Fuzzy spider monkey optimization routing protocol to balance energy consumption in heterogeneous wireless sensor networks

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ABSTRACT

Wireless sensor network (WSN) nodes have high computation limitations, limited communication capabilities, and limited power resources because of the difficulty or impossibility of replacing or recharging the sensor battery. Energy consumption in nodes is a critical issue to consider while developing WSNs. Many routing protocols are proposed for energy conservation as an important goal for improvement. Nonetheless, just delivering energy is not enough to prolong the life of a WSN. Unbalanced energy depletion is a significant problem in WSNs, often resulting in network splits and a reduction in network lifetime, as well as performance retrogression. This article, therefore, proposes a robust protocol called the fuzzy spider monkey optimization routing protocol (FSMORP) to determine the best data path routing for heterogeneous WSNs (HWSNs). In this case, an FSMORP computes the best path across the cluster heads from a sensor to the sink. This work uses the clustering method to organize heterogeneous nodes in HWSNs. The simulation result indicates that the FSMORP considerably enhances data latency reduction, energy balancing, and lifetime maximization for the network.

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1. INTRODUCTION

The self-managing network systems known as wireless sensor networks (WSNs) comprise a dispersed network of sensor nodes. The objective of a WSN is to either monitor the environment's parameters, such as temperature, humidity, and wind or detect the movements of mobile objects, such as volcanoes erupting and spreading [1]. In this light, sensor nodes must cooperate in querying the environment and then collecting and sending data to the sink density to monitor the target accurately [2], [3]. Generally, sensor devices are computationally constrained and have limited power resources. As a result, wireless communication between them quickly depletes their battery energy, resulting in a reduction in network lifetime. It is difficult, if not impossible, to replace or re-energize their batteries owing to the riskiness or inaccessibility of their deployment location. Thus, lifetime is a necessary factor to consider while constructing a WSN [4], [5]. Partitioning the WSN into numerous clusters is one tactic for using the shortage of energy-inefficient processing and communication resources. The cluster head (CH) is a gathering point, grouping all data into a single cluster [6], [7]. Clustering routing solutions rely on nodes aggregating into clusters to alleviate the shortcomings of flat routing protocols; as described in [8], [9], they can achieve efficiency and scalability. Further, clustering techniques have proposed approaches to address the unbalanced energy depletion (UED) issue inside networks [9].

This paper seeks to deal with the UED problem in the HWSNs. Firstly, the clustering partition method [6] is used to arrange the sensor nodes in the network. This method helps CH identify the N-sensors that make up their cluster and recognize their CH on the N-sensors. After that, a robust routing system called fuzzy spider monkey optimization routing protocol (FSMORP) is used to maximize network lifespan while balancing energy consumption. FSMORP looks at the node's three routing metrics (i.e., the highest remaining energy, the least number of hops, and the least traffic load) to determine the best inter-and intra-cluster routing path for heterogeneous WSNs (HWSNs).

The organization of this paper: a review of routing protocol-related works has been discussed in section two. The assembly method for HWSN in section three is introduced. Next, the recommended method for HWSNs is provided in Section four. Section five presents the simulation results. In the sixth section, we present a summary of the research.

2. RELATED WORKS

Several researchers have highlighted the problem of routing in WSNs [5], [6], and [10]. The energy in the sensor network can be distributed more uniformly by employing a clustering strategy presenting a bio-inspired ensemble procedure based on the Firefly and SMO algorithms as a clustering-based routing protocol for WSN. These protocols reduce potential energy waste by reusing data between the source and sink nodes. Also, these protocols can choose the best possible routing path by utilizing several parameters, including node residual energy, inter-cluster distances to the sink, and cluster overlaps, to select the best cluster heads at each round. It is possible to adaptively optimize the parameters of the projected solution during the clustering process to provide the best performance for the needs of the network [11]. The ant colony optimization method with the K-means clustering approach has been used to offer a unique design for WSNs [12]. Ashawi *et al.* [4] proposed fuzzy Dstar-Lite as a routing technique for producing the optimum information routing for HWSNs.

