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Energy Sparing of the Leach Communication Mechanism With Mobile Sink Node

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Abstract

In the process of crafting routing protocols for Wireless Sensor Networks (WSN), clustering became an important aspect to spare network energy consumption and data delivery efficiently. Low-Energy Adaptive Clustering Hierarchy (LEACH) is a hierarchical cluster-based, energy-efficient routing protocol. It extends the network lifetime by randomly selecting Cluster Heads (CH) to aggregate and forward the routing information from the cluster members to the Sink node. LEACH in its archetype is a distributed routing protocol and one of the most efficient energy management mechanism for WSN. However, there exist some disadvantages, that lead to uneven energy consumption in the network when the nodes far away from the Sink die more quickly than the nodes closed. Hence, we propose a new approach for network lifetime improvement, where the Sink node is mobile and cross the whole network physical area to have a better energy consumption rate uniformly distributed across the network.

Keywords: Low-energy adaptive clustering hierarchy (LEACH), Wireless Sensor Network (WSN), routing, clustering, energy consumption, mobility, uniform energy distribution.

MSC: 65C60, 60G35, 91A28

1. Introduction

In a Wireless Sensor Network (WSN), the nodes are deployed to monitor an Area of Interest (AoI) and collect date depending on their function. The captured information is then forwarded to the Base Station (BS) or Sink Node (SN) for further processing. This procedure is done by different routing mechanisms that lean on the network architecture and the researchers' needs. However, since the devices have restricted energy capacity, the primary issue in the deployment of sensor nodes is to guarantee their power efficiency. Moreover, such sensors are commonly and heavily concentrated in areas that are unreachable to human beings, therefore, the battery modules cannot be charged up or replaced. Because of this, the battery of the sensors must be exploited to the greatest extent, this mechanism is referred to as energy efficiency.

Routing protocols play a key role in achieving an efficient transmission and proper routing for the aggregated data, due to the lack of network resources as they have less energy and memory. Therefore, it is important to exploit these assets efficiently and intelligently. A successful model of WSN is a model that can have a good compromise between maximum data collection and least energy consumption. In the process of crafting routing protocols for WSN, clustering becomes an important aspect to spare network energy consumption and data delivery efficiently. Hierarchical routing including clustering can be an adequate sensor nodes organization method [1, 14]. Furthermore, applying clustering in WSN can increase the scalability, reduce energy harvesting and latency, ensure good connectivity, perform load balance, diminish energy hole and increasing network lifetime [2, 17, 19].

Low-Energy Adaptive Clustering Hierarchy (LEACH) is a hierarchical cluster-based, energy-efficient routing protocol. It extends the network lifetime by randomly selecting Cluster Heads (CH) to aggregate and forward the routing information from the cluster members to the Sink node. This intermediate delivery step decreases the quantity of energy consumed by the nodes. The formation of clusters makes the routing robust and scalable. The fusion technique of the LEACH collects data and delivers only valuable information to all the nodes. The main goal of the LEACH protocol is the energy sparing based on the random election of the CH nodes from the whole WSN in consecutive epoch times. Each CH has its own cluster with zero or higher number of node members. The two alternating phases based mechanism are executed for each time interval, a setup phase where the election of the CH and the assignment of the member nodes is executed and a steady phase where the member of the same cluster send their messages to the CH without collision [1, 15, 20].

LEACH in its archetype is a distributed routing protocol and one of the most efficient energy management mechanism for WSN. However, there exist some disadvantages, when the probability of becoming CH is independent of the node energy level, random cluster formation that leads to uneven clusters distribution in the network [2, 11, 16]. This method results also from inequitable traffic distribution between the nodes because the heads of the cluster deliver the information whether via routing between the CHs of the cluster or straight forward to the BS. Some CHs thereby weaken their energy more quickly than others and trigger energy-hole issues in the system [3, 4, 18]. In such circumstance, the entire network infrastructure will indeed be divided though much energy remains unused, which dramatically reduce the network.

The paper structure is as following: in the second chapter related work of the basic LEACH mechanism is given. Architecture and energy aspect of the LEACH mechanism are presented in chapter three. The impact of the Sink mobility in LEACH is analyzed with simulation methods and is discussed in chapter four. Last chapter concludes the results and gives possible continuation targets of the topic.

