Fuzzy dstar-lite routing method for energy-efficient heterogeneous wireless sensor networks

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ABSTRACT

Sensor devices, in Wireless Sensor Networks (WSNs), are usually equipped with low-capacity batteries and scattered on areas that cannot be reached in most of the cases to recharge or replace these sensors. The available battery energy in the sensor nodes is barely sufficient to transmit a limited quantity of data packets. In this regard, most of the works are designed aiming at achieving high energy efficiency. Due to multiple-hop data transmission and many to one traffic connection, the Imbalanced Energy Depletion (IED) is an immanent issue in WSNs. Accordingly, this paper suggests an energy efficient routing protocol called Fuzzy Dstar-lite to produce an optimal pathway data routing for Heterogeneous WSNs (HWSNs). This protocol can also reuse the product path to keep the energy consumption fairly distributed over the nodes of a network. Interestingly, the proposed protocol is demonstrated to be more efficient in decreasing the transmission delay and balancing power consumption when compared with other protocols, i.e. chessboard clustering (CC), PEGASIS, and LEACH. The comparison also showed the proposed protocol has been increased the network lifetime approximately 15%, 40%, and 50% compare with CC, PEGASIS, and LEACH, respectively.

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1. INTRODUCTION

A Wireless Sensor Network (WSN) is formed by numerous small-sized sensor devices (nodes) that are wirelessly interconnected with each other and with a data collection unit called sink. In WSNs, each sensor monitors or collects information relevant to its adjacent environment then it sends sensory reports toward the base station to let the user access the information via several communication technologies. These networks are exploited in too many applications including remote monitoring of the environment, medical care, emergency warning and response, outward space discovery, and so forth. In most of the case, WSNs are randomly scattered over a large geographical area to monitor the fluctuations related to one or more physical phenomena [1-3]. Generally, sensor devices are of limited computational capabilities and are powered by small and inexpensive batteries. So, the wireless communication among them exhausts their battery energy rapidly leading to shortness of network lifetime and it is infeasible or even impractical to substitute or re-energize their batteries due to the riskiness or inaccessibility of their deployment area. Hence, the lifetime is a crucial issue that should be highly considered when designing a WSN [4-6].

The majority of the works in the field of WSNs consider economizing energy consumption to prolong the network lifetime. However, decreasing energy consumption is not completely enough to maximize the lifetime of WSNs. The Imbalanced Energy Depletion (IED) is an immanent issue in the WSNs, the reasons behind this issue are the multiple-hop data transmission as well as m:1 (many to one) connection fashions. IED problem leads to network partition and diminishes network lifetime, which enervates the functionality of the whole WSN [7-10]. Thus, balancing energy depletion is a significant matter in the development of WSNs and requires energy-efficient routing methods that optimize the network lifetime. Additionally, using complicated routing algorithms may reduce energy drainage but may increase processing delay [11, 12]. Therefore, this paper attempts to investigate the problem of IED and lifetime prolongation for Heterogeneous WSNs (HWSNs). Generally, the HWSN consists of two sensor types: the basic sensors (B-sensors) powered by limited resources and some others as the cluster heads (CH-sensors) with high resources [4, 11]. B-sensors perform the sensing task and send the data to their CH-sensor. The CH-sensor, in turn, performs a data aggregation from the B-sensors that belong to the same cluster and carries out the data to the sink. For this and to organize the heterogeneous sensor nodes, this paper proposes to use the clustering partition method [13-15]. The main purpose of using this clustering method is to make the CH-sensor recognizes which B-sensors are in its cluster and also make the B-sensors recognize their CH-sensor.

After the sensors organization process finished, an energy-efficient routing protocol is proposed to produce an optimal pathway data routing in both intra-cluster and inter-cluster for HWSNs. This proposed called Fuzzy Dstar-Lite routing protocol which couples Dstar-Lite search algorithm together with Fuzzy Logic to elongate the running time of HWSNs considering fair power consumption. Fuzzy Dstar-Lite is able to calculate an optimal path form a B-sensor to its CH-sensor head, in intra-cluster, and from this CH-sensor to the sink, in inter-cluster, by preferring three routing metrics of the node (shortest routing path to the sink, remaining battery power in the node, and minimum traffic load in the node). This proposed protocol can also reuse the optimal path smartly to minimize the delay produced by path planning each time while keeping energy consumption balanced between discovered paths. Fuzzy Dstar-Lite routing protocol is therefore proposed for HWSNs to address IED problem and prolonging of network lifetime. The rest of this paper as follows: Section 2 reviews the related work. Organization of heterogeneous sensors as described in Section 3. The proposed method is presented in Section 4. In Section 5, the performance evaluation of the proposed method is demonstrated. Finally, the conclusion is presented in Section 6.

