulation based mechanism is presented [12] where the headings of sensors is adjusted to coverage improvement. This proposed scheme not only improves the coverage of the network but also is able to strengthen the coverage of vulnerable points of the network. Based on the simulation results, the scheme enhances the coverage of the network effectively. In [13], a harmony search based deployment algorithm is introduced that optimizes the number of nodes and their locations to maximize the coverage of network area and minimize the network cost.

In [14], a coverage hole detection and restoration (CHD-CR) algorithm is proposed which aims to solve the coverage hole problem in the target area. CHD-CR consists of two phase: detecting the coverage holes in the network area and then restoring the coverage to the network. At the coverage hole detection phase, each sensor node independently detects any hole by updating certain information with its neighbor nodes. In addition, at the second phase, the node with higher remaining energy is given priority to cover the hole closer to it by adjusting its sensing range up to a maximum limit to restore the coverage. Verma and Sharma [15] have proposed a new decentralized, node-based, localized algorithm called Coverage Hole Detection and Restoration. In such scheme, each node detects the crucial intersection points between neighbor nodes and itself in order to detect coverage holes in the network where are restored by deploying new nodes over detected locations. In [16], a distributed algorithm has been proposed which employs mobile nodes to repair the coverage holes in the network. In such scheme, the nodes collaborate to detecting the area of the coverage hole, then consider their coverage redundancy, residual energy, and moving distance to select a suitable replacement to cover it. Based on the discussion, it can be concluded that the existing coverage hole avoiding based schemes attempt to repair and restore the coverage holes which are costly and time-consuming. Accordingly, a practical coverage hole preventing scheme need to be discovered to enhance the network performance.

B. SOJOURN LOCATION OF MS OPTIMIZATION BASED SCHEMES

In the past few years, a number of studies have been performed to optimize the sojourn location of MS which lead to enhance network performance. In [17], the authors proposed a routing algorithm which employs MS in hierarchical WSNs to enhance network lifetime by balancing the energy consumption among nodes. The upper and lower bound of delay is considered in optimizing sojourn locations and sojourn time of MS. A MS-based adaptive Immune Energy-Efficient clustering Protocol (MSIEEP) has been proposed [18] to remove the energy hole problem. In such scheme, the Adaptive Immune Algorithm (AIA) is exploited to optimize the sojourn locations of the MS and the optimum number of Cluster Heads (CHs) and their locations. The main objective of that scheme is to minimize the total energy consumption in the communication process and overhead control packets of all sensor nodes within the network.

In [19], the sojourn locations of MS is optimized in such a way that, when the data packet reaches to the last node of the shortest path to the BS, MS starts to move to the possible nearest position of that node. Such scheme aims to reduce the energy consumption of nodes and enhance the network performance. A new mixed-integer linear programming model has been proposed in [20] to optimize sojourn locations of MS and information paths between sensors and sinks when sensor locations are given. In the first part of the proposed scheme, the total routing energy is minimized, whereas the objective of the second part of the proposed scheme is to minimize the total cost of the network. An energy-efficient distance-aware routing algorithm with multiple MSs has been proposed in [21]. The aim behind this scheme is to enhance the network performance by selecting the optimal number of MS and their parking positions. In such scheme, sojourn location is chosen from parking positions which are determined according to the nodes distribution and transmission range of sensor nodes.

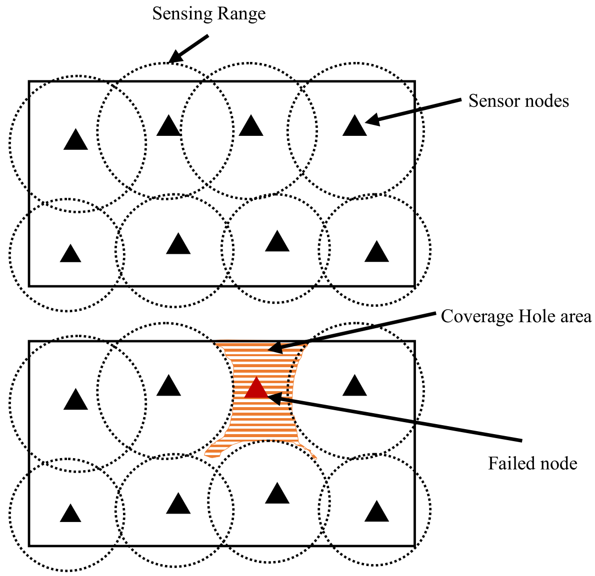

FIGURE 2. Coverage time of the network.