2. Related Work

A heuristic method named Weighted Rendezvous Planning (WRP) was proposed by H. Salarian and. Al. A near-optimal tour for the mobile sink which minimizes the nodes' energy consumption was considered. WRP determines a group of Rendezvous Points that avoid the creation of energy holes. WRP allows a mobile sink to collect all data from nodes over a given time-limit whereas maintaining energy needs. This energy-efficient, WSN trajectory selection approach reduces energy consumption and helps increase lifespan [5].

Virtual Grid Distributed Clustering (VGDC) has been introduced for the effective mobile WSN clustering. To perform distributed clustering the entire network area is divided into equally sized grids. Every grid features only one cluster head, whereas all cluster heads are connected together. This offers full coverage of adding further nodes to the cluster heads. VGDC strengthens cluster head stability and reduces the immediate communication across the sink and nodes [6].

Z. Zhou et. al developed a heuristic three-phase approach for the effective management of mobile sinks in hybrid WSN. The network is split into grid sheets, and the grids will form clusters. Such clusters organize themselves in order to balance the energy usage in them by assigning or freeing up gird cells. This approach achieves an effective network grid cell division that extends the network life span [7].

S. Sharma and. Al implemented a Mode Switched Grid-based Routing (MSGR) protocol that utilizes grid protocol advantages. It induces sensors to affectively transmit data toward a mobile sink. Any nodes that don't participate in the routing are put on sleep mode. The energy is saved, and the lifetime is enhanced [8].

P.Y. Chi et. Al suggested an Energy-Aware Grid Routing Scheme (EAGER) designed to distribute data between the source and several mobile sinks. The network area is fragmented into equally sized grid cells and all cells are allocated a unique identifier labelled Grid Identification. EAGER uses the rerouting method, which recreates new paths of data transmission among various mobile sinks and sources. Also, it provides a framework for time scheduling during which the idle grid head is permitted to sleep during a certain time period [9].

3. Architecture and Energy Aspects of the LEACH Mechanism

Routing protocol in WSN is a method to transmit data from the source to the destination by selecting convenient routes. In a WSN a source node senses data and sends the packet through intermediate nodes to the base station (BS) using single hope communication in small network where the source node and the BS can communicate directly and in multi-hope communication mode where the covered area is large. There exist three main categories to classify routing protocols: Network Organization (Flat, Hierarchical and Location-Based), Route Discovery (Reactive, Proactive and Hybrid), Protocol Discovery (Negotiation, Multi-Path, Query and QoS-Based). Another type of network is Delay Tolerant Networks (DTN), they use a specific type of routing protocols such as Epidemic Routing Protocol (ERP), ProPHET (PRO) and Direct Delivery Routing (DDR). LEACH is a hierarchical routing protocol, its main goal is the energy saving, to do so cluster heads (CH) are randomly elected in successive epoch times while alternating between two phases [10, 12, 13].

Set-up phase: In this phase are elected the heads of the clusters and assignment of the member nodes to the clusters. Signalling and communication between the CH and the members are executed with Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA). WSN nodes take part in the election phase of the CH by generating own random priority number in the range (0,1). If the generated value is less than the threshold *T(n)*, then the node becomes head. The value of the threshold is modified conform to the following formula:

$$T(n) = \begin{cases} \frac{p}{1-p\cdot \mathrm{mod}(r,1/p)}, & \text{if } n \in G, \\ 0, & \text{otherwise,} \end{cases}$$

where $T(n)$ is the threshold, n is a random variable taking values between [0, 1] and [0, N], respectively. The p denotes the CH election probability or the percentage of a node to become a CH and is constant for a given simulation scenario. r is the current round and G is the set of sensor nodes that did not become CH in previous *1/p* rounds. We refer round r to be epoch. A node with index n becomes CH for the current round if the generated random value of a sensor node is strictly less than a threshold *T(n)*. For a given round we have a fixed threshold and it is compared to the sensor node random values. If it is equal to 0, it means that n does not belong to G but belongs to the complementary set of node that were already elected as CH or died. Once a node is elected CH it cannot participate in the next *1/p* round of CH election: i.e. if $p \in \{0.05, 0.10\}$ than the elected CH cannot be reelected in the next *1/p* $\in \{20, 10\}$ rounds respectively. This criterion is useful for the energy load balance inside the network, since every node gets better chance to become CH. Based on this rule any of the nodes can become CH with similar probability, making uniformity on WSN extra energy consumption level of the CH function. The CHs announce the other nodes with radio channel broadcast about its new CH function. The ordinary nodes receive these signals and based on the intensity of the signal decide which cluster to become a member with. The signal intensity in practice depends on different environmental parameters but for the classical version of the LEACH, just the distance between the node and the CH is considered. The ordinary nodes send their responses to the most advantageous CH, becoming in this way member of that cluster. The CH schedule the communication inside of cluster for the members during the actual epoch time.

