ENERGY SPARING OF THE LEACH COMMUNICATION MECHANISM IN HETEROGENEOUS WSN

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ABSTRACT

In current years, there have been a large progress in Wireless Sensor Networks (WSN) due to their development in term of hardware and cost reduction. Plenty of routing protocols have been proposed and developed depending on the application and network architecture. One of the most efficient energy management of the wireless sensor networknodes is provided by the LEACH (Low Energy Adaptive Clustering Hierarchy) mechanism. This hierarchical protocol uses cluster head function of the nodes to aggregate and forward the messages from the cluster members to the Sink node. Each node decides to become cluster head stochastically in each epoch time intervals. Nodes have enough energy to reach directly through radio channel any of the nearest cluster nodes, as well as the sink node. Optimization algorithm is required to provide efficient energy consumption on the WSN clusters level. A node being cluster head in the actual epoch time can repeat this function just with a probability p in time. Classical nodes find the nearest cluster head to minimize the transmission energy consumption and use time division multiple access method (TDMA)to send the radio frames in each epoch time. In this paper we use own developed simulation method and software to analyze the remaining energy process in time of the whole WSN network and the number of forwarded frames in function of the probability p for a set of nodes having heterogeneous levels of the initial energy.

KEYWORDS
Internet of Things (IoT), Wireless Sensor Network(WSN), Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, radio communication, energy sparing, stochastic process.

1. INTRODUCTION

The wireless sensor network is a system with high number of sensor nodes apt to sense, process and communicate in a reduced domain. These sensors are spread in large territory and the connection to the wireline network is provided by one or more Sink nodes [1]. WSNs have diverse application possibilities, like monitoring the temperature, the pressure, the humidity, the habitat or catastrophe management, military reconnaissance, forest fire supervision, security surveillance, etc. In the most cases these sensor nodes are installed in random geographic coordinates with finite energy sources. The efficient forwarding of the sensed data to the destination requires optimal WSN routing mechanism. Majority of such protocols differ from the classical routing mechanisms applied in the Internet because the most important WSN routing metric is the energy usage instead of the quality of service (QoS) aspects (delay time, jitter, bit error rate, transmission rate) used for the classical IP networks. Because the replacement or recharge of the WSN batteries for spread WSN nodes is not possible in practice very low energy consumption strategies of WSN nodes is required. High number of low energy-based routing strategies exist where the solution depends on the application and network architecture. Issues of such routing protocols are energy sparing, low transmission rate, low processing capacity, extra processing task for non-unified addressing scheme, self-organization of the sensors [2].

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WSN applications can be classified into two main categories:

1.Tracking Applications: One of the most important applications in WSN in which sensor nodes monitor and report the positions of moving objects to the application's user with a minimum latency [3].

2.Environment Monitoring: Requires sensor devices to be deployed within the system. These sensors will be the entities responsible for measuring the parameters of interest, like temperature, water level or salinity, health care, humidity and flood detection [4].

A sensor node has numerous subsystems like sensing and data acquisition unit (DAU), data processing and control unit, communication unit and power, supply and power management unit. Architecture design of a WSN Node should address the technical requirements of each subsystem and whole system [5].

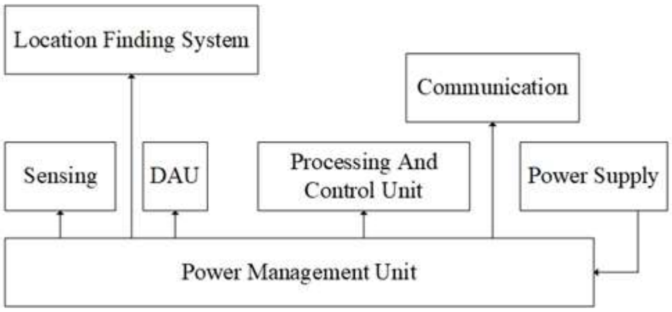

Figure 1. General Components of Wireless Sensor Node

The classification of the routing protocols is based on four orthogonal aspects: Structure of the network, topology,communication model and reliability [6]. Two routing categories exist based on the node deployment: single level and multiple hierarchical levels routing protocols. In the former case all the sensor nodes have uniform functionality,used in small area networks, the main problem of this type of routing is the leak of scalability, making usable for systems with low number of nodes. Flooding and Gossiping [7], Directed diffusion [8], Rumor [9], SPIN [10] are the most popular single level routing protocols. Hierarchical routing use more efficiently the energy and suchmechanismshas better scalability. In hierarchical systems the whole network is organized in clusters. Each cluster has a head (CH – cluster head) elected on special criteria. Members of the cluster send their messages to the CH which aggregates and compress the messages and forward to the Sink node. Because the CH has extra tasks of aggregation and compression, energy usage by this is higher than for the member nodes. For very high population of nodes multiple hierarchy-based clustering is proposed. In such systems cluster_{i+1} of the set of CH_i nodes is created reducing the transmission distance to the Sink node and reducing implicitly the energy usage for the transmission, as well. The optimum number of hierarchies depends on multiple factors like propagation conditions, number of nodes, CH election algorithm, etc.