Two data gathering schemes have been presented in [22]: (1) MS moves on a random trajectory and (2) the moving path of MS is defined. Both schemes divide the area into small squares. The MS sojourns at the center point of each square. Moreover, three linear programming models have been introduced: (1) to maximize network lifetime, (2) to minimize path loss, and (3) to minimize end to end delay. Wang *et al.* [23] proposed an improved ant colony optimization-based approach which aims to avoid imbalance energy consumption of nodes via optimizing the moving path of MS. In such scheme, the MS collects the data packets during the movement over an optimal trajectory where is determined by improved ACO algorithm. Based on the aforementioned discussion, it is obvious that most of the existing sojourn location optimization-based schemes aim to overcome the energy hole problem and much less attention has been devoted to solve the coverage hole problem. Moreover, most of the previous works have been specially designed for homogeneous networks; however, most of the home networks consist of a set of heterogeneous consumer devices (e.g. camera, Micaz, biosensors) that are different in terms of energy consumption and initial energy of the battery. Consequently, to overcome the limitations of such schemes, providing a new sojourn location optimization-based scheme is vital.

III. PROBLEM FORMULATION AND SYSTEM MODEL

In a WSN, the sensor nodes may get failure due to energy depletion which results in deficient coverage of the sensing area of failed node and appearing the coverage holes in the network as shown in Figure 2. In single-hop communication, which is usually employed for small size networks such as home networks, the sensors nodes located far away from sink, consume more energy and deplete their batteries earlier than other nodes. This unbalanced energy depletion time leads to reducing the coverage time of the network and appearing the coverage holes. The coverage time is the elapsed instant since deploying the nodes in network till dying the first node due of its energy depletion, and resulting in a defective coverage of the sensing area and decreased network performance.

In single-hop communication, the sensor nodes only use energy for transmitting their own data packets toward the sink node, which can be formulated by Equation 1.

$$E_i = l\left(E_{elec} + \propto d_i^n\right) \tag{1}$$

where *Eelec* and $\propto$, indicate the electronic energy consumption and the energy consumed in the op-amp in data transmission, respectively. Furthermore, n denotes the path loss exponent, which depends on the specific propagation. Moreover, d and l show the distance between the ith node to the destination node and the packet length, respectively.

Moreover, the lifetime or the energy depletion time of ith node can be calculated by dividing the initial energy of ith node to its energy consumption level in each round, which is formulated by Equation 2 [24].

$$l_i = \frac{\varepsilon 0_i}{E_i} = \frac{\varepsilon 0_i}{l\left(E_{elec} + \propto d_i^n\right)} \tag{2}$$

where $\varepsilon 0_i$ indicates the initial energy level of the ith node and E_i shows the energy consumption of the node in each round. As can be observed in Equation 2, the lifetime of a node depends on the distance to the sink node since other parameters are constant values and adjusted before starting the network operation. Consequently, increasing the distance between the source node and sink leads to increase energy consumption and degrade the lifetime of the node. Therefore, based on this discussion, the node with the maximum distance to the sink node has the minimum lifetime in the network, which leads to unbalanced energy depletion time of nodes and decreasing the coverage time of the network. To overcome the mentioned problem, EMSLO scheme is proposed.

EMSLO is specially designed for consumer home networks. Figure 1 shows a home network containing different types of nodes (consumer devices) such as camera, Micaz, biosensor, and RFID. Assume the home network consists of N heterogeneous sensor nodes which are randomly deployed throughout the network area. Sensor nodes detect the data packets and send directly to the sink, which is located at the center point of the network at the beginning of the network operation. Furthermore, in the proposed scheme, the sink node is embedded in a self-charging Robovac with larger computational power, which moves along the sojourn locations which are determined by EMSLO. In fact, the Robovac is navigated by the proposed EMSLO, which leads to success in achieving two objectives in a single action. The details of the proposed EMSLO is presented in the next section.

IV. ENERGY-EFFICIENT MOBILE-SINK SOJOURN LOCATION OPTIMIZATION SCHEME

This section presents the Energy-Efficient Mobile-sink Sojourn Location Optimization (EMSLO) algorithm, which aims to determine the optimal sojourn position of MS. The main goal of EMSLO is to balance the energy depletion time of consumer devices and enhance the network performance and coverage time.