Steady phase: Members of the same cluster use TDMA (time slot) and CDMA (chip node) mechanisms to send their message to the CH without collision. The CH forwards the aggregated and compressed cluster level message to the Sink node. For the basic version of the LEACH, each cluster member is allowed to send at most one message per epoch time. The nodes are in a sleeping mode in the time inactive communication intervals to increase their lifetime. The CH nodes of the actual epoch time use TDMA and CDMA communication mechanisms during the communication of the Sink node to avoid collisions.

4. Impact of the Sink Mobility in LEACH Network

A mobile sink has been used in the proposed research to gather data from the sensor nodes with the goal of reducing the dulled energy of the WSN. We considered several N sensor nodes randomly spread with geographic coordinates in a circle area. The intention here is to improve the sensor's battery life, as data is now being conveyed over a smaller range. Doing so will result in fewer packet drops and less packet delay. Before describing the simulation result in depth, we need to outline some network assumptions:

- The network nodes have heterogeneous initial energy amounts, and are static in physical space after deployment.
- Same initial total energy for the WSN by setting both E_0 and $(a \cdot m + 1) \cdot N$ terms constant in the equation (4.1).
- The range between a sender and a receiver may be determined by the intensity of the received signal.
- The mobile sink has abundant resources.

The simulations were achieved with two subsets of the WSN nodes. Normal Nodes (NN) and Advanced Nodes (AN) have E_0 and $(a + 1) \cdot E_0$ initial energy levels, respectively where a is the energy factor of the advanced nodes and $a > 0$. The population of these subsets are $m \cdot N$ and $(1 - m) \cdot N$, respectively, where $m \in [0, 1]$. The initial energy (NE_0, AE_0, TE_0) of the subsets and the whole WSN is given by the next formula:

$$AE_0 = (a + 1) \cdot m \cdot N \cdot E_0,$$

$$NE_0 = (1 - m) \cdot N \cdot E_0,$$

$$TE_0 = AE_0 + NE_0 = (a \cdot m + 1) \cdot N \cdot E_0.$$

Parameters	Value(s)
Diameter of the circle field, D	100 m
Center of the circle field	(0, 0)
Initial position of the Sink node	(-D, 0)
Farthest position of the Sink node	(D, 0)
Number of nodes of the WSN, N	157
Ratio of the AN node to the total nodes, m	0.5
Velocity, v	0, 5, 10 m/s
Radio frames length, Fs	4000 bits
Energy factor of the AN, a	1
Aggregation level, g	0.10, 0.90
Ratio of the CH nodes, p	5 %
Initial energy unit, E_0	2.5 J
Energy consumption of the electronics, E_{elec}	50 nJ/bit
Energy multipath factor in function of antenna height, E_{mp}	1.3 pJ
Energy consumption of the antenna amplifier, E_{amp}	0.1 nJ/bit
Energy consumption of the frame aggregation, EDA	5 nJ/bit
Radio antenna height, δ	1.5 m
Radio channel distance threshold, d_0	87.7 m
Energy Free Space Factor, E_{fs}	10 pJ/bit/m^2
Path loss exponent, b	4

Table 1: Parameters of the heterogeneous LEACH system simulation

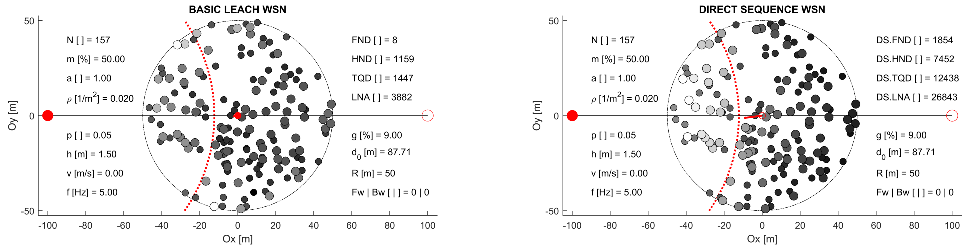
The attenuation A to distance d of the energy during the radio communication is given by the following formula:

$$A(d) = E_{Rx}(d)/E_{Tx}(d)$$

$$A(d) = \begin{cases} (\delta/d)^2, & \text{if } d \in (0, d_0), \\ (\delta/d_0)^2 \cdot (d_0/d)^b, & \text{if } d \in [d_0, \infty), \end{cases}$$