Additionally, it brings up the point of outdoing the obstruction example and elucidates the UED problem in the network. A routing scheme for WSNs is proposed in [13]. It improves the topology of the particle swarm algorithm, which increases network efficiency by allowing particles to be contacted directly by each other while building them. Nandan *et al.* [14] proposed a genetic algorithm (GA) to select the optimal cluster head. Cluster head (CH) selection using GA includes four distinct criteria: node density, distance, energy, and the ability of heterogeneous nodes to form fitness functions. By these factors, it is easier to calculate how much power is in the cluster, how many hops, and what nodes are best for CHs. Rajendran *et al.* [15] suggested technique extends the network's lifespan and treats sensor node connection failures. To facilitate speedy rerouting between sources and destinations, the EFRP proposes that each node have a backup route. Using the method, the new route path may be added without a break. Hussain *et al.* [16] proposed a unique routing protocol on the ocean's surface that combines two-dimensional under-water sensor networks with sleep-scheduling routing to identify and report oil traces to the sink promptly. Tembhre *et al.* proposed a routing approach based on the K-NN algorithm and the clustering method for reducing the end-to-end delay and energy consumption [17]. This proposal presents a node classification-based clustering method with the least distance generation. The authors of [18] contributed a new balanced routing system with two uncorrelated pathways to reduce energy usage in WSNs. Each node has two different shortest paths to the sink to reduce the traffic load in the network. Pandey *et al*. [19] and Al-Mazaideh and Levendovszky [20] described a novel technique for clustering the HWSNs approach that efficiently selected the head of the cluster nodes, the degree of sensor nodes, and the remaining energy. Here, the chaining technique is collected and sent to the information package. They proposed a swarm-based intelligence method called SMORP used in the homogeneous WSNs [21] and the heterogeneous HWSNs [22]. This method finds the optimal path in the network based on a set of routing criteria.

3. ORGANIZATION OF HWSNS

For the organization of a heterogeneous network, two types of sensors (i.e., N-sensors and CH-sensors) are used. The N-sensors represent the simple sensors, while the CH-sensors represent the lead sensors of the simple sensors. An HWSN necessitates randomly deploying many standard sensors (N-sensors) in the field. Further, the network comprises several sensor nodes with sufficient capacity to serve as cluster heads (CH-sensors).

As for clustering, this work uses the clustering method, which is used in homogeneous WSNs [23], [24] and also in heterogeneous HWSNs [4], [6]. Under this clustering, the CH-sensors broadcast messages that include their location based on their IDs. The CH-sensor with the shortest ID number will take the first-place position. The N-sensors then compile a list of the CH-sensors they've heard according to the intensity of the signal received, starting with the one with the strongest signal. Since CH-sensor may be a candidate, each N-sensor will prioritize it as its preferred CH-sensor beyond this point. Following that, CH-sensor begins deciding which N-sensors should be included in its cluster. Each cluster is handled the same regardless of its size. In this organizing process, we ensure that all the simple sensors are connected to the cluster head, thus ensuring the integrity of the entire network. Figure 1 shows the technique's clustering procedure for HWSNs.