2. RELATED WORK

The significant matter in WSNs is how can designing of efficient protocols to lengthen the network lifetime significantly. So, the lifetime challenge has drawn the attention of researchers in the present time. This section gives a review of the literature related to the impact of developing and adopting the routing protocols with the aim of extending the lifetime of WSNs. Chun-Cheng *et al.* [16] proposed a new method for dynamic HWSNs with energy-harvesting nodes to extend the overall network lifespan. This method called Harmony Search Algorithm with Multiple populations and Local search (HSAML) which can find the maximum number of nodes covers each of which is a part of all nodes so that all goals can be monitored by these nodes. In [17], the authors proposed a Dynamic network model for HWSNs called (DHWSNs). This model builds based on the idea of dynamic energy heterogeneity to allow extra nodes to be added to the network. Also, under this model, the authors developed an adaptive clustering-based method to present how the cluster head sensor is optimized. This clustering method has enhanced the model lifetime and increased data transmission packets of HWSNs. In [18], a hybrid scheme in HWSNs is present to adjust the power consumption of whole sensor nodes and to overcome the bottleneck problem near the sink by adjusting the communication load. To avoid the bottleneck problem, when the sensors near a sink become low power, the sink goes to a new location (mobile sink). This paper also used Hilbert Curve method [19] to prolong the network lifetime by clustering the nodes of HWSNs.

The authors [20] introduced a new clustering method for HWSNs. This method is used to select the cluster head nodes by an efficient way in terms of energy power consumption, residual energy and degree of sensor nodes. Also, the chaining approach is used to gather and transmit the data packet. In [21], the authors proposed a new clustering scheme called Distributed Energy-Efficiency Clustering (DEEC) which aimed to energy-efficient in HWSNs. DEEC scheme is proposed to improve the network lifetime by adaptive the thresholds of cluster head selection in HWSNs. The work in [22] considered heterogeneous sensor nodes with random variations in the rate of data generation (traffic) to represent realistic clustering-based HWSNs. A routing technique called Traffic and Energy Aware Routing (TEAR) is proposed to improve the cluster heads selection by considering the traffic along of node with its energy level. The authors in [23] proposed a new algorithm called Energy-Efficient Topology Control (EETC) which used to select the cluster heads in HWSNs. In this proposed, after the clusters have built, the authors used Breadth-First

Search (BFS) to find the routing path intra-cluster (i.e. from sensor cluster member to the cluster head). Besides, they built the shortest-path to get the routing path inter-cluster (i.e. from the cluster head to sink). In [24], the paper proposed an Enhanced Balanced Energy-Efficient Network-Integrated Super-Heterogeneous (E-BEENISH) routing protocol. E-BEENISH is proposed to analyze the communication power consumption of the clusters in HWSNs. it is based on balanced election probabilities of each sensor node to become a cluster head according to the remaining power and the distance from the sink to the node. In [25], the authors presented a new region-based energy-conscious sink movement (RESM) to improve the lifetime of HWSNs. In this work, the topographical area is divided into some of the equal regions, each region also split into some of the clusters. The division of regions keeps energy due to the short-distance communication of sensor nodes. Further, the authors used the Stable Election Protocol (SEP) to minimize the overall amount of energy spent in each region due to the randomized re-selection of the cluster head node.

On the other side, paradigms of Computational Intelligent (CI) have been broadly used to solve different WSNs challenges [2, 26]. Energy-aware routing to maximize the lifetime of WSNs is one of these challenges and many routing algorithms were built based on CI paradigms. The authors in [8, 9, 27] proposed routing protocols that named Fuzzy-Astar protocol, Fuzzy Arterial Bee Colony protocol, and Fuzzy Dstar-Lite protocol, respectively. These protocols have been proposed to avoid unfair energy depletion and to prolong the homogeneous WSNs lifespan significantly. In [7], the authors have designed an energy-efficient protocol called Fuzzy Chessboard Clustering and Artificial Been Colony Routing Method (FCC-ABCRM). It proposed to overcome the bottleneck issue and solve the IED problem in HWSNs. In this protocol, firstly, fuzzy logic and clustering partition method are used to organize the nodes of HWSNs and to select the best cluster heads. After that, ABCRM is used to determine the best routing path in both of intra cluster and inter cluster in HWSNs. The authors in [28] introduced a Distributed Energy-aware Fuzzy Logic (DEFL) based routing algorithm which made a suitable trade-off between energy efficiency and balance power consumption to prolong the WSNs lifetime. This proposed regard the network status through suitable energy criteria and maps these criteria into corresponding cost values for calculating the shortest routing path. The work in [29] used a fuzzy system to cluster the nodes in HWSNs. It is proposed a method called MACHFFL-FT which tried to select the best nodes as cluster heads by using three clustering approaches. By availing from a fixed threshold in HWSNs, this method avoids holding the cluster head election in some rounds to decrease the number of communications among nodes and to keep more power in the whole network.