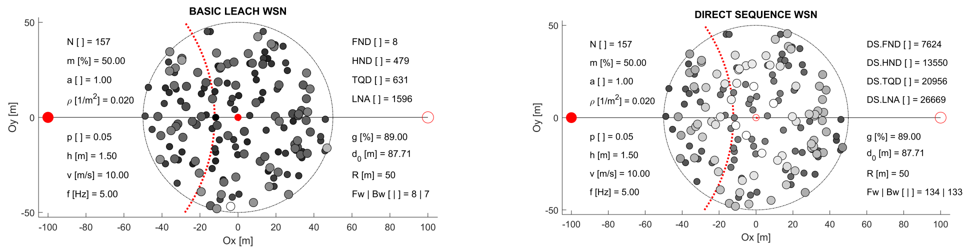
where $E_{Rx}(d)$ and $E_{Tx}(d)$ are the received and transmitted energy to distance d, respectively. δ is the radio antenna size (in the range of centimeters) at the transmitter that has an effect on the radio energy attenuation during the transmission between the nodes and d_0 the crossover distance being the threshold distance between the source and destination. Parameter b is the path loss exponent (path attenuation) which includes the effect of the physical environment to the radio channel being dependent on the distance d.

To visualize the details of the communication process much more intensively we created new markers of the WSN behaviour. FDN (First Node Die), HND (Half of the Nodes Die), TQD (Third Quarter of the Nodes Die), LNA (Last Node Alive) represent epoch IDs when first node, 50% of the nodes, 75% of the nodes and all



a) LEACH b) Direct Sequence (DS)

Figure 1: LEACH and Direct Sequence simulation case (N=157, m=0.5, a=1, v=0 m/s, g=0.1). Dark, dark gray nodes die first. Light gray, white nodes die last.



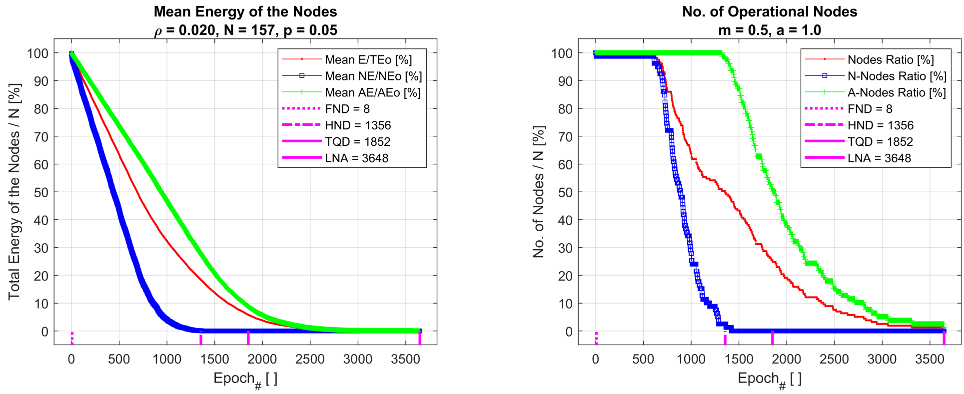
a) LEACH b) Direct Sequence (DS)

Figure 2: LEACH and Direct Sequence simulation case (N=157, m=0.5, a=1, v=10 m/s, g=0.9). Dark, dark gray nodes die first. Light gray, white nodes die last.

except one of the nodes loss all remaining energy, respectively. Velocity (v) denotes the speed of the mobile sink in meter per seconds. Aggregation level (g) describe the uniformity or heterogeneity of the gathered data. The higher the value of g the more heterogeneous is the data.