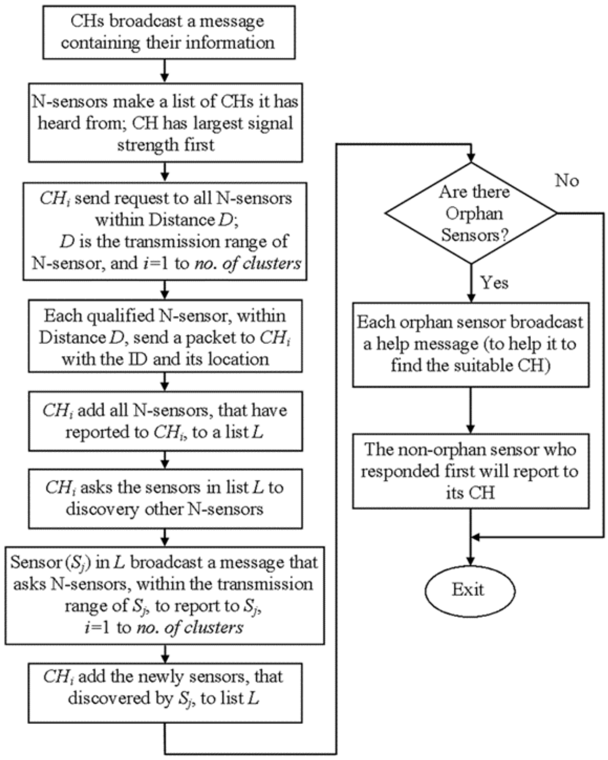

Figure 1. Clustering method flow-chart

4. FUZZY SPIDER MONKEY OPTIMIZATION ROUTING PROTOCOL (FSMORP)

The routing protocol is one of the significant concerns in extending the lifetime of HWSNs. If any sensor node (N-sensor or CH-sensor) runs out of energy during the routing protocol, the information exchange between (N-sensor and CH) and (CH and the sink) will likewise be broken. Typically, this results in a shortage of HWSNs over their lifetime. The amount of power each sensor in an HWSN gets affects how long it lasts. It is imperative to keep energy in those sensors so the network can last as long as possible. In this light, the FSMORP can extend the lifetime of HWSNs by lowering energy expenditures and evenly distributing energy usage. To achieve the FDMORP, we combine the spider monkey optimization (SMO) [22] method with the Fuzzy approach.

The FSMORP selects the appropriate next hop to the sensor node based on the routing criteria (maximum remaining energy, fewest hops, and lowest traffic load). This work supposes: i) All N-sensors have the same transmission range and begin with the same amount of battery power. Each N-sensor in ii) is aware of its position, as well as that of its CH and neighbors. iii) All CHs have the same transmission range and start-up power from the battery. iv) Each CH knows its position and neighbors, namely the other CHs and the sink location. The sink generates the routing schedule and distributes it to all network nodes (N-sensors and CH-sensors). Each sensor is used an FSMORP to find the optimal route to the destination node. The FSMORP consists of two stages:

4.1. SMO implementation in FSMORP

Here, the SMO method evaluates a tree structure in the course of *(N, Fit)*, where *N* is the candidate nodes set in the forwarding route and Fit is the fitness functions set that each candidate node n ∈ N is assigned a fitness function value fit(n). The tree node will explore depending on its fitness function. So, to calculate the value of each node's fitness function, a fuzzy approach is used, as illustrated in Section 4.2. In FSMORP, the created routing route is used repeatedly (rounds), and the status of each node along the way is evaluated to decide if the same path should be used for the next round. According to the previous assumption, the sink can access current information on each node's battery energy, position coordinates, and network traffic load. In (1) is used to determine the fitness of a contiguous node (n_i).

$$fit(n_i) = fuzzy\ (RE(n_i), TL(n_i), D(n_i)) \quad (1)$$

Where *RE(n), TL(n), and D(n)* are the remaining energy, traffic load, and the distance to the destination for node *n*, respectively, all these parameters are the inputs to the fuzzy approach that will calculate the fitness value of the node n. After that, the GLSM assesses the information gathered from all of LLSM's neighbor nodes and chooses the optimal node with the greatest probability P with the probability value specified by (2):

$$P(n_i) = \frac{fit(n_i)}{\sum_{i=1}^{n} fit(n_i)} \quad (2)$$

$P(n_i)$ is the probability associated with node n_i, fit (n_i) is the fitness related to node n, and N is the number of neighbor nodes.