3. ORGANIZATION HWSNs UNDER CLUSTERING PARTITION OPERATION

In this section, we describe how the sensors of HWSN are organized under the clustering partition concept. This paper will use B-sensors to indicate the basic sensors and CH-sensors to indicate the cluster heads. The paper also assumes that CH-sensors and B-sensors know their locations and no of them can send and receive the data simultaneously.

3.1. Deployment

In HWSN, the B-sensors will be deployed in the topographical area randomly. While, to sure all B-sensors are insured and each of them can connect with one CH-sensor at least, the CH-sensors should be carefully deployed.

3.2. Cluster parttion operation

Clustering partition operation (CPO) is used to distribute the B-sensors to clusters. This operation has been more used in homogeneous WSNs [13, 14], and also in HWSNs [15].In HWSN, it is used to let the CH-sensor aware which B-sensors belong in its cluster and to let the B-sensors aware to which cluster they belong. For this, clusters are formed around CH-sensors. The following paragraph briefly depicts the idea of CPO around the CH-sensors. CH-sensors broadcast the messages that include their location based on their IDs, where the CH-sensor which has the smallest ID will be first. Then according to the received signal strength, each of B-sensors creates a list of CH-sensors it has heard from where the largest signal strength becomes first. After that, each B-sensor will know to which CH-sensor it may belong and will choose the CH-sensor at the top of the list as its preferred CH-sensor. Then, the CH-sensor starts to find which B-sensors should be in its cluster. This process is the same for all clusters. Figure 1 shows the CPO flow-chart.