The EMSLO scheme consists of two main phases: Sensor Nodes Valuation and Sojourn Location Optimization. At the Sensor Nodes Valuation phase, based on the remaining lifetime of sensor nodes, values are assigned to the nodes. Then, the sojourn locations of MS are optimized, in the second phase of the proposed scheme. After calculating the optimal sojourn position, the MS moves to the determined position. Upon arriving the MS to a determined sojourn location, it informs the sensor nodes about its location via propagating a packet containing sojourn position (x, y) throughout the network. Then, all sensor nodes send their data to the MS for a given limited time. After expiring the sojourn time, EMSLO runs again and this process is repeated until all nodes deplete their power supplies.

A. SENSOR NODES VALUATION PHASE

In this phase, the sensor nodes are valuated based on their remaining lifetime. To this end, first, MS should determine a Critical Node (CN) with the minimum remaining lifetime as a reference node.

The remaining lifetime of the nodes is calculated by the following Equation, which is derived by dividing the remaining energy of the ith node to the energy consumption of the node.

$$RL_i = \frac{Res_i}{l\left(E_{elec} + \propto dtoMS_i^n\right)} \tag{3}$$

where Res_i denotes the remaining energy of the ith nodes and $dtoMS_i$ shows the distance between the ith node and the current position of MS. After calculating the remaining lifetime of nodes, the CN is identified as the following:

$$CN = Min\,(RL) \tag{4}$$

In EMSLO scheme, the node with the lowest lifetime has the highest value in the network ($\text{weight}_{\text{CN}} = 1$) which is considered as the reference node in the valuation of the other sensors. Consequently, the weight of other nodes is assigned by the following Equation.

$$weight_i = \frac{RL_{CN}}{RL_i} \tag{5}$$

where RL_{CN} denotes the remaining lifetime of the CN and RL_i shows the remaining lifetime of the ith node. According to Equation, the weight of ith node depends on the difference in remaining lifetime with the CN.

B. SOJOURN LOCATION OPTIMIZATION PHASE

The optimal sojourn positions of the MS are determined in this phase of the proposed EMSLO. To this end, EMSLO attempt to select the position as the next sojourn location of MS where the variance of the remaining energy of sensors is minimized as much as possible. To achieve this goal, a Genetic Algorithm (GA) has been utilized, which generate random positions from the network area. Afterward, the location with the minimum cost is selected as the next sojourn location of MS [24].

During the sojourning of MS at a sojourn location, all nodes send their data packets directly to the MS, therefore, the remaining energy of nodes after expiring the sojourn time of MS is formulated as following:

$$ResNew_i = Res_i - \left(ST \times l \left(E_{elec} + \propto dtoMSNew_i^n\right)\right) \quad (6)$$

where Res_i is the residual energy of nodes before arriving the MS to the selected sojourn location. In addition, ST shows the sojourn time of MS in the location where is generated by the EMSLO algorithm. In addition, $dtoMSNew_i$ shows the distance between the ith node to the location, where is supposed to be the new sojourn location of MS.

Consequently, the variance of the remaining energy of nodes when the MS stays at the new location can be formulated as the following:

$$\sigma^2 = \frac{\sum_{i=1}^{N} (Mean\,(ResNew) - ResNew_i)^2}{N} \quad (7)$$

The cost function of EMSLO algorithm is computed using two factors: *i*) the variance of the remaining energy of nodes, and *ii)* the weight of the nodes as the following:

$$Cost = Min(\boldsymbol{\alpha}.\sigma^2 + \boldsymbol{\beta}.\sum_{i=1}^{N}(weight_i \times dtoMSNew_i)) \quad (8)$$

In Equation 8, a and β are used to calculate the percentage of contribution for each factor in calculating the cost function of the proposed algorithm, where, a is the weighting factor for the variance of remaining energy of the nodes after leaving the MS from the location where is determined by the proposed algorithm. In addition, β denotes the weighting factor for the assigned value to the nodes. The aim behind considering the weight of the nodes in cost function calculation is to improve the service to the nodes with lower remaining lifetime. In fact, the sojourn locations are selected from locations where are close to the nodes with higher weight, which results in degrading their energy consumption. Algorithm 1 describes the Energy-efficient Mobile-sink Sojourn Location Optimization (EMSLO) scheme in details.