4.2. Fuzzy approach implementation in FSMORP

Here, the fuzzy approach is used to determine the fitness function value of the node *n*, which is dependent on the *RE(n), TL (n), and D(n).* The fuzzy approach uses three input parameters which are *RE(n), D(n), and TL(n),* with a single *fit (n)* output parameter, which is shown in Figure 2. All *RE*, *D*, *TL*, and *fit* all have a universal discourse of [0...0.5], [0...1], [0...10], and [0...1], respectively.

As seen in Figure 3, FSMORP employs five membership functions for each input and output variable. FSMORP processes the fuzzified data using an inference engine that consists of a rule base and multiple techniques for inferring the rules. The IF-THEN rules used in FSMORP are listed in Tables 1 to 5, with 5^3=125 rules in the fuzzy rule base.

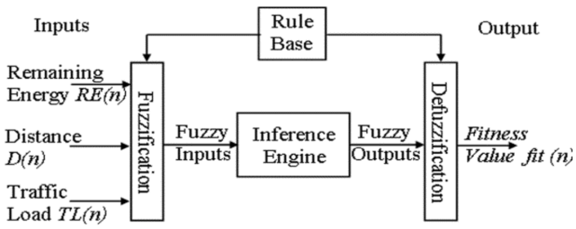

Figure 2. Fuzzy structure for FSMORP

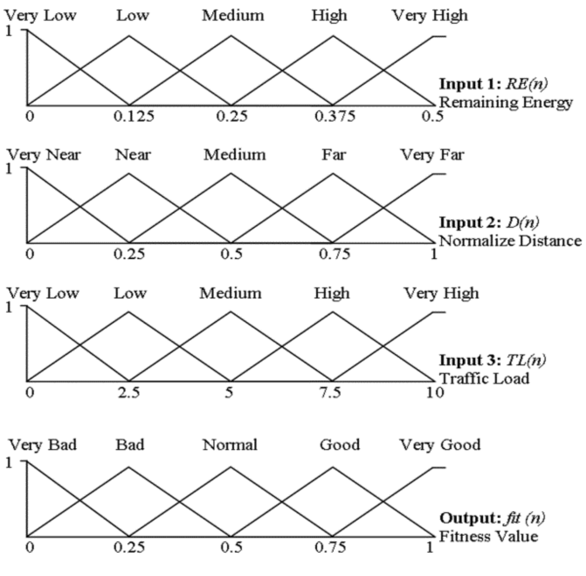

Figure 3. Membership graphs for FSMORP

Table 1. The energy when is very low (FSMORP IF-THEN Rules)

D \ TL	Very.Near	Near	Medium	Far	Very.Far
Very.Near	Ordinary	Ordinary	Very.Defective	Very.Defective	Very.Defective
Near	Ordinary	Defective	Very.Defective	Very.Defective	Very.Defective
Medium	Defective	Very.Defective	Very.Defective	Very.Defective	Very.Defective
Far	Defective	Very.Defective	Very.Defective	Very.Defective	Very.Defective
Very.Far	Very.Defective	Very.Defective	Very.Defective	Very.Defective	Very.Defective

Table 2. The energy when is very low (FSMORP IF-THEN Rules)

D \ TL	Very.Near	Near	Medium	Far	Very Far
Very.Near	Perfect	Ordinary	Ordinary	Defective	Very Defective
Ordinary	Ordinary	Defective	Very Defective	Very Defective	Very Defective
Ordinary	Defective	Very.Defective	Very Defective	Very Defective	Very Defective
Defective	Very.Defective	Very.Defective	Very Defective	Very Defective	Very Defective
Very.Defective	Very.Defective	Very.Defective	Very Defective	Very Defective	Very Defective

Table 3. The energy when is medium (FSMORP IF-THEN Rules)

D \ TL	Very Near	Near	Medium	Far	Very Far
Very.Low	Very Perfect	Perfect	Perfect	Ordinary	Defective
Low	Perfect	Perfect	Ordinary	Ordinary	Defective
Medium	Perfect	Ordinary	Ordinary	Defective	Very.Defective
High	Ordinary	Ordinary	Defective	Defective	Very.Defective
Very.High	Defective	Defective	Very.Defective	Very.Defective	Very.Defective