This paper has following structure: in the second chapter main aspects of the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol are presented. Related work of the basic LEACH mechanism is given in chapter three.Behavior of the LEACH communication mechanism based wireless sensor network with inhomogeneous initial energy level nodes were analyzed with simulation method and the experienced features are discussed in chapter four. Last chapter concludes the results and gives possible continuation targets of the topic.

2. MAIN ASPECTS OF THE LEACHMECHANISM

The LEACH (Low Energy Adaptive Clustering Hierarchy) protocol invented by Heinzelman is a hierarchical WSN routing mechanism where the cluster head (CH) election is based on the energy level of the nodes. In the original version [11] one level of clusters exits, but several modifications were proposed for multiple hierarchy levels, as well. The local CH function is to act as a special relay to forward the messages received from the cluster members to the unique Sink node of the WSN. Considerable number of enhancement proposals were made in the last decade and good surveys exist in this topic [12]. In the next part of the paper we highlight just the main features of the basic version to highlightthe essence our proposal and its influences to the behavior of the LEACH mechanism.

The main goal of the LEACH protocol is the energy sparing based on random election of the CH nodes from the whole WSN in consecutive epoch times. Each CH has own cluster with zero or higher number of node members. The mechanism has two alternating phases during one epoch time interval [13] [14]:

a) Set-up phase: In this phase are elected the heads of the clusters and assignment of the member nodes to the clusters. Signaling and communication between the CH and the members is executed with Time Division Multiple Access (TDMA) or Code Division Multiple Access (CDMA). WSN nodes takes 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 thresholdT_n, then the node becomes head. The value of threshold is modified conform to the following formula:

$$T_n = \begin{cases} \frac{p}{1-p\cdot(epoch_{\#}\ mod\ \frac{1}{p})} & ,\ if\ n\ \in G \\ 0 & ,\ otherwise \end{cases} \qquad (1)$$

where p is the maximum ratio of the CH nodes in the WSN, $epoch_{\#}$ is the ID of the actual epoch time and G is the set of nodes not taking part in the CH election process in the last 1/p number of epoch intervals. When a node is elected CH no possibility exists for that node to become CH again in the next 1/p number of epochs. Based on this rule any of the nodes can become CH with the same probability, making uniform on WSN level the extra energy consumption 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 join. 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, the active and the sleeping states of the members during each epoch time.

b)Steady phase: Members of the same cluster use TDMA (during the time slot) and CDMA (chip code) mechanisms to send their message to the CH without collision[16] [17]. 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 [15]. The nodes are in sleeping mode during the inactive communication time intervals to increase their life time.

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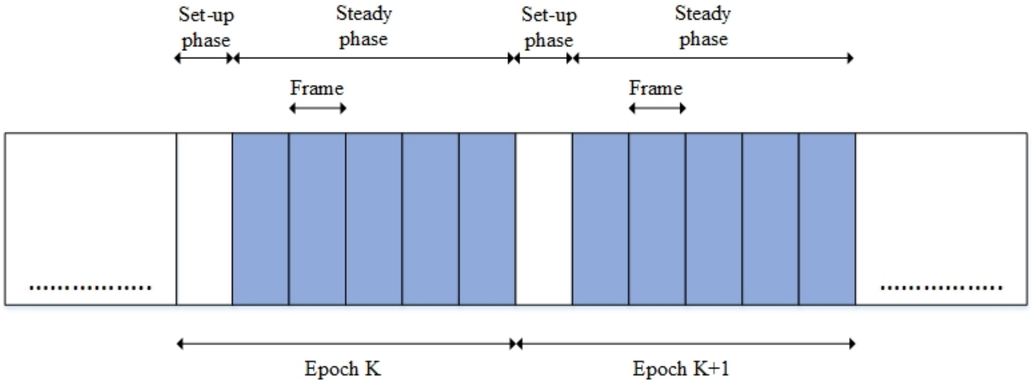

Figure 2. LEACH operation: the set-up and steady phase

However, the basic LEACH protocol has significant energy sparing properties the CH election mechanism requires enhancement for better efficiency.Because the number of clusters changes from epoch to epoch the optimal distance to the closest CH for the ordinary nodes varies in time and no guarantee exist that the overall energy consumption of the WSN is minimal during the life tm interval. Election of the CH function does not depend of the actual energy status of the node, implying risky situation for the whole cluster to not to have enough energy to transmit the aggregated frames to the Sink node. Advantages and disadvantages of the classical LEACH protocol is given in Table 1. [12].