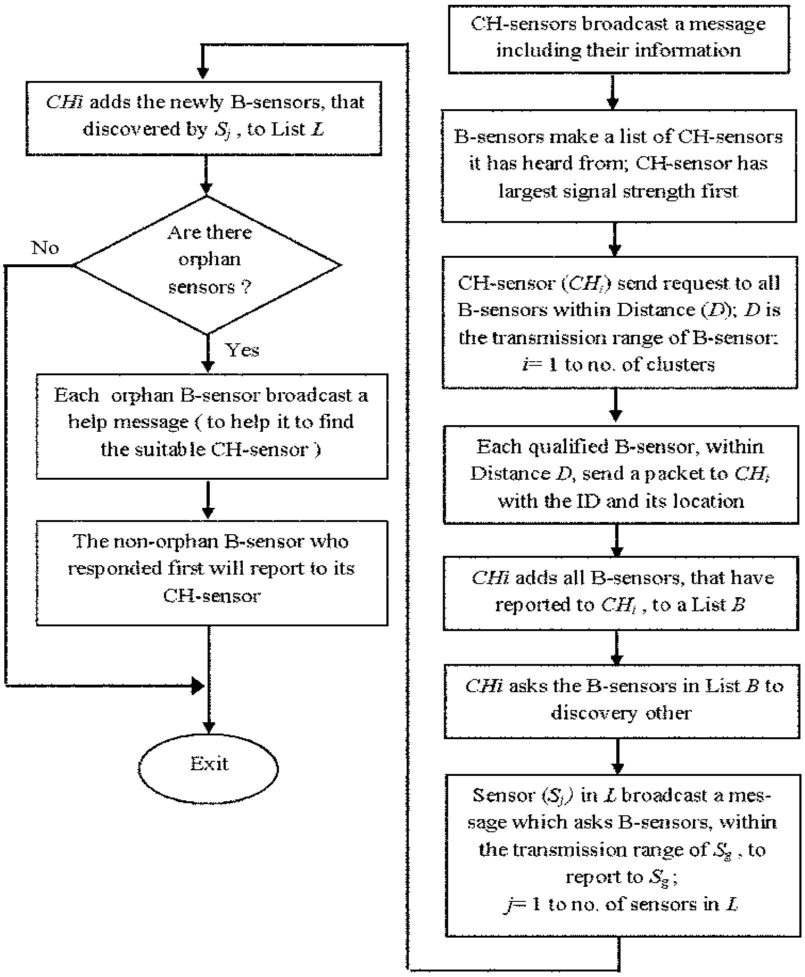

Figure 1. Clustering partition operation

4. FUZZY DSTAR-LITE ROUTING METHOD FOR HWSNs

The network lifetime is one of the main challenges of WSN. However, in the proposed routing protocol when any sensor node (whether CH-sensor or B-sensor) runs out of its energy the data communications among several B-sensors and their CH-sensors will disconnect also the same thing will happen among the CH-sensors and the sink. This causes a loss in the WSN lifetime in general. Whereas the lifespan of each sensor in WSN based on power exhaustion, it is the main issue to preserve the remaining power in these sensors that lead to extend the overall network lifetime as possible as. Therefore, this paper aims to design an energy-efficient routing protocol called Fuzzy Dstar-Lite that couples Dstar-Lite search algorithm [30] together with Fuzzy Logic [31]. Fuzzy Dstar-Lite uses to extend the lifetime of HWSNs that by limiting energy cost among the communication paths of nodes (in both intra-cluster and inter-cluster), as well as to overcome the IED problem that is happened in HWSNs.

In this paper, the CPO is firstly used to organize the heterogeneous sensors under the clustering concepts (each cluster has a CH-sensor as a leader and has some of the B-sensors as members). Later, the proposed protocol is used to obtain the best routing pathway from B-sensor to its CH-sensor and from a CH-sensor to the sink, sequentially, by considering and balancing some of routing criteria (i.e. remaining battery power, shortest routing path, and minimum traffic load). This proposed is also capable of reusing the obtained pathway smartly to reduce the delay generated by path planning each time among HWSN nodes.

The paper assumes: (i) the transmission range and the initial batteries power are the same in all B-sensors, (ii) each B-sensor know its location also know its neighbors and its CH-sensor, (iii) the transmission range and the initial batteries power are the same in all CH-sensors, and (iv) each CH-sensor know its location also know its neighbors i.e. the other CH-sensors) and the sink's location. According to organize HWSN, the proposed routing method is implemented for two times in intra-cluster and inter-cluster, sequentially in the same way. Detail of Fuzzy Dstar-Lite implementation is given as the following:

4.1. The role of dstar-lite algorithm

This section describes how can be Dstar-Lite search algorithm applied to discover the optimal routing path. This algorithm strives to carefully utilize the total energy available in the network and to boost the network lifetime in addition to performing path calculation quicker by using information from previously handled path calculations to sidestep the cost of beginning the path calculation procedure from scratch in each round, thus reducing the delay of data transmission. Dstar-Lite computes the optimal path for the source sensor (i.e. B-sensor in intra-cluster or CH-sensor in inter-cluster) in order to be used for data transmission toward the destination (i.e. CH-sensor in intra-cluster or Sink in inter-cluster) under some criteria (i.e. remaining battery energy, minimum of hops, and traffic load) per the first period as:

a) The algorithm starts with the destination sensor node as the current node. It then scans all neighboring sensor nodes that are located inside the communication domain of the current node and evaluates these neighbor sensors by calculating their *key values* as the following steps:
   - As in the previous assumptions, all node coordinates are known and can calculate the distance (d) between each of nodes (*n*) and the sender node (*s*) by:

$$d(n) = \sqrt{(X_s - X_n)^2 + (Y_s - Y_n)^2} \quad (1)$$

where the coordinates (*Xs, Ys*) and (*Xn,Yn*) are for the sender node *s* and the evaluated node *n*, respectively. Then, *h* value for node *n* is the rescaling of its distance to the range [0...1] as following:

$$h(n) = \frac{d - minmum\ distance}{maximum\ distance - minmum\ distance} \quad (2)$$

In the topographical area, the maximum distance is the diagonal length while the minimum distance is 0. So:

$$h(n) = \frac{d}{maximum\ distance} \quad (3)$$

   - The remaining battery energy level in the node (*n*) is represented by *g(n)* value.
   - A number of the current traffic in the queue of the node (*n*) is represented by *rhs(n)* value.
   - Afterward, Fuzzy Logic is applied to calculate the Node Fitness *NF(n)* by the two input variables *g(n)* and *rhs(n)*. This processing will be explained later.
   - The values of *h(n)* and *NF(n)* are used to obtain a suitable evaluation function, That is the *key(n)* value which is calculated by:

$$key(n) = NF(n) + \frac{1}{h(n)} \quad (4)$$

b) The expanded node is considered as the successor (parent) for the set of its predecessor neighboring nodes that are discovered and evaluated during the same expansion process.
c) After the expansion process of any node, it will be removed from the Priority Queue (*PQ)*. The set of discovered and evaluated neighboring nodes is then inserted into PQ and sort all inserting nodes descending order according to their k values.
d) Step 1 up to step 3 is repeated, sequentially, until to reach the source node. The best routing path can be then easily constructed through tracking the back pointers from the source toward the destination.
e) If the source sensor has reached, the algorithm is succeeded and stopped. Otherwise, the algorithm fails if no nodes in PQ and the source has not found.