Different stages of the simulation with different set of parameters can be seen in Figure 1, where the sink node is static with velocity *v=0 m/s*. We can observe that the nodes positioned far from the Sink and having the distance greater than the threshold d_0 tend to die more quickly as they consume a large amount of energy in both LEACH and Direct Sequence (DS), each of the nodes in DS send his frame directly to the Sink node. No cluster creation or transit frame forwarding is executed by any of the nodes.

In the second set of figures (see Figure 2) the mobile sink in moving throughout the whole network area, crossing the circle from its radius with *v=10 m/s*, we can stat the inverse where the two protocols do not share the same behavior with velocity > 0. This is due to the characteristics of DS, when the data is transmitted from the node directly to the sink, we can observe a uniformly distributed energy consumption and the node close to the centroid and its vicinity die last. The



a) Energy decreasing of the NN, AN and total nodes

b) Number of residual NN, AN, and total nodes

Figure 3: Behavior of the LEACH wireless sensor network system ($N=157$, $\rho=0.020$, $m=0.5$, $a=1$, $p=0.05$, $v=10$ m/s, $g=0.1$)

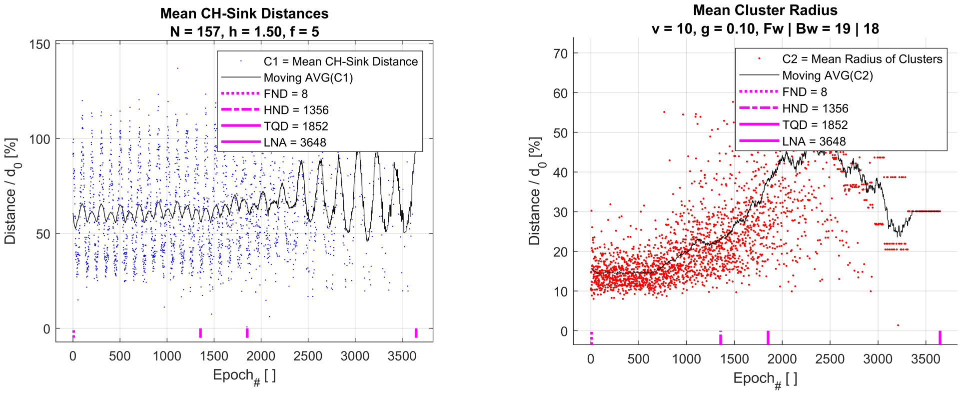
Data type	v=0 m/s		v=5 m/s		v=10 m/s		v=15 m/s		v=20 m/s	
Uniform Data: g = 0.1	FND	8	FND	8	FND	8	FND	9	FND	8
	HND	1159	HND	1368	HND	1356	HND	1325	HND	1348
	TQD	1447	TQD	1817	TQD	1852	TQD	1825	TQD	1777
	LNA	**3882**	LNA	**3615**	LNA	**3648**	LNA	**4488**	LNA	**4553**
Heterogenious Data: g = 0.9	FND	8	FND	9	FND	8	FND	8	FND	9
	HND	314	HND	487	HND	479	HND	490	HND	458
	TQD	435	TQD	626	TQD	631	TQD	658	TQD	645
	LNA	**2062**	LNA	**1528**	LNA	**1596**	LNA	**1322**	LNA	**1667**

Table 2: Correlation Between Epoch Metrics and Velocity

energy consumption for the transmission between the nodes decreases, helping to maintain longer lifetime. The mean energy ratio of the normal nodes *(NE / NE_0)*, the advanced nodes *(AE / AE_0)* and the total nodes *(E / TE_0)* of the corresponding subset's initial energy is shown in Figure 3.a. The number of residual NN and AN node is shown with blue and green curves in Figure 3.b.

First half of the flatted nodes depend slowly on the initial energy of the nodes, but in the second time period the AN node dies much more later than the NN nodes. The remaining energy of the AN and NN nodes decreases conform to two linear phases (see Figure 3.a). The number of operational nodes for both the NN and AN node sets is step-wise in time (see Figure 3.b).

In Figure 4.a, mean distance between CHs and Sink is relatively constant for the first half of the live nodes. This distance gets attenuated periodicity in the second half of the network life time because the Sink node is moving periodically. In Figure 4.b in the last quarter of the network life, the radius of clusters increases temporarily then decays because of the re-election of CHs that act upon the new topology as the network becomes disconnected, CHs will form to be in a one hope short distance from the Sink. Furthermore using a mobile sink will not only eliminate



a) Distance CH and Sink vs. epochs

b) Radius of clusters vs. epochs

Figure 4: Cluster behavior of LEACH wireless sensor network system (N=157, h=1.50, f=5, m=0.5, a=1, v=10 m/s, g=0.1)

the constraint of far nodes, but does provide a method for accessing and gathering data from disconnected network regions, thus increasing network life.

