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An Energy Efficient Routing Protocol in Wireless Sensor Networks using Genetic Algorithm

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ABSTRACT

Background: To achieve the energy efficiency in wireless sensor networks, many routing protocols have been proposed and LEACH is the representative one. **Objective:** This paper aims to introduce an adaptive low power routing protocol that takes into account some concepts from nodes to elect optimal cluster heads. Genetic algorithm is applied to optimize controllable parameters of the proposed protocol, in order to prolong the network lifetime. The fitness function can be defined according to the application specifications. **Results:** Simulation results demonstrate the efficiency of the proposed routing protocol. The average gain in the network lifetime is 82%, as compared with three other LEACH-based protocols. **Conclusion:** In contrast to other routing protocols, the main advantage of our protocol is that it can be adaptively tuned based on the application. The proposed routing protocol can efficiently balance the energy consumption of nodes and maximize the network lifetime.

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INTRODUCTION

A group of wireless sensor nodes can make a wireless sensor network (WSN) which provides unprecedented opportunities in several domains ranging from military to agriculture and civil, as well as structural monitoring, industrial control, health monitoring, and home networks [1]. A routing protocol should take into account the energy-awareness at all layers of the networking protocol stack in such a way that the network lifetime is maximized [2]. In WSNs, a routing protocol is required when a node cannot send its data packet directly to its destination node, and has to rely on the assistance of intermediate nodes to forward its packet [3-4]. In general, routing protocols for WSNs can be categorized into *flat*, *hierarchical*, and *location-based* [5]. In flat routing, all nodes have the same functionality and they work together to sense and route [6]. Hierarchical routing techniques divide the network into distinguished clusters. The most famous and attractive hierarchical protocol is Low Energy Adaptive Clustering Hierarchy (LEACH), which has been widely accepted for its energy efficiency and simplicity [7]. In location-based routing protocols, the information about the location of sensor nodes is used to generate the routing path [8].

There are some popular criteria for definition of network lifetime in WSNs, including First Node Dies (FND), Half Node Die (HND), Last Node Dies (LND), etc [3]. It is notable that the network lifetime is defined based on the application. For example, in heterogeneous networks (e.g., a hospital health-monitoring network), lifetime should be defined as FND, due to the information of sensor nodes are distinguished in data type. In these networks perishing of a sensor node may generate irreparable damages. On the other hand, for the applications containing the homogeneous nodes (e.g., construction structural monitoring in Buildings, Tunnels, Bridges, etc), perishing of some nodes is not critical, and network is trustable as long as at least the pre-determined number of nodes have been alive.

Recently, Swarm Intelligence (SI) algorithms have begun to attract attention from researchers to develop clustering-based routing protocols in WSNs [3], [9-14]. The main goal of these SI-based protocols is to dynamically cluster sensor nodes such that the energy consumption of the network is minimized. They have proved that their protocols outperform other attractive routing protocols such as LEACH in prolonging the network lifetime. However, precise inspection of their results shows one common drawback emerges. While

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these SI-based routing protocols prolong the network lifetime, they decrease the stability period of the system, which is crucial for many applications like health-monitoring networks.

In this paper, an adaptive clustering-based routing protocol (LEACH-LPR) is introduced, that takes into account some concepts from the current situation of sensor nodes in the network (e.g., distances from sensors to BS, remained energy of sensors, etc), and can optimally balance the energy consumption among the sensors. Genetic algorithm is used to optimize the proposed protocol. The main advantage of the proposed protocol is that it can adaptively tune its parameters in order to generate the maximum lifetime in each specific application. Therefore, we are motivated by the fact that there are many applications that would benefit highly from maintaining the stability as well as the network lifetime, thus maintaining better tradeoff between reliability and lifetime of the system. On the other hand, the proposed LEACH-LPR protocol can maximize the defined lifetime scheme (e.g., FND, HND, etc.), based on the specific application.