When the proposed method succeeds to find an optimal path to a specific source sensor, the path is then used by this source sensor to transmit data several times. After each transmission round, the proposed method inspects the status of the routing path in a reversed direction from the destination to the source node to decide whether the path can be used for the next transmission round or not. This is called the change detection process, it is considered to the second period by:

a) In the routing path, each node is comparing its *key*-value against that of the best substitute node by *step 2* in the finding path process. Change is said to be detected if the *key* value of the compared node is less than that of its best substitute node in the list of substitutes.
b) In case of detecting a change, the compared node is replaced by its best substitute node and the later becomes the starting point of the next finding path process. Therefore, the time of the finding path from the destination to the change node location could be saved.

4.2. The role of fuzzy logic

In the proposed method, fuzzy logic uses to calculate the suitable fitness value *NF(n)* of the node *(n)* by taking its parameters as the input variables, which are the remaining energy *g(n)* of this node and the traffic load *rhs(n)* in its queue. Figure 2 shows the fuzzy structure with the two input variables (*g(n)* and *rhs(n)*) and one output variable (*NF(n)*) with universe of discourse [0…0.5], [0…10], and [0…10], respectively. Each of these variables is described by five membership functions, as shown in Figure 3. After the fuzzification process has finished, the produced fuzzified values will then be pushed in the inference engine part to calculate the output in the form of the linguistic variable which belongs to the consequents set in the IF-THEN rules. The set of linguistic IF-THEN rules used in the proposed method illustrates Table 1.

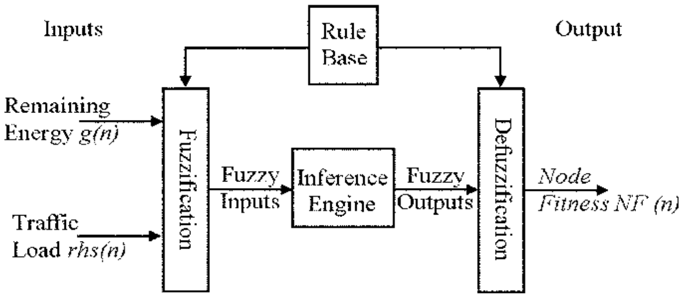

Figure 2. Fuzzy structure for fuzzy dstar-lite routing method

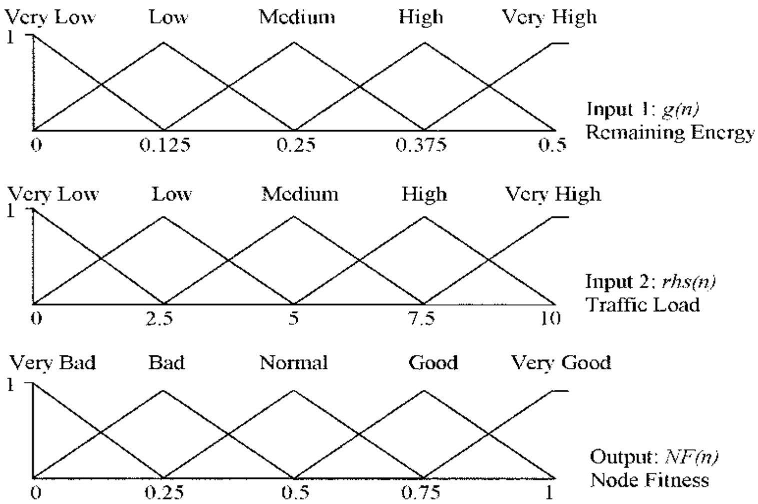

Figure 3. Membership functions of fuzzy logic in Fuzzy Dstar-Lite routing method

Table 1. IF-THEN in fuzzy dstar-lite routing method

Rhr/g	V.Low	Low	Medium	High	V. High
V.Low	Bad	V. Bad	V. Bad	V. Bad	V. Bad
Low	Normal	Normal	Bad	Bad	V. Bad
Medium	Good	Good	Good	Normal	Normal
High	V. Good	V. Good	Good	Good	Good
V. High	V. Good	V. Good	V. Good	V. Good	Good

There are 25 rules in the rule base to cover all the possible consequents since there are two input variables and five memberships for each ($5^2 = 25$ rules). The fuzzy inference engine utilizes these rules to calculate the fuzzy output for each input variables. For instance, **IF *g*(*n*) is Low and *rhs*(*n*) is Low Then *NF*(*n*) is Normal**. At the final stage, the output crisp value *NF(n)* is calculated, in the defuzzification part, by using the center of gravity method shown as following:

$$NF(n) = \frac{\sum_{i=1}^{n} U_i * C_i}{\sum_{i=1}^{n} U_i} \quad (5)$$

where U_i is the fuzzy output of rule i, and c_i is the membership center relevant to the output variable and n is the number of rules. Figure 4 shows the flowchart of the Fuzzy Dstar-Lite routing method in HWSNs.