Table 1. Advantages and disadvantages of the classical LEACH protocol

Advantages	
Characteristic	**Aspect**
Intensity of the Node – Sink communication	Low
Aggregation possibility of the locally correlated data	High
Energy sparing effect of the sleeping time intervals	High
Fairness channel access	Guaranteed

Disadvantages	
Characteristic	**Aspect**
Probability to become CH of a cluster	Independent of the energy level
Number of clusters on a given epoch time	Non-uniform and superior limited
Geographic position of the CH in the cluster	No closed to the mass point
CH-Sink distance	1 Hop

3. RELATED WORKS OF THE BASIC LEACH MECHANISM

Cognitive radio sensor network (CRSN), also called Cognitive LEACH (CogLEACH) [18] is a spectrum aware algorithm. The probability P_i for each node to become a CH take into consideration the number of idle channels as a weight. CogLEACH improves the lifetime and the throughput of the network when comparing to basic LEACH. However, the network suffers from uneven energy consumption and load balance due to not considering the residual energy of individual nodes during the CH selection process.

Mahmood *et al.* [19] proposed a new variant of LEACH protocol named Modified LEACH (MOD-LEACH). Instead of using the same communication signal in intra and intercluster, the new modified protocol uses two different signal amplification for the two type of communication to save a significant amount of energy. Another modification is, the way the CH changes from one epoch to another, in MOD-LEACH, the same CH selection algorithm is used but not in every epoch. When anepoch ends, the CH checks its residual energy, if it is below a predefined threshold, the CH changes and a new CH selection starts. On the contrary, the CH remains; no changes are needed, and the energy consumption reduces. The protocol has better performance considering the energy consumption and network lifetime compare to LEACH, but it is not suitable for periodically sensing data in WSN.

Vice Cluster LEACH (V-LEACH) [20] consider having two CHs instead of one in each cluster. The first type is the usual CH which receives data from member nodes and the second type is a vice CH which act as a CH when the original CH dies before the completion of the current epoch, it is elected by calculation the residual energy of the nodes and the one with the most residual energy play as vice CH. The election procedure and the steady phase of V-LEACH are the same as in basic LEACH. This protocol has a relatively good data delivery success rate because of the two CHs use but it causes overhead and scalability problems.

The auteurs in [21] thought of a completely different approach when dividing the network using hexagonal cells for better network coverage. Cell-LEACH (C-LEACH) protocolforms a cluster when seven nearby cells are connected, each cell has a specific node called cell head and other normal nodes called cell members. A cluster of seven cells has its own CH. The cell members transmit their data during an allocated time slot using TDMA scheduled by the cell head. The same idea is used when sending the data from cell heads to CHs. During data transmission, all the cell is shut down, except for the cell member that send the data to the cell member which in return aggregate the data and direct the aggregated data its CH. Shortest path algorithm is used to transmit the aggregated data from the CH to the BS. This protocol is famous for its network coverage considering the use of hexagonal cells, its scalability, and energy efficiency. Figure 3 shows the hexagonal cells and data packets forwarding.

Orphan-LEACH (O-LEACH) [22] considers nodes that are not connected to any CH as orphan nodes. In a first scenario, a node member of a cluster is used as a gateway of last resort for orphan nodes. The orphan nodes send join and send the data to the gateway node, the later aggregates the data and send it back to the BS using a single hope connectivity. In a second scenario, the orphan nodes form a sub-cluster and select a CH depending on the shortest path to the gateway node. The CH collects the data from the orphan nodes and transmits it to the gateway. O-LEACH maintains a high connectivity rate,

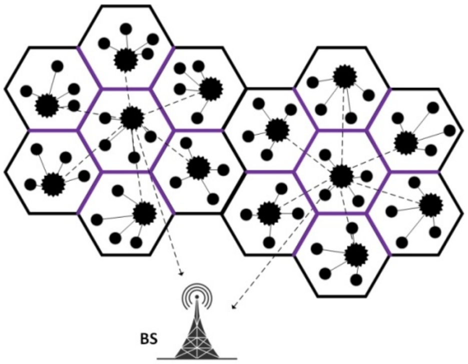

Figure 3. Hexagonal cells and packets forwarding from CH to BS

great coverage area, and grant scalability. However, data delivery delay, overhead and finding orphan nodes' information are the main problems of the protocol.