Algorithm 1 Energy-Efficient Mobile-Sink Sojourn Location Optimization Scheme

Input:
N : number of nodes in the network
Output: Optimal Sojourn Location
1. *Pos= MS. gets (position)*
2. *MS. propagates (Pos (x,y))*
3. *For i=1:N*
4. *i. send to MS (info packet (i.Residual Energy, i.pos))*
5. *DistanceToMS(i)= distance(i.pos, Pos)*
6. *Equation (3)*
7. ***Endfor***
8. *CN=argmin(Remaining Energy)*
9. ***For*** *i=1:N*
10. *Equation (5)*
11. ***Endfor***
12. *GA runs with the cost function (Equation (8))*
13. ***Return*** *Optimal Sojourn location*

V. PERFORMANCE EVALUATION

The performance of the introduced EMSLO is evaluated by using OMNET++ simulator. In the experiments, there are 50 heterogeneous nodes which are randomly distributed throughout the 100 × 100 network area. Some relevant network parameters are given in Table 1.

For the purpose of benchmarking, EMSLO is compared to DCHS [5] and EPMS [6], since both schemes aim to optimize the sojourn positions to enhance the balanced energy consumption. Moreover, in order to evaluate the importance of sojourn location optimization in the mobility-based schemes, the proposed scheme is compared with CMS2TO [7] and CM2SV2 [8], which optimize the sojourn time and the velocity of MS, respectively.

TABLE 1. Simulation parameters.

Parameters	Value
Number of sensor nodes	50
Energy dissipated in the op-amp	0.0013e-12 J
The electrical energy consumption	50e-9 J
Network area	100 ×100 m2
Path loss exponent	2

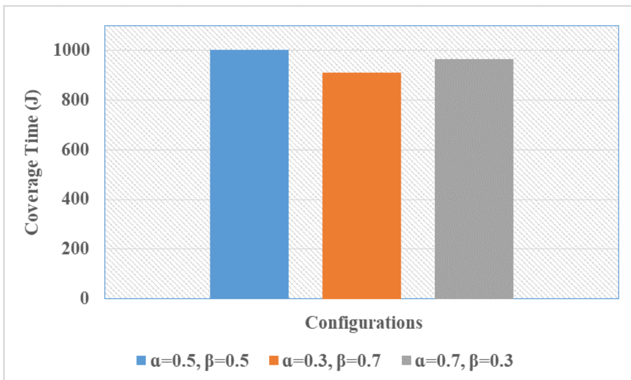

FIGURE 3. Coverage time under different configurations.

Figure 3 evaluates three different configurations to analyze the effect of α and β (Equation 8) on the network coverage time. It can be observed that $\alpha = 0.5$ and $\beta = 0.5$ configuration provided the best performance in terms of network coverage time. The reason behind such improvement is that this configuration gives equal preference for the variance of the remaining lifetime of nodes and the remaining energy

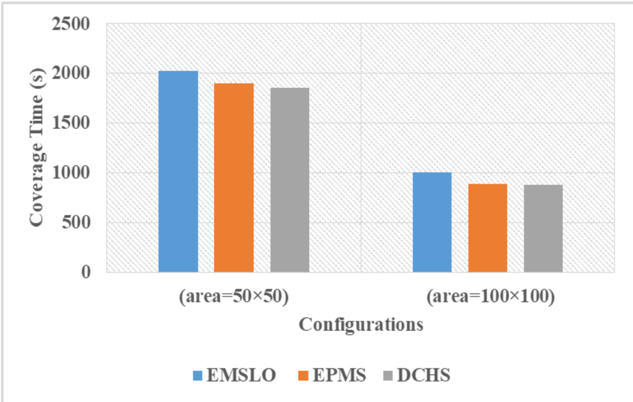

FIGURE 4. Coverag time of the network.

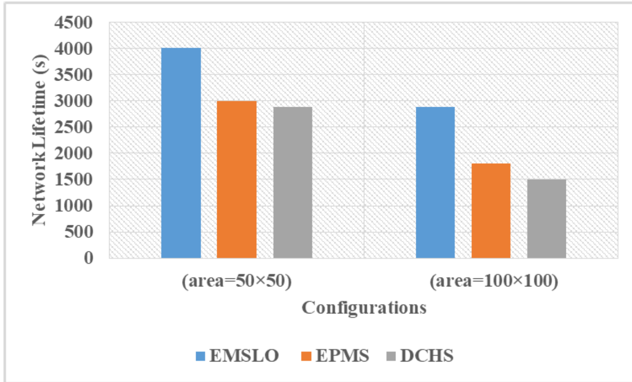

FIGURE 5. Network lifetime.