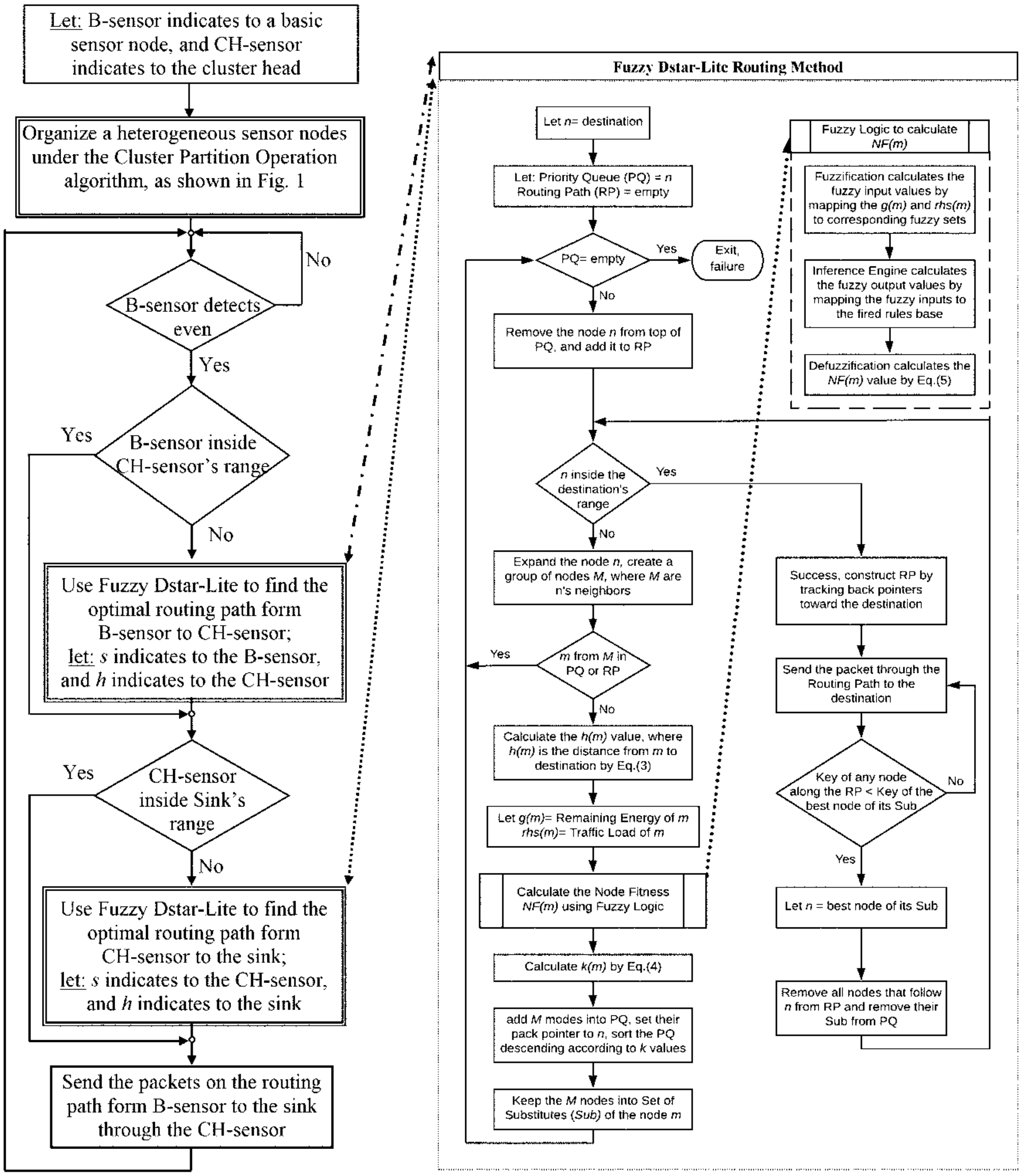

Figure 4. Fuzzy Dstar-Lite routing method for HWSNs

5. PERFOMACE EVALUATION

In this section, the performance of the Fuzzy Dstar-Lite routing protocol, in Heterogeneous WSNs, is evaluated through extensive simulations. To show the efficiency of the proposed protocol by making energy utilization balanced over the heterogeneous network, prolonging the network lifetime and shortening the time of the finding path process, we compared its simulation results with those of CC method [32], which has applied in Heterogeneous WSN environment, and also with those of the two clustering methods, i.e. LEACH [13] and PEGASIS [33], that have applied in homogeneous WSN environment. The systems simulation processes carried out in MATLAB simulator software.