The rest of the paper is organized as follows: Section 2 briefly reviews some hierarchical routing protocols in WSNs. Section 3 describes radio energy and communication models in WSNs. In Section 4, we address the drawback of the current hierarchical clustering-based routing protocols and provide the adaptive LEACH-LPR protocol as an effective solution to this problem. Section 5 presents simulation results, and finally Section 6 concludes the paper with possible future directions.

Related Works:

In the clustering-based routing protocols, data gathered by the sensor nodes is transmitted to the sink through the cluster heads (CHs). As the nodes communicate data over shorter distances, the energy spent in the network is likely to be substantially lower compared to direct communication to the Base Station (BS). The LEACH protocol [7] uses stochastic self-election, where each node has a probability *P* of becoming a CH in each round. On the other hand, LEACH forms clusters via a distributed algorithm, where nodes make autonomous decisions to be CHs without any centralized control. It guarantees that each node would be a CH only once in consecutive 1/*P* rounds. Initially, each node decides to be a CH with a probability *P*. The role of being a CH is rotated periodically among the nodes of the cluster aims to balance the load and distribute the energy consumption. The operation of LEACH in the every round can be separated into two phases: the setup phase and the steady phase. During the setup phase, each sensor node *n* chooses a random number between 0 and 1. The node *n* becomes a CH for the current round, if its random number is less than the threshold T(*n*). The threshold T(*n*) is calculated according to Eq. (1), where *P* is the desired percentage of nodes to become CHs, *r* is the current round number, and *G* is the set of all nodes that have not being selected as CH in the last 1/*P* rounds.

$$T(n) = \begin{cases} \dfrac{P}{1 - P \times [r \mod(1/P)]} & if\ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

After CHs have been selected, they advertise to all sensor nodes in the network that they are the new CHs. Once each non-CH node receives the advertisement from CHs, it determines its CH with the minimum communication distance. Once the clusters are created and the TDMA schedule is fixed, data transmission can begin. After a given time spent on the steady phase, the network goes into the setup phase again and enters another round of selecting CHs. As proved in Ref. [7], the optimal number for CHs can be calculated based on the WSN details, network size, and number of alive sensor nodes, according to Ref. [7].

Compared with flat protocols, LEACH has good performance in extending the network lifetime. However, residual energy of nodes is not taken into account for CH-election in LEACH protocol. On the other hand, if the node with lower residual energy decides to become a CH, it will be rapidly dead. Considering the fact that more energy consumption is involved in collecting the average residual energy of all nodes compared with all CHs, LEACH-EP [15], an extension of LEACH has been proposed, in which, an energy factor is also takes into account. In LEACH-EP protocol, the nodes with more energy have more opportunities to serve as CH. Authors in [15] show that LEACH-EP improves the FND lifetime over 33% in contrast to the LEACH. Recently, several distance-based routing protocols have been proposed.

In [17], a CH election algorithm was proposed using the minimum and maximum of the distance to the sink. In [16], the authors investigated a distributed LEACH-based CH election algorithm called LEACH with Distance-based Threshold (LEACH-DT), aims to balance the energy consumption among all nodes. In LEACH-DT, nodes are self-selected to become CH with different probabilities based on their distances to the sink. LEACH-DT uses the same formula as the original LEACH (see Eq. 1). Unlike LEACH, *P* for node *n* in LEACH-DT is calculated as a function of distance from node *n* to sink. Authors in [DT] show that their protocol outperforms the original LEACH with improved lifetime over 10%.

Energy Consumption Model:

In order to calculate energy consumptions, the first order radio model [7] is used. In this model, a radio dissipates E_{elec} (per a bit) to run both the transmitter and the receiver circuitry. Also, depending on the transmission distance the free space and the multi-path fading channel models are used for the transmitter amplifier [18]. To transmit an l-bit data packet from the transmitter node to the receiver node with a distance d between them, the energy consumption for the transmitter node can be calculated as follows:

$$E_{TX}=\begin{cases} l\times E_{elec}+l\times E_{fs}\times d^2 & if\ d\le d_0 \\ l\times E_{elec}+l\times E_{mp}\times d^4 & if\ d>d_0 \end{cases} \tag{2}$$

where the threshold distance d_0 is defined as $d_0=(E_{fs}/E_{mp})^{1/2}$. Also, to receive the above data packet, the energy consumption for the receiver node can be calculated as $E_{RX}=l*E_{elec}$. The electronic energy E_{elec} depends on such electronic factors as digital coding, modulation, filtering, and spreading of the signal, whereas the amplifier energy in free space E_{fs} or in multipath environment E_{mp} depends on the distance from the transmitter node to the receiver node.