In Figure 5.a, we can observer that the energy of transmission is not constant and that the operational nodes die not homogeneously, some transmissions require more energy and others requires less energy.

In Figure 5.b, the number of clusters is constant with 8 clusters per epoch but starts to decreases in time. For the last 25 % of the operational nodes the CH election basic algorithm has epochs with no elected CH. In these epochs no message is sent to the Sink node, even if the ordinary nodes have frames to transmit. The number of sent messages to the Sink becomes smaller as the time elapse because the number of clusters decreases as well.

Based on the simulations with the parameter set given in Table 1., following assumptions can be stated in connection with the heterogeneous initial energy-based LEACH routing mechanism:

- The nodes situated far away from the Sink and having a gap greater than the d_0 threshold start dying faster because they lose a significant amount of energy in both LEACH and DS.

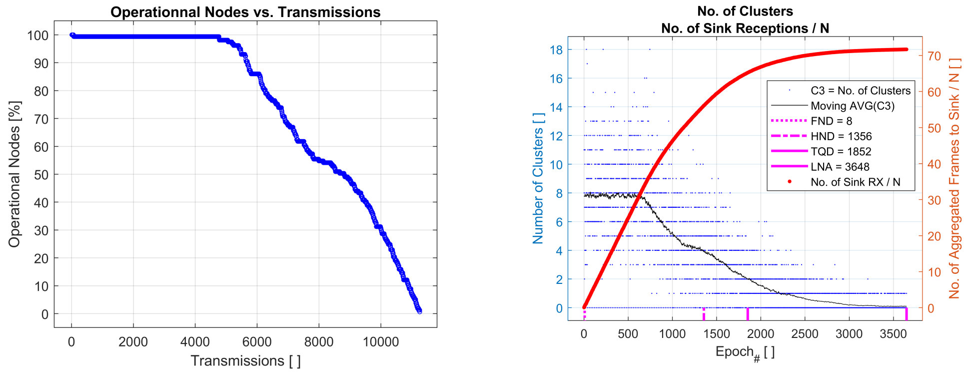
- Neither Leach nor DS protocol shares the same behavior when the Sink node is mobile. We state a uniformly distributed energy consumption and the node close to the centroid and its vicinity die last.

- The volume of operating nodes for either NN and AN node sets is step wise in time.

- The residual energy of the nodes AN and NN diminishes according to two linear phases.

- The greater the Sink node velocity the longer is the network longevity with uniform data (See Table 2.).

- Both LEACH and DS WSNs with fixed Sink node concentrate alive nodes



a) Operational Nodes vs. Transmissions

b) Number of Aggregated Frames to Sink/N vs. epoch

Figure 5: Activity of LEACH wireless sensor network system (N=157, h=1.50, f=5, m=0.5, a=1, v=10 m/s, g=0.1)

around the Sink. It can be seen on Figure 1.a and 1.b where the virtual energy mass point of the network represented by red line moves toward the Sink.

- Both LEACH and DS WSNs having mobile the Sink node maintain the virtual energy mass point of the network in the center of area (red dot in the center of circle).

- LEACH WSN with mobile Sink consumes energy uniformly for both normal and advanced energy nodes, but in case of DS WSN first die all of normal energy nods and just after it start to elapses the energy of advanced nodes.

5. Conclusions and Future Work

In this work, we investigate the heterogeneous protocol LEACH with our own developed simulation software. Two groups of nodes were included with different initial energies Normal Node (NN) and Advanced Node (AN) to find behavioral impacts of the Sink mobility. It was found that with the introduction of the Sink mobility the result was, an enhanced network lifetime and a uniformly distributed energy consumption for both LEACH and Direct Sequence routing protocols.

It is necessary to extend and take advantage of the Sink mobility, a solution would be to program the Sink node to be mobile and a Cluster Head at the same time and to find the optimal trajectory of the Sink as a continuation of this work in the next research time period.

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References

[1] Heinzelman, W. B, Chandrakasan, A. P., An application-specific protocol architecture for wireless micro sensor networks, *IEEE Transactions on Wireless Communications* Vol. 1 (2002), 660–670.