5.1. Simulation parameters

For the Heterogeneous WSN, this paper assumes to deploy (1000) B-sensors with (36) CH-sensors randomly over a square topographical area that has (300 m x 300 m) dimensions. Here, the CPO algorithm utilizes, as we described in Section 3.2, to clustering all B-sensors around their CH-sensors. Besides that, the LEACH and PEGASIS protocols have used for homogeneous WSN with (1500) B-sensors deployed over the same topographical area randomly. For a fair comparison and making a similar investigation, the LEACH and PEGASIS protocols have used more B-sensors. All compared protocols run out (2000) transmission packets (rounds). Per each round, B-sensor in our proposed and CC method generates three data packets, while generates two data packets in LEACH and PEGASIS. So, the number of data generated in all protocols will be equal. Energy consumption amounts are calculated applying the "*first-order radio model*" that is frequently utilized to evaluate most of protocols efficiency and it described in [13]. For this, Table 2 gives all parameters that are used in the systems simulations in detail.

Table 2. Simulation parameters for all routing methods

Parameter		Value
Topographical area (meters)		300 m x 300 m
Sink location (meters)		(0.150)
Control data packet lemgth		2k bit
No. of transmission packets (rounds)		2 x 10^3
Max traffic in each heterogeneous node's queue		10
B-sensors	No. in our proposed & CC	1000
	No. in LEACH & PEGASIS	1500
	Limit of transmission distance	20 m
	Initial energy	2 J
	E_{elec}	50 nJ/bit
	E_{amp}	100 pJ/bit/m^2
CH-sensors	No. in our proposed & CC	36
	Limit of transmission distance	80 m
	Initial energy	2.5 J
	E_{elec}	100 nJ/bit
	E_{amp}	200 pJ/bit/m^2

5.2. Simulation results

By focused on studying the term of "the network lifetime" throughout most of the literary works, this term defines as the period time elapsed to drain the (first/last) node energy in the network. Figures 5 and 6 are shown the rates of both B-sensors and CH-sensors that still alive, respectively, by using the four routing methods for the determined routing area.

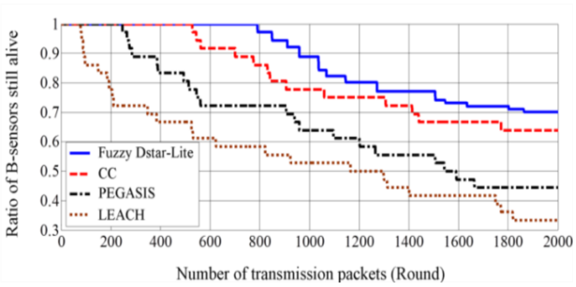

Figure 5. Ratio of B-sensor nodes still alive in the four protocols

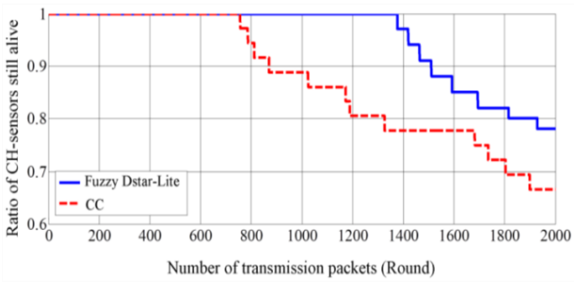

Figure 6. Ratio of CH-sensor nodes still alive in chessboard clustering (CC), and fuzzy dstar-lite

From Figures. 5 and 6, it is obvious that the proposed more outperforms than against other methods. Also, it conserves the most number of effective nodes compared to the others after sending all data packets through the network. The ratio of the network lifetime has appeared by our proposed is in the rate of 15%, 40%, and 50% more than that by CC, PEGASIS, and LEACH, respectively, after sending all data packet. Besides, Table 3 has shown the number of sending packs that cause to dead the first sensor in the whole network for the four methods. The first node death happening in the proposed method is remarkably much later than that the other methods.

Table 3. First dead B-sensor node based on the four approaches

Approaches	LEACH	PEGASIS	CC	Fuzy Dstar-lite
Life of the first dead B-sensor (Rounds)	79	247	529	790
Life of the first dead CH-sensor (Rounds)	-	-	757	1377

From the above simulation results, it is obvious that our method has outdone the other methods by balancing energy utilization and prolonging the lifetime of the network. Figure 7 shows the mean of total energy remained in all B-sensor nodes in the entire network during the transmission of data packets using the four routing methods. On the other hand, Figure 8 shows the mean of total energy remained in all CH-sensor nodes using the proposed methods and CC method. By increasing the transmitted packets, the proposed method remains conservative the highest energy compared to the others methods. That means the proposed provides the best balancing of energy in the network.