Proposed Routing Protocol:

In this paper, an adaptive clustering-based routing protocol (named LEACH-LPR) is introduced, that takes into account some concepts from the current situation of sensor nodes in the network (e.g., the distance from the sink, the residual energy, the number of neighborhood nodes). Thus, it can optimally balance the energy consumption among the sensors. As the proposed routing protocol is complex with some controllable parameters, a hybrid algorithm based on genetic algorithm and simulated annealing is applied to adaptively optimize the LEACH-LPR protocol based on the application, thus maintaining better tradeoff between reliability and lifetime of the system. On the other hand, the LEACH-LPR protocol can maximize the defined lifetime scheme (e.g., FND, HND, LND, etc.), based on the application specifications.

As mentioned above, the residual energy of nodes is not taken into account for CH-election in LEACH. If a node with lower residual energy and large distance from sink decides to become a CH, it will be rapidly dead. It is obviously that this mechanism leads to unbalanced energy consumption. On the other hand, this incurs more energy consumption for those nodes that are farther from the sink. Here, LEACH-LPR protocol is introduced, in which the adaptive threshold $T_{LPR}(n)$ for node n is calculated as follows:

$$T_{LPR}(n)=\alpha\times T_1(n)+\beta\times T_2(n)+\gamma\times T_3(n) \tag{3}$$

Where α, β and γ are three constant parameters, each between 0 and 1, applied to adjust the relative influence of the sub-threshold terms within the $T_{LPR}(n)$. Note that it must $\alpha+\beta+\gamma=1$, in order to normalize the proposed threshold $T_{LPR}(n)$ in contrast to the LEACH. The three sub-threshold terms from $T_1(n)$ to $T_3(n)$ can be formulated as follows:

$$T_1(n)=P\times E(n)/\frac{1}{N}\sum_{i=1}^{N}E(i) \tag{4}$$

$$T_2(n)=P\times N\times d^{-1}(n)/\sum_{i=1}^{N}d^{-1}(i) \tag{5}$$

$$T_3(n)=P\times K\times\sum_{i=1}^{N}ND(n,i)/N \tag{6}$$

where N is the number of alive sensor nodes in the network, P is the desired percentage of nodes to be CHs, K is the desired number of nodes to be CHs, $E(n)$ is the current residual energy of node n, $d(n)$ is the distance from node n to the sink, and, t_1 and t_2 are two selective constant parameters. Also $DN(n,i)$ is a binary parameter determining whether node i is a neighbor of node n, or not. $DN(n,i)=1$, if the distance between node n and node i is less than a constant parameter namely dt_{max}, and $DN(n,i)=0$, if the distance between node n and node i is larger than dt_{max}.

Genetic Algorithm (GA) [19] is a meta-heuristic population-based evolutionary algorithm that belongs to the larger class of evolutionary algorithms, which generate solutions to optimization problems using techniques inspired by natural evolution, such as selection, crossover, and mutation. In this paper, a new adaptive routing protocol is presented which utilizes some concepts from the sensor nodes details in order to elect optimized CHs. There are five controllable parameters in the proposed LEACH-LPR protocol (including α, β and γ). According to the application, changing in these parameters leads to operate LEACH-LPR in different operation models. We used GA to optimize these three controllable parameters. The each weighting parameter (α, β and γ) must be optimized in range of [0,1], in such a way that $\alpha+\beta+\gamma=1$. Here, binary encoding is used, in which every optimization parameter is discretized with the resolution of 0.01. Therefore, seven digits are required for encoding of each controllable parameter. Therefore, a feasible solution can be represented as a binary string of length 21. The overall flowchart of the GA-based algorithm to optimize the LEACH-LPR protocol can be seen in Fig. 1.