Table 4. The energy when is high (FSMORP IF-THEN Rules)

D \ TL	Very Near	Near	Medium	Far	Very Far
Very.Low	Very.Perfect	Very.Perfect	Perfect	Ordinary	Defective
Low	Very.Perfect	Perfect	Perfect	Ordinary	Defective
Medium	Perfect	Ordinary	Perfect	Ordinary	Defective
High	Ordinary	Ordinary	Ordinary	Defective	Defective
Very.High	Defective	Defective	Defective	Defective	Very.Defective

Table 5. The energy when is very high (FSMORP IF-THEN Rules)

D \ TL	Very.Near	Near	Medium	Far	Very.Far
Very.Low	Very.Perfect	Very.Perfect	Very.Perfect	Perfect	Ordinary
Low	Very.Perfect	Very.Perfect	Very.Perfect	Perfect	Ordinary
Medium	Very.Perfect	Very.Perfect	Perfect	Ordinary	Defective
High	Perfect	Perfect	Ordinary	Ordinary	Defective
Very.High	Ordinary	Ordinary	Defective	Defective	Very.Defective

A fuzzy inference engine processes all of these rules simultaneously. Defuzzification reduces the solution fuzzy space to a single crisp output value. This number indicates the value of the node s's fitness function. Defuzzification of practice is carried out by utilizing the COG approach [25] by (3):

$$fit(n) = \frac{\sum_{i=1}^{n} U_i * c_i}{\sum_{k=1}^{n} U_k} \quad (3)$$

where U_k denotes the rule base k output, and c_k represents the center of the rule base n output membership function.

Figure 4 illustrates the FSMORP flow chart, which employs a combined SMO algorithm with a Fuzzy approach to determine the ideal routing route two times in inter-cluster (from N-sensor to its CH-sensor) and intra-cluster (from the CH-sensor to the sink), in the same manner in sequential.