4. SIMULATION SCENARIOS AND ANALYSIS RESULTS

It was developed own simulation software to test the behavior of the LEACH mechanism for different set of parameters. We considered a number of N sensor nodes spread in random geographic coordinates of a square area. The Sink node is placed in the North pole of the vertical

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symmetry axe. The simulations were executed with two subsets of the WSN nodes. Normal Nodes (NN) and Enhanced Nodes (EN) have Eo and $(a+1)\cdot Eo$ initial energy levels, respectively where$a$ is the energy factorof the advanced nodes and $a > 0$. The population of these subsets are $m \cdot N$ and $(1-m)\cdot N$, respectively, where $m \in [0, 100\%]$. The initial energy (NEo, AEo, TEo) of the subsets and the whole WSN is given by the next formulae:

$$AEo = m \cdot n \cdot (a+1) \cdot Eo \qquad (2)$$

$$NEo = (1-m) \cdot n \cdot Eo \qquad (3)$$

$$TEo \; = \; AEo + NEo = (a \cdot m + 1) \cdot n \cdot Eo \qquad (4)$$

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

$$A(d) = \; ERx(d)/ETx(d) = \begin{cases} 1 & if\ d\ \in [0, \delta) \\ (\delta/d)^2 & if\ d\ \in [\delta, d_0) \\ (\delta/d)^b & if\ d\ \in [d_0, \infty) \end{cases} \qquad (5)$$

where $ERx(d)$ and $ETx(d)$ are the received and transmitted energy to distance d, respectively. δ and $d_0$are the radio antenna size (in the range of centimetres) at the transmitter and the threshold distance between the source and destination, respectively. Parameter b is the path loss exponent (path attenuation) which includes the effect of the physical environment to the radio channel, where $b \in (2, 4)$.

During the graphical representation of the simulation process we used specific notations. Small and large rings represent NN and EN nodes, respectively. Node with character "+" inside is dead because all its battery was flatted. The biggest red ring is the Sink node and rings with red color represent CH nodes. The circle arc with dashed line on Figure 4. represents the distance threshold d_0 and has effect on the radio energy attenuation during the transmission between the nodes conform to relation (5). Simulation cases with different values of the parameters are given in the Table 2. Should be observed that we used fixed sized (500 bytes) radio messages, so we are not dealing yet in the actual phase of the research with the statistical aspects of the frame size influences to the energy sparing. This aspect will be analysed in the next research phase.

All the simulation cases were executed holding a special term: the initial energy of the WSN was the same. This condition was guaranteed by setting both Eo and $(a \cdot m + 1) \cdot n$ terms constant in the equation (4).

Table 2. Parameters of the heterogeneous LEACH system simulation

Parameter	**Value(s)**
Physical area size	100 m x 100 m
Physical position of the Sink node	50 m to North on the vertical symmetry axe
Number of nodes of the WSN	N = 115 … 400
Ratio of the AN nodes to the total nodes N	m = 0.3 ; 0.4 ; 0.5
Radio frames length	Fs = 4,000 bit
Energy factor of the AN	a = 1 ; 3 ; 7
Ratio of the CH nodes	p = 10 %

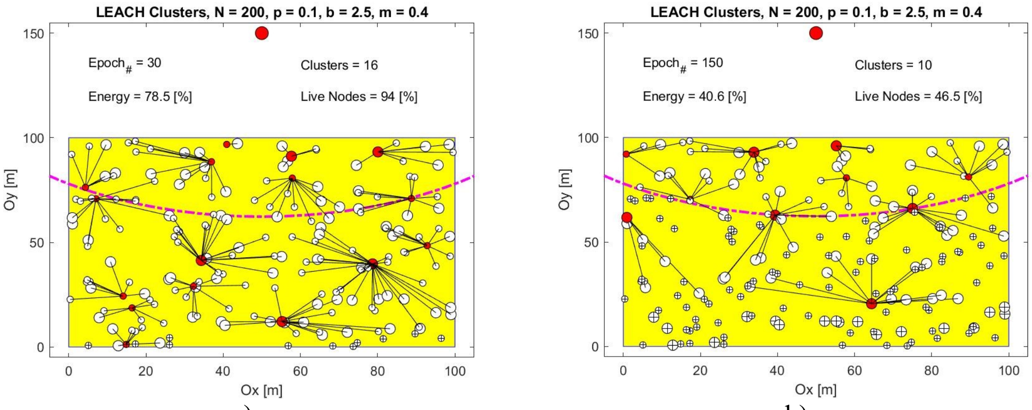
Parameter	**Value(s)**
Initial energy unit	Eo = 0.25 J
Energy consumption of the electronics	Eelec = 50 nJ/bit
Energy consumption of the antenna amplifier	Eamp = 0.1 nJ/bit
Energy consumption of the frame aggregation	EDA = 5 nJ/bit
Radio antenna size	δ = 0.1 m
Radio channel distance threshold	d_0 = 87.7 m
Path loss exponent	b = 2.5 ; 3.5