As mentioned above, binary encoding is used. Therefore, each chromosome can be represented as a binary string with L genes, where L=21. At the first step, the initial population of GA is randomly generated. Then, two overall steps are consequently done, until the maximum number of iterations of GA has been reached: *fitness evaluation* and *population updating*. After fitness evaluation of the current population, some of the best chromosomes are selected as the parents for updating the population. Then, offspring are constructed from the parents via crossover operator. After that all offspring have been generated, the mutation operator is applied to change randomly in the value of some genes within the generated offspring, aim at avoid trapping in local minima points. In every iteration, the fitness of each chromosome is evaluated according to the proposed fitness function which is considered to maximize the FND lifetime. Then, all chromosomes are sorted from the best to the worst, and some of the best ones are selected based on a elitism selection strategy, as the parents for updating the population. In order to generate an offspring, two parents are randomly chosen among the best individuals (parents) of the population, and the crossover operator is performed on them. In this paper, the uniform crossover operator was performed, in which, each gene in the offspring is filled from the same gene of one of the two parents, with the same probability. Also, binary swap mutation operator was used, in which, each gene may be selected with probability of P_m, and its value will be complemented.

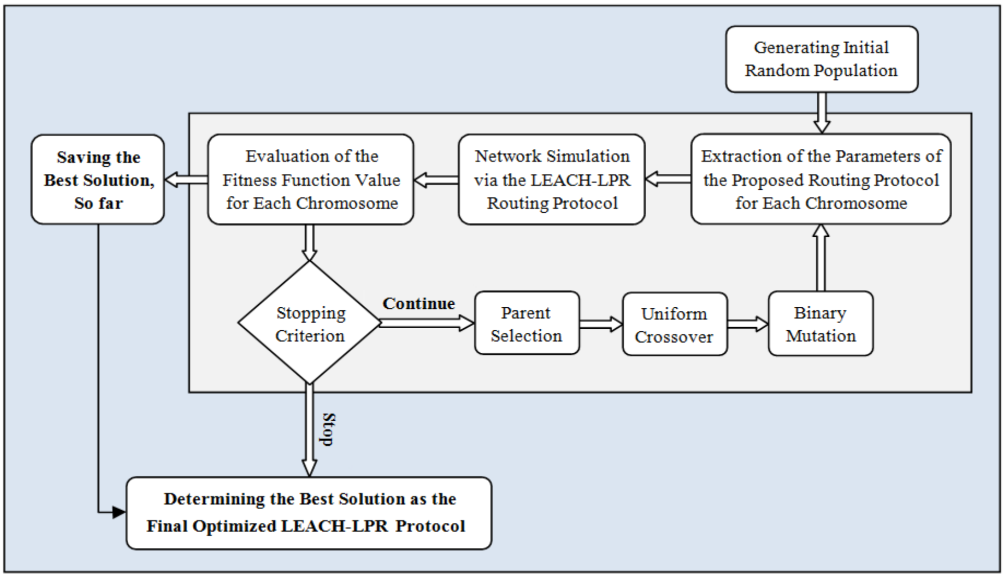

Fig. 1: The overall flowchart of the proposed GA-based algorithm for the optimization of the LEACH-LPR routing protocol.