[2] Moh'd Alia, O., Dynamic relocation of mobile base station in wireless sensor networks using a cluster-based harmony search algorithm , *Information Sciences*, (2017), 76–95.

[3] Kim, J., In, J., Hur, K., Kim, J., & Eom, D., An intelligent agent-based routing structure for mobile sinks in WSNs, *IEEE Transactions on Consumer Electronics* Vol. 4 (2010), 2310–2316.

[4] Liang, W., Luo, J., & Xu, X., Prolonging network lifetime via a controlled mobile sink in wireless sensor networks, *IEEE global telecommunications conference GLOBECOM* (2010), 1–6.

[5] Salarian, H., Chin, K.W., & Naghdy, F., An energy-efficient mobile-sink path selection strategy for wireless sensor networks, *IEEE Transactions on Vehicular Technology* (2014), Vol. 63 2407–2419.

[6] Ismat, N., Qureshi, R., & Mumtaz, I., Efficient Clustering for Mobile Wireless Sensor Networks, *17th IEEE International Multi Topic Conference* (2014), 110–114.

[7] Zhou, Z., Du, C., Shu, L., Hancke, G., Niu, J., & Ning, J., An Energy-Balanced Heuristic for Mobile Sink Scheduling in Hybrid WSNs, *IEEE Transactions on Industrial Informatics*, Vol. 12 (2016), 28–40.

[8] Thakur, M., Mobile Sink Based NLEACH Protocol by using Ant Colony Optimization, *International Journal of Science Research and Technology*, Vol. 2 (2016), 1–10.

[9] Chi, Y., P., Chang, H., P., An energy-aware grid-based routing scheme for wireless sensor networks, *Telecommunication Syst*, (2013).

[10] Gal, Z., Korteby, M., A., Energy Sparing of the Leach Communication Mechanism in Heterogeneous WSN, *8th International Conference on Advanced Computer Science and Information Technology*, (2019), 53–64.

[11] Abo-Zahhad, M., Ahmed, S. M., Sabor, N., & Sasaki, S., Mobile sink-based adaptive immune energy-efficient clustering protocol for improving the lifetime and stability period of wireless sensor networks, *IEEE Sensors Journal*, Vol. 15 (2015), 4576–4586.

[12] Ghosh, N., & Banerjee, I., An energy-efficient path determination strategy for mobile data collectors in wireless sensor network, *Computers & Electrical Engineering*, Vol. 48 (2015), 417–435.

[13] Khan, A. W., Abdullah, A. H., Razzaque, M. A., & Bangash, J. I., Vgdra: A virtual gridbased dynamic routes adjustment scheme for mobile sink-based wireless sensor networks, *IEEE Sensors Journal*, Vol. 15 (2015), 526–534.

[14] Moh'd Alia, O., Dynamic relocation of mobile base station in wireless sensor networks using a cluster-based harmony search algorithm, *Information Sciences*, (2017), 76–95.

[15] Wang, J., Cao, Y., Li, B., Kim, H. J., & Lee, S., Particle swarm optimization based clustering algorithm with mobile sink for WSNs, *Future Generation Computer Systems*, Vol. 76 (2016), 452–457.

[16] Salarian, H., Chin, K. W., & Naghdy, F., An energy-efficient mobile-sink path selection strategy for wireless sensor networks, *IEEE Transactions on Vehicular Technology*, Vol. 63 (2014), 2407–2419.

[17] Baljinder, S., Amit, V., Manit, K., A survey on various energy-efficient routing protocols in WSN, *International Journal of Advanced Research, Ideas and Innovations in Technology*, Vol. 4 (2019), 862–865.

[18] Harjit, S., Varun, S., Energy Efficient Clustering for Network Stability and Longevity for Heterogeneous Wireless Sensor Network, *International Journal of Engineering Science and Computing*, Vol. 8 (2018), 18867–18872.

[19] Mittal, N., Singh, U., Sohi, B., A stable energy efficient clustering protocol for wireless sensor networks, *Wireless Networks*, Vol. 23 (2017), 1809–1821.

[20] Preeti, Belwal, M., Energy Efficient LEACH and Improved LEACH: A Review, *International Journal of Advanced Research in Computer Science*, Vol. 10 (2019), 51–52.