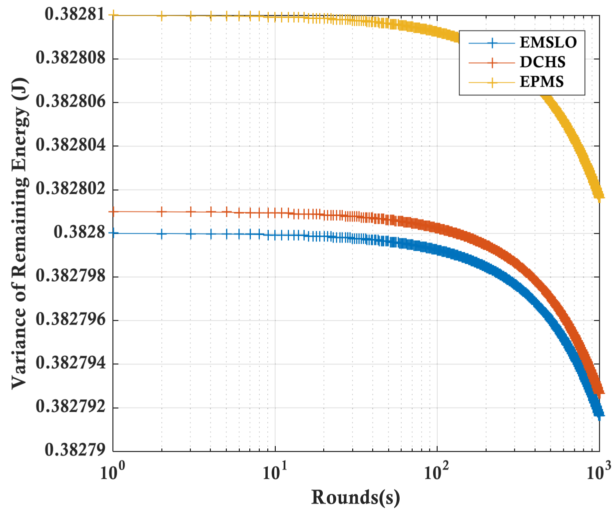

FIGURE 6. Variance of remaining energy versus time.

of sensor nodes, which both of these parameters are vital to improving the network performance.

In other words, $\alpha = 0.3$ and $\beta = 0.7$ configuration undervalue the remaining energy of nodes in determining the sojourn location of MS, which results in decreased network coverage time. On the other hand, in $\alpha = 0.7$ and $\beta = 0.3$ configuration, decreasing the importance of variance of the remaining lifetime of nodes in electing the sojourn location leads to reduce the network performance. Therefore, the configuration of $\alpha = \beta = 0.5$ is considered in all subsequent simulations, which gives equal importance for both variance of the remaining lifetime and the weight of nodes.

Figure 4 shows the coverage time of the network under two different configurations. Based on the depicted graph, the proposed scheme outperforms the previous schemes. We note that this is due to valuating the nodes based on the remaining lifetime of the nodes and assigning higher values to the nodes with lower remaining lifetime. In fact, MS is placed in the locations where are close to the critical nodes with lower remaining lifetime, which leads to enhance the coverage time and energy efficiency of the network.

Moreover, as can be observed from Figure 4, the coverage time of the network increases by decreasing the network area size. This is because decreasing the area size leads to decrease in the transmission range of nodes which results in degrading the energy consumption of nodes and enhancing the network coverage time.

In addition, the network lifetime of three different schemes under two different configurations is evaluated and presented in Figure 5. In the proposed EMSLO scheme, the network lifetime is defined as the elapsed instant since the nodes deployment in network till all nodes deplete their power resources. The aim of evaluating network lifetime is to show the energy efficiency level of the proposed mechanism. As shown in the figure, EMSLO achieved a remarkable improvement as compared to existing schemes in terms of network lifetime. This is because EMSLO attempt to balance the remaining energy among nodes to the fullest possible extent and energy balancing is an essential design issue which results in prolonging the network lifetime in WSNs.

Figure 6 depicts the variance of the remaining energy of nodes as time increases. As can be observed, the proposed EMSLO outperforms other relevant schemes. This is due to considering the variance of the remaining energy of nodes, in calculating the cost function of the proposed algorithm. Accordingly, the locations with the minimum variance of the remaining energy have higher chance to be chosen as the sojourn location, which leads to enhance the energy efficiency of the network.

The variance of the remaining lifetime of the network is depicted in Figure 7. The purpose of evaluating this parameter is to show the improvement of the proposed mechanism, in terms of balancing the energy depletion time of the nodes. Based on the simulation result depicted in Figure 7, EMSLO mechanism outperforms than other related schemes as it brings lower variance of the remaining lifetime. This is because in the proposed EMSLO scheme, the remaining energy level of all sensors is considered in sojourn location optimization which leads to enhance the energy efficiency of the network.