Simulation Results:

All of experiments were carried out in MATLAB. In this section, we investigate the performance of our LEACH-LPR protocol against the well known heuristic protocol LEACH [7], the energy-aware LEACH-EP protocol [15], and the distance-aware LEACH-DT protocol [16]. In order to tune the parameters of GA, different values were tested for each parameter, and the best values were selected for final simulations. To demonstrate the effectiveness of the proposed LEACH-LPR protocol in terms of balancing energy consumption and maximizing network lifetime, obtained simulation results of the proposed were compared with those of LEACH, with those of LEACH-EP, and with those of LEACH-DT for two different workspace, namely WSN-1 and WSN-2. 100 sensor nodes are randomly deployed in WSN-1 of dimension 100m×100m. Another set of 200 nodes are randomly deployed in a topographical area WSN-2 of dimension 150m×150m. The performance of the mentioned routing protocols is tested in these two topographical areas. There is only one sink which located at (50m,50m) for WSN-1 and at (75m,75m) for WSN-2. All sensor nodes have the same initial energy 1 Joul. Both WSN-1 and WSN-2 use the first order radio communication model that is largely used in the evaluation of routing protocols in WSNs. Table 1 presents the GA and network parameter setting in details.

Table 1: Setting the controllable parameters of GA.

GA Parameter	Value/Description	Network Parameter	Value
Maximum iterations	50	Initial Energy	1 J
Population size	20	dt_{max}	30 m
Number of parents	4	E_{elec}	50 nJ/bit
Selection strategy	Elitism selection	E_{fs}	100 pJ/bit/m^2
Crossover operator	Uniform	E_{mp}	0.013 pJ/bit/m^4
Crossover probability	0.8	Data Packet Size	4 k bit
Mutation operator	Binary swap	Control Packet Size	50 bit

The optimized LEACH-LPR controllable parameters achieved via GA can be summarized in Table 2, in which there is no major variance for each parameter optimized in difference workspaces. Fig. 2 illustrates the distribution of alive sensor nodes with respect to the number of rounds for each algorithm, in WSN-1. This figure clearly shows that our proposed approach is more stable than the other protocols, because sensor node deaths begin later in LEACH-LPR and continue linearly until all sensor nodes die. Also, the mean and standard-variation of energy-consumption with respect to the number of rounds in WSN-1 can be seen in Figs. 3 and 4, respectively. Table 3 compares the network lifetime (with FND, HND, and LND criteria) in WSN-1 and WSN-2 achieved via different routing protocols. Also, comparison of the total number of received data packets at the base station before arrival the network lifetime can be seen in Table 4. The average results achieved in WSN-1 and WSN-2 can also be shown in Figs. 5 and 6, respectively for network lifetime and total data packets.

Table 2: Optimized values for the controllable parameters of LEACH-LPR protocol.

WSN #	α	β	γ
WSN-1	0.74	0.19	0.07
WSN-2	0.75	0.16	0.09

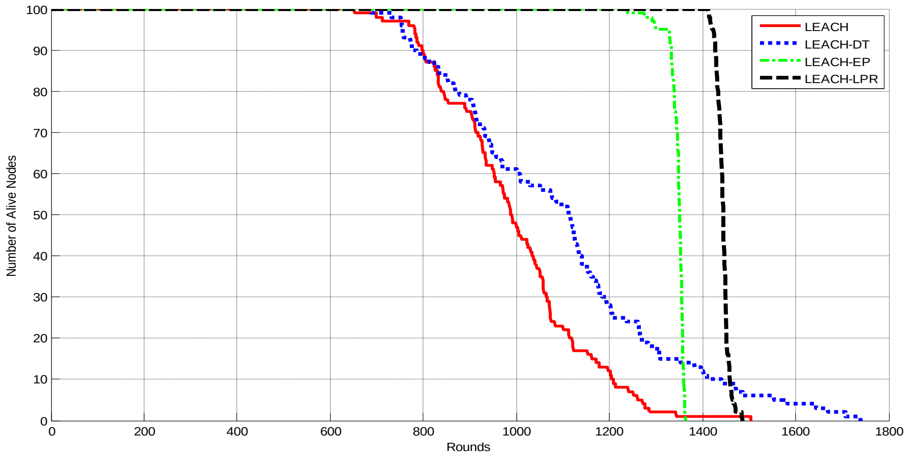

Fig. 2: Distribution of the alive sensor nodes with respect to the number of rounds, for WSN-1.