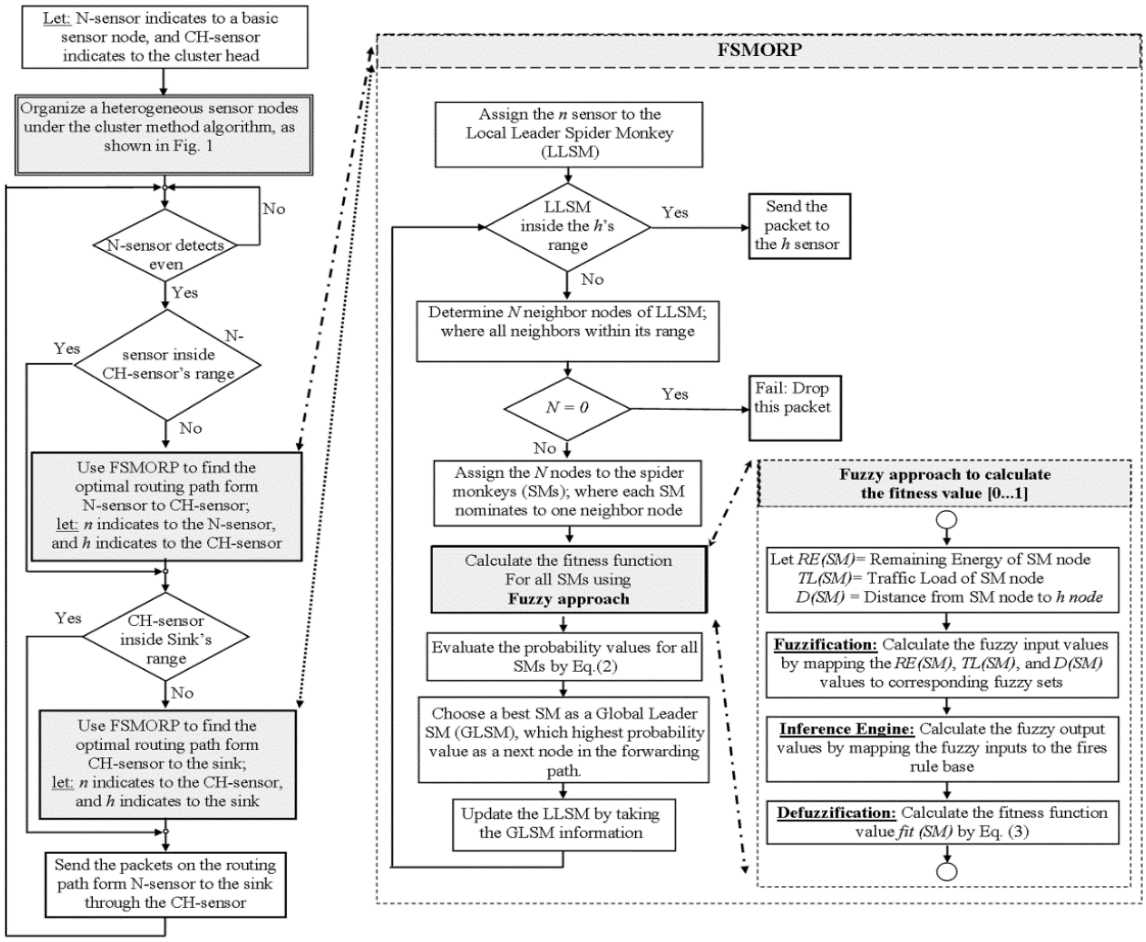

Figure 4. FSMORP flow-chart

5. EVALUATION OF PERFORMANCE

The primary goal of this paper is to develop the SMORP [22]. Thus, determining the best node is improved by using the fuzzy approach. The simulation results of the proposed method are compared with those of the SMORP algorithm according to the same routing criteria.

5.1. Simulation setting

MATLAB is used to run the simulations. To make the network as realistic as possible, some parameters must be set in the system. A heterogeneous network with 1000 N-sensors and 36 CHs deployed randomly over a 300x300 m topographical area, as shown in Table 6. Both systems are used the clustering method to group the N-sensors around CH-sensors. Also, they used a radio model [26] and exhausted their transmission cycles (2000).

5.2. Simulation results

Network lifetime results obtained using the two systems are compared by counting the number of sensors kept alive after each data transmission round. On this point, Figures 5 and 6 demonstrate the ratio of the N-sensors and CH-sensors, respectively, which are still alive in both the proposed system and the SMORP. As a result, the proposed outperforms the SMORP system based on the total number of nodes still alive in the network. Here and after sending (2000) packets through the network, the result of the network lifetime achieved with the proposed is nearly (15%) more than that of SMORP.

Once any sensor (N-sensor or CH-sensor) in the network dies, the network lifetime is terminated. The proposed system has achieved an increment in the network lifetime. Where Table 6 gives a comparison in terms of the first node that will die in each of the systems. The proposed requires a longer time than the SMORP system does. The proposed method outperforms the SMORP strategy in balancing energy depletion and optimizing network longevity, as shown in Figures 5, 6, and Table 6.

Table 6. Simulation variables

Parameter		Value
Area of topographical (meters)		300x300 m
Location of the sink (meters)		(0, 150)
Length of control packets		2k
No. of transmission packets (rounds)		2 x 10^3
N-sensors	Number of nodes	1000
	Limit of transmission distance	20 m
	Initial energy	0.5 J
	E_{elec}	50 nJ/bit
	E_{amp}	100 pJ/bit/m^2
	Max. traffic in node's queue	10
CHs	No. of nodes	36
	Limit of transmission distance	80 m
	Initial energy	2.5 J
	E_{elec}	100 nJ/bit
	E_{amp}	200 pJ/bit/m^2
	Max. traffic in node's queue	50