The total remaining energy of the network has been depicted in Figure 8. Based on the results of Figure 8, it is obvious that the proposed EMSLO algorithm consumes less

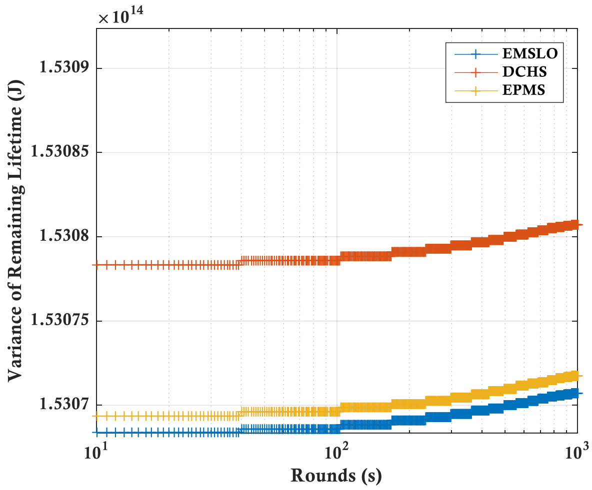

FIGURE 7. Variance of remaining lifetime versus time.

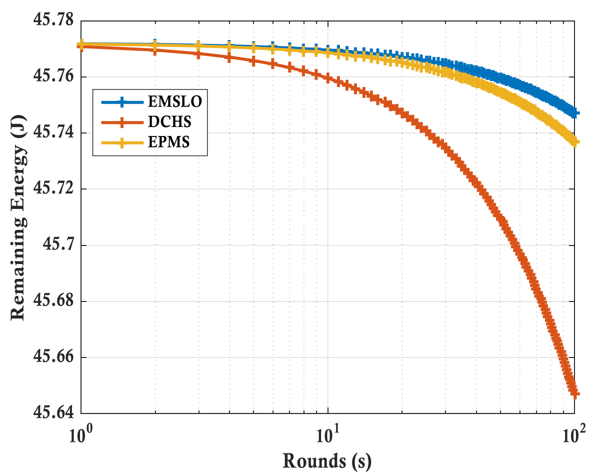

FIGURE 8. Remaining energy of whole network versus time.

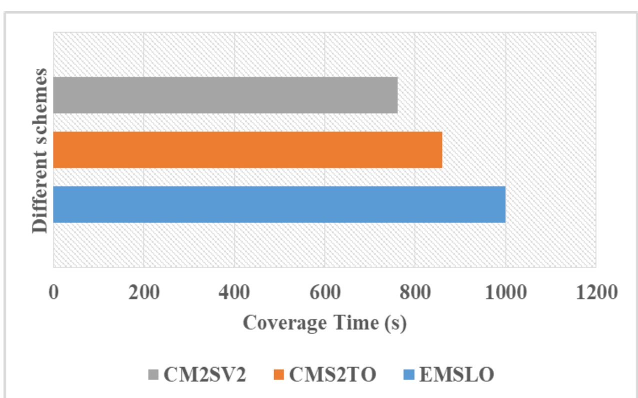

FIGURE 9. Coverage time in different parameters optimization.

energy in comparison with two other mechanisms, which leads to increasing the network lifetime and enhancing the network performance. This is due to balancing the energy consumption among sensor nodes to the fullest possible extent in the proposed scheme.

Furthermore, Figure 9 shows the coverage time of the network in the three different schemes. The first one is CMS2TO scheme which optimizes the sojourn time of MS. The second one is CM2SV2 scheme that adjusts the velocity of MS to enhance the network lifetime. Moreover, the third one is EMSLO scheme which optimizes the sojourn location of MS. As can be observed, optimizing the sojourn location of MS has much better performance than sojourn time and velocity optimization schemes.

VI. CONCLUSION

We described EMSLO, a new routing protocol for heterogeneous consumer home networks. EMSLO utilizes a Robovac as a MS in order to enhance the energy conservation and balance the energy depletion time of consumer devices. To this end, this paper aims to optimize the sojourn location of MS in order to enhance the network coverage time while the remaining energy of all devices is balanced. We have tested EMSLO by using OMNET++ simulator under different configurations. The results show that EMSLO enhances the coverage time and decrease the variance of the remaining lifetime of nodes in comparison with other relevant schemes. Moreover, based on the experimental results, optimizing the sojourn location has more impact on the energy efficiency of the network in comparison with optimizing sojourn time and velocity of MS.

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