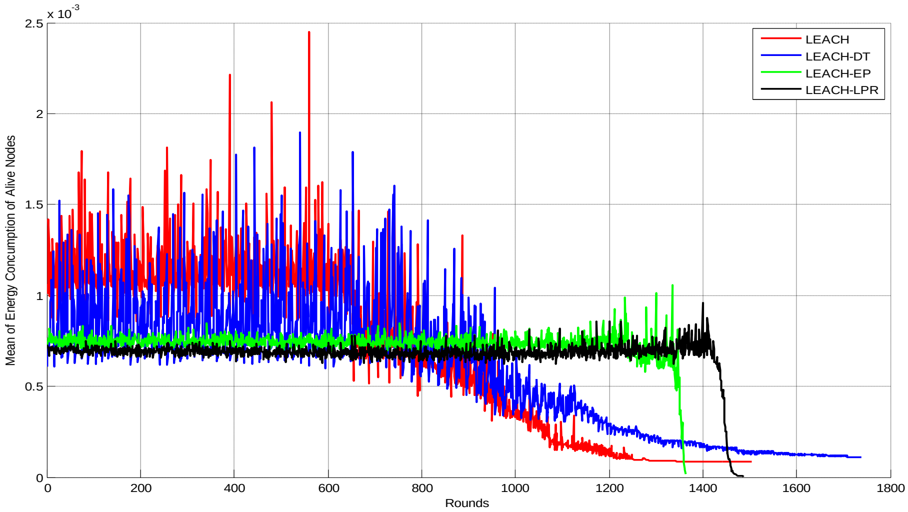

Fig. 3: The mean of energy consumption among all nodes versus the number of rounds, for WSN-1.

Table 3: Comparison of the network lifetime.

		LEACH [7]	LEACH-DT [16]	LEACH-EP [15]	LEACH-LPR
WSN-1	FND	653	689	1241	1414
	HND	990	1115	1350	1444
	LND	1504	1739	1363	1486
WSN-2	FND	520	554	1021	1185
	HND	778	885	1114	1217
	LND	1182	1392	1142	1245

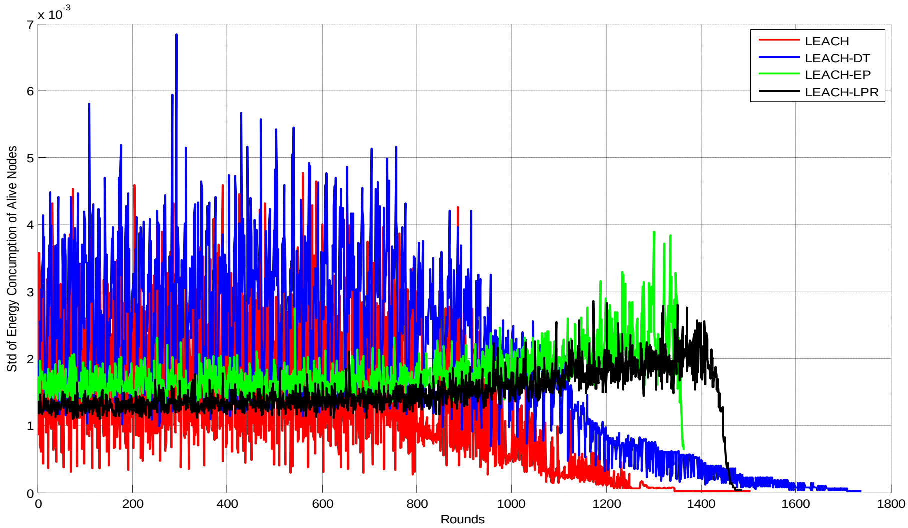

Fig. 4: The standard deviation of energy consumption among all nodes versus the number of rounds, for WSN-1.

Table 4: Comparison of the total data packets received in sink.