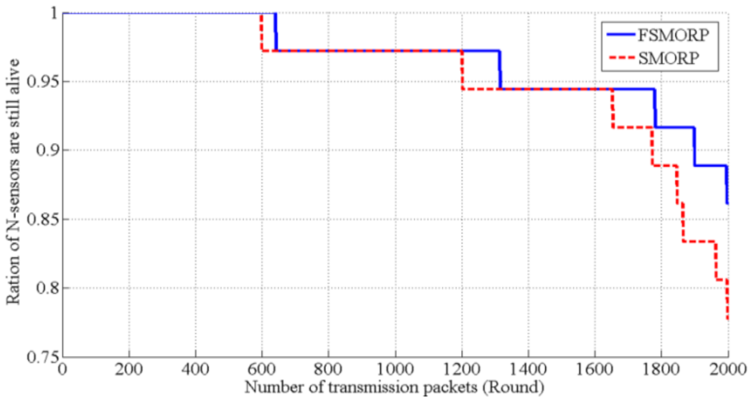

Figure 5. N-sensors ratio remains alive

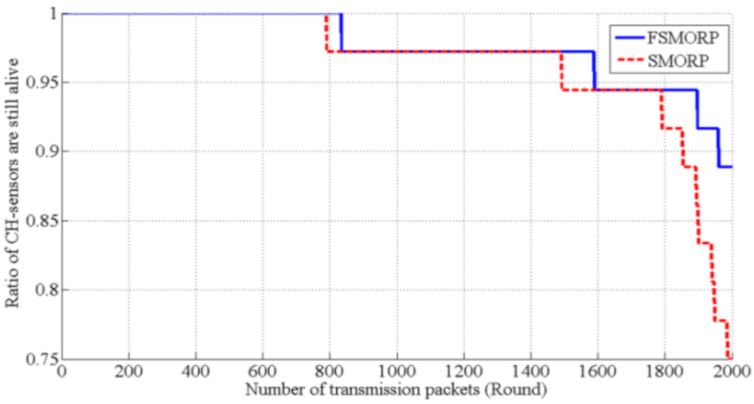

Figure 6. CH-sensors ratio remains alive

Table 6. The number of rounds that have died the first node

Approaches	SMORP	FSMORP
The first N-sensor that died	589	641
The first CH-sensor that died	790	834

The proportion of leftover power in both N-sensors and CH-sensors varies with the number of transmission rounds depending on which of the two systems is employed in the routing. By increasing the number of routes, the proposed system outperformed the SMORP in terms of overall performance and efficiency. Figures 7 and 8 illustrate how the ratio of residual energy for N-sensors and CH-sensors, respectively, varies based on the transmission mode employed. As can see, the proposed method is better than the SMORP while keeping the network stilling for as long time as possible.