Different phases of the simulation for a set of parameters can be seen on Figure 4. Compact regions were created at the beginning but because CHs were placed far from the Sink node they consume large amount of energy and the number of running CH nodes decreases quickly (see Figure 4.a, Figure 4.b). The remaining nodes are included in clusters with bigger radius (see Figure 4.c), therefore the energy of the ordinary nodes decreases quickly, as well. Nodes having distance to the Sink greater than the threshold distance d_0 die more rapidly (see Figure 4.a, Figure 4.b, Figure 4.c). Nodes placed to the Sink node closer than d_0 are closed to each other and to the elected CH node, too, therefore the energy consumption for the transmission between the nodes decreases, helping to maintain longer life time. In these epochs the number of remaining active nodes decreases slowly in time (see Figure 4.d). In these epochs larger number of frames are able to send to the Sink node.

To visualize the details of the communication process much more intensively we created new markers of the WSN behavior. FDN (First Node Die), HND (Half of the Nodes Die), TQD (Third Quarter of the Nodes Die), LND (Last Node Die) represent epoch IDs when first node, 50% of the nodes, 75% of the nodes and 100% of the nodes loss all remaining energy, respectively (see Figure 5, Figure 6).

Ratio of the mean energy of the normal nodes (NE/NEo), advanced nodes (AE/AEo), and total nodes (E/TEo) to the initial energy of the corresponding subset, respectively is given on Figure 5.a. The number of remaining NN and AN node is given with blue and green curves, respectively on Figure 5.b. The geometry of the curves belonging to these ratios are explained above. The distance of the CH to the Sink node and the radius of the clusters is represented on Figure 5.c. When the cluster has just the CH without ordinary member nodes the radius becomes zero. Such situations appear intensively for low number of active nodes. The red dots of the mean CH-Sink distance suggest Gauss distribution. The number of clusters, the theoretical and the realistic receptions by the Sink node is given in Figure 6.a. As the number of clusters become smaller the number of aggregated frame receptions by the Sink node becomes flatted. This reduction of the frame reception is caused by the increased blocking effect of the CH election when the number of live nodes becomes low.

To understand more deeply the efficiency of the LEACH protocol we compared the collected simulation values with a WSN system having direct sequence communication. In this case each of the nodes send his frame directly to the Sink node. No cluster creation or transit frame forwarding is executed by any of the nodes. The number of transmissions executed by active nodes is limited with the probability parameter $p,\ p \in (0, T_n)$, where T_n is the threshold given in formula (1). Each node waits an epoch times greater or equal than $1/p$ to be able to send a new frame to the Sink. The comparison results are represented on Figure 6.b.



a) b)

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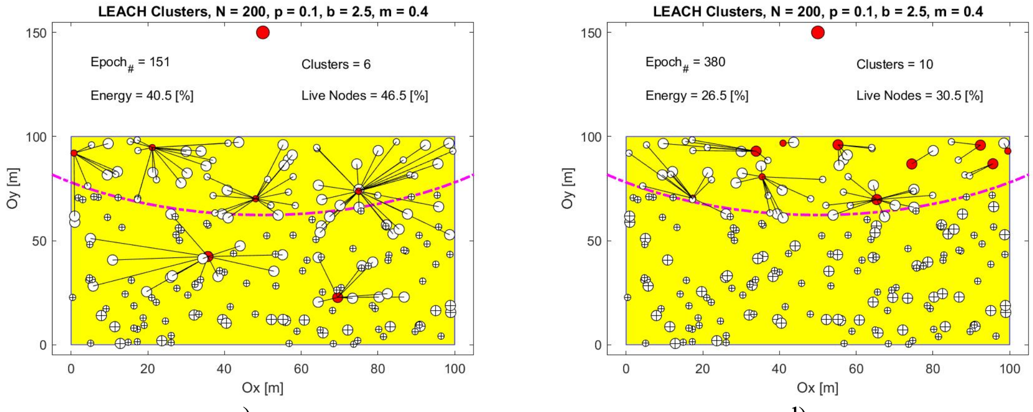


c) d)