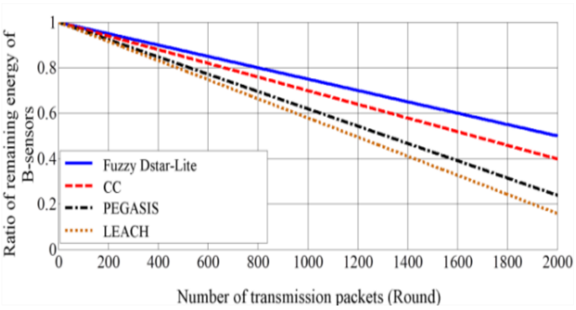

Figure 7. Ratio remaining energy of B-sensors in the four protocols

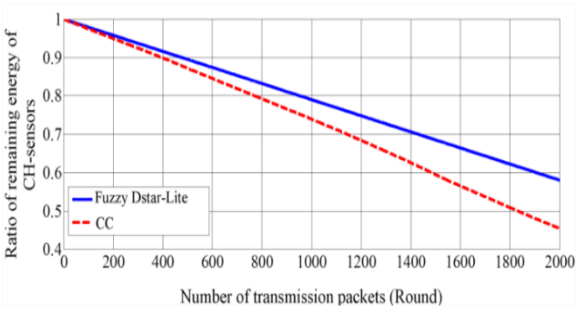

Figure 8. Ratio remaining energy of CH-sensors in chessboard clustering (CC), and Fuzzy Dstar-lite

The time spent in the process of the finding path used in the data packet transmission process is a significant factor for most applications. Moreover, it is necessary to compute an optimal routing path for the sender sensor rapidly using the available information about the status of each node to avoid calculating a faulty path due to the dynamic changes of the network. Figure 9 shows the simulation time for the number of transmitted packets using the four compared routing methods. It can be seen the proposed method works much faster than the others. Also, the proposed method achieved a low end to end transmission delay, as shown in Figure 10. Less delay implies more efficient energy utilization and more efficient information transmission.

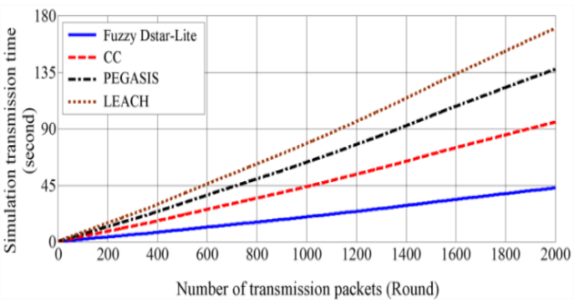

Figure 9. Simulation transmission time in the four protocols

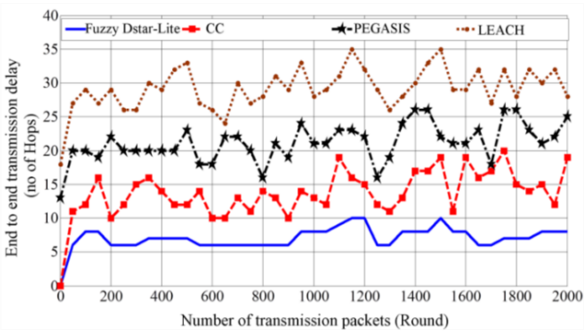

Figure 10. End to end delay in the four protocols

6. CONCLUSION

Imbalanced energy utilization is an inherent matter in WSNs, where some nodes in the network perform more data forwarding tasks than other nodes. The reasons behind this problem are the multi-hop data transmissions and many-to-one connection patterns. Some sensor nodes are very important to remain alive for the longest possible time because each of which plays the role of the exclusive connector between-group(s) of nodes and the sink. If any of these sensors becomes dead, the sensor network will be divided into two or more disconnected portions and it is said to be partitioned. This debilitates the functionality or aborts the lifetime of WSNs. So, an ideal routing path should consist of the least possible number of sensor nodes and that their residual energy levels should be the highest and their traffic loads should be the lowest. This paper is therefore proposed the Fuzzy Dstar-Lite protocol to produce an optimal pathway data routing for HWSNs. The proposed is capable of reusing the optimal path to reduce the delay produced by the path calculating while keeping energy consumption balanced between discovered paths. The simulations have shown that our method achieved significant efficiency in HWSNs by addressing of Imbalanced Energy Depletion problem and seeking to decrease the transmission data delay. All this, in turn, leads to an increase in the network lifetime as much as possible.

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