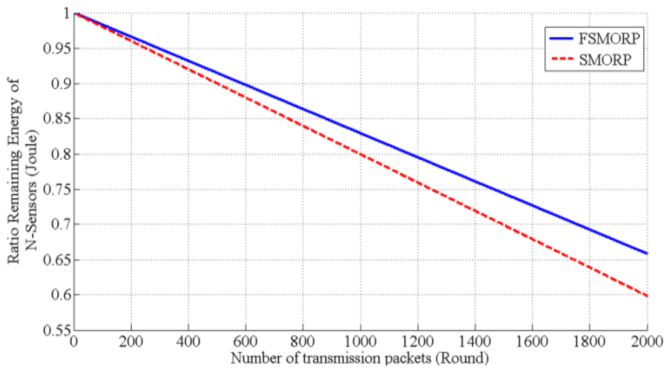

Figure 7. The energy ratio of the remaining N-sensors

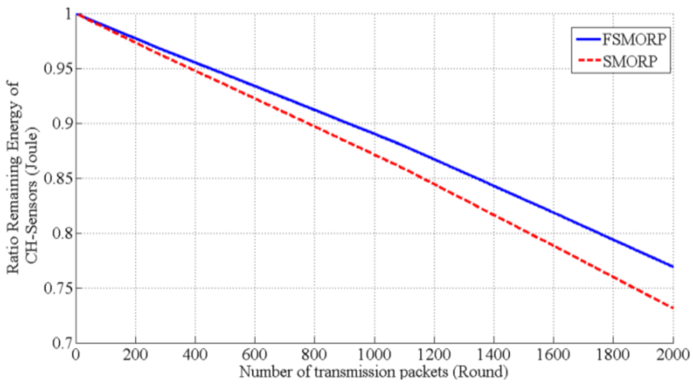

Figure 8. The energy ratio of the remaining CH-sensors

On the other hand, the delay introduced during data packet transmission is a critical element for some applications. Figure 9 compares the two systems regarding simulation time inside the routing area. However, when comparing the results of the proposed model to those of the SMORP, the proposed seems slightly larger due to the fuzzy logic processors.

As seen in Figure 10, the proposed system minimizes end-to-end latency. Reduced time delays indicate that energy is saved and data is sent more effectively. Multipath routing uses data packet segmentation down to the node level to reduce congestion and maximize network longevity.

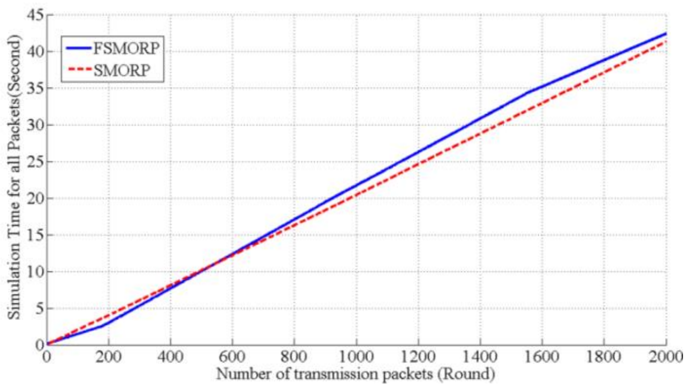

Figure 9. Data transmission round delay on transmission

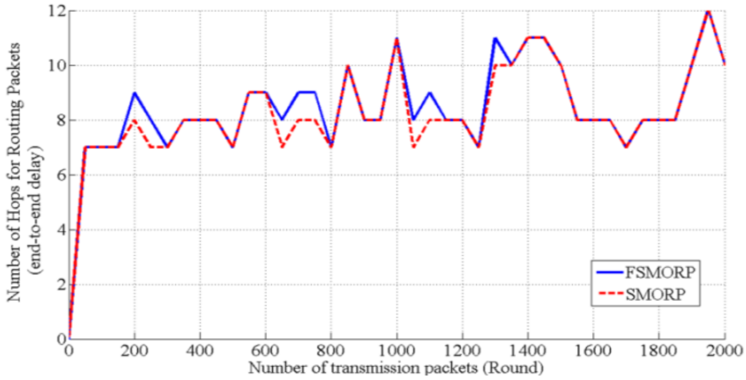

Figure 10. Transmission rounds affect the number of hops

6. CONCLUSION

Many routing protocols have been used in WSNs to save energy. Nevertheless, just saving energy is inadequate to prolong the life of the networks. UED is a significant problem in these networks. It often leads to network splits and therefore reduces the network lifetime. In this context, this paper proposed a new routing system called FSMORP for determining the best data route for HWSNs. FSMORP is determined as the optimal path in both the intra-clusters (from the N-sensor to its CH-sensor) and the inter-clusters (the CH-sensor to the sink) in HWSNs. Here, the clustering method was utilized to organize the heterogeneous sensor nodes in the network. As shown in the simulation results, the proposed system improves the data latency reduction, energy balance, and lifetime maximization for HWSNs compared with the SMORP. In future work, it may use an intelligent algorithm for data aggregation in the cluster head to get rid of redundant and unnecessary data that causes many problems in the networks.

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