		LEACH [7]	LEACH-DT [16]	LEACH-EP [15]	LEACH-LPR
WSN-1	Data-FND	65300	68980	124100	141400
	Data-HND	93167	100886	134269	143876
	Data-LND	99578	109443	134563	144321
WSN-2	Data-FND	104000	110800	204200	237000
	Data-HND	156320	173875	221046	278934
	Data-LND	169235	187836	221789	280110

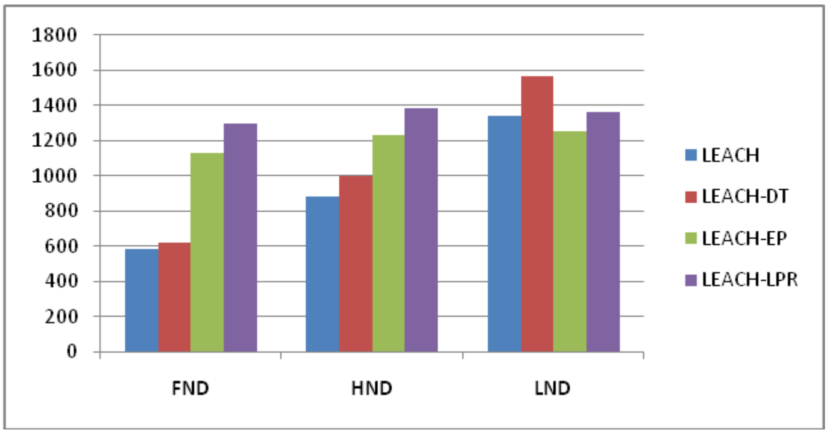

Fig. 5: Comparison of the average network lifetime for WSN-1 and WSN-2.

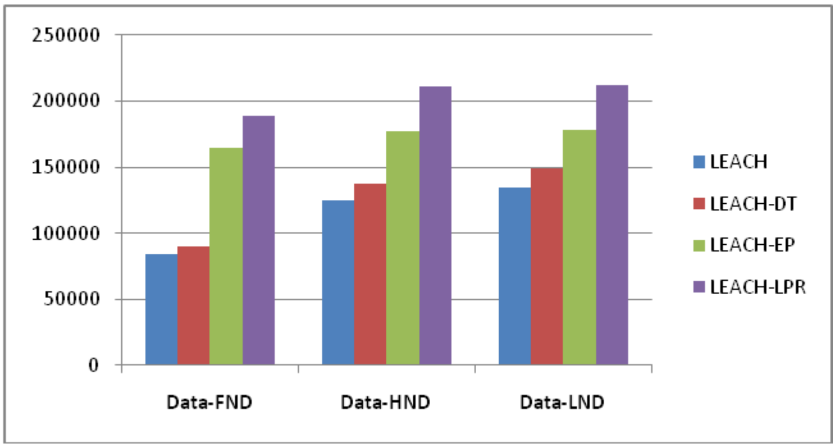

Fig. 6: Comparison of the average number of received data packets at the base station for WSN-1 and WSN-2.

Conclusion:

In this paper, an application-specific low power routing protocol based on LEACH architecture with an extension to the energy predication has been proposed for WSNs, namely LEACH-LPR. The main objective of the proposed protocol is to prolong the lifetime of the WSN according to the application. As the proposed routing protocol is complex and has some controllable parameters, tuning these parameters is an important problem to achieve the best performance. To achieve this goal, the paper focused on optimization of the LEACH-LPR controllable parameters via genetic algorithm, based on the application specifics. Simulation results show that the proposed hybrid optimization algorithm can efficiently balance the energy consumption of nodes and maximize the network lifetime. The LEACH-LPR outperforms the LEACH-based algorithms with improved network lifetime. The gain in total received data packets in sink was 58%, 43%, and 19% as compared with LEACH, LEACH-EP, and LEACH-DT, respectively. In spite of the mentioned advantages, the proposed protocol needs extra computations in centralized processor in sink. The proposed LEACH-LPR protocol was designed for the WSNs that have stationary sensor nodes. As a future work, it can be extended for handling mobile sensor nodes. Also we plan to extend the proposed protocol with multi-hop routing to cope our protocol for routing in large-scale topological areas.

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