Figure 4. Simulation of the LEACH WSN system for four different epoch times (N = 200; p = 10%, b = 2.5; m = 0.4; a = 3). Yellow area represents the sensors region in uniform randomly distributed physical coordinates. The cluster heads (CH) have red colour. Nodes with small or large circles have normal or enhanced initial energy, respectively. Character „+” represent dead node because of energy flatting.a) Epoch = 30; b) Epoch = 150; c) Epoch = 151; d) Epoch = 380.

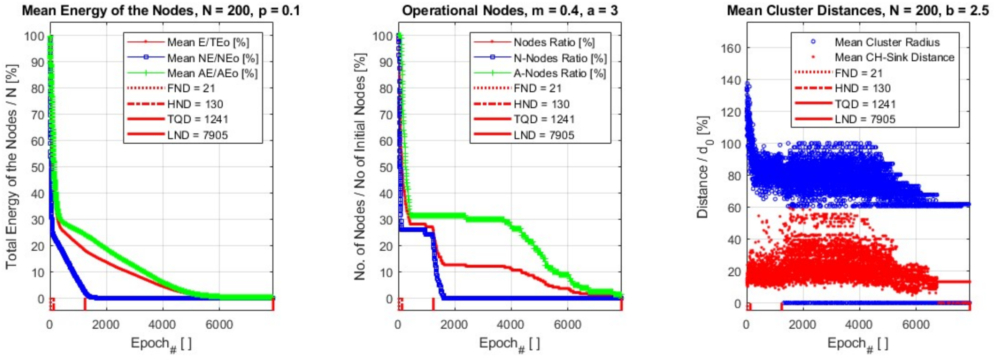
Based on the simulations with the parameter set given in Table 1., following assumptions can be stated in connection with the heterogeneous initial energy-based LEACH routing mechanism:

1) 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 5.a).

2) The number of operational nodes for both the NN and AN node sets is stepwise in time (see Figure 5.b).

3) Majority of the mean radius of the clusters is around the 80% of the threshold distance d_0 of the radio transmission system, but when the number of remaining nodes becomes small this main radius decreases to 60 % of the d_0. The mean distance of the CHs to the Sink nodes decreases in time because the LEACH mechanism depletes more intensively the energy of the nodes placed far from the Sink (see Figure 5.c).

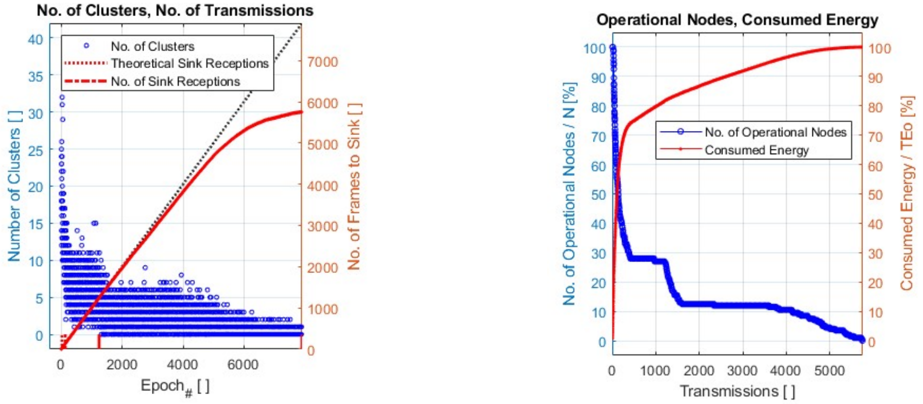
4) The number of clusters is randomly but decreases in time. For the last 25 % of the operational nodes the CH election basic algorithm has epochs with no elected CH. In these epochs no message is sent to the Sink node, even the ordinary nodes have frames to transmit. The number of sent messages to the Sink becomes smaller as the time elapse because the number of clusters decreases, as well (see Figure 6.a).



a) b) c)

Figure 5. Behavior of the LEACH WSN system (N = 200; p = 10%, b = 2.5; m = 0.4; a = 3).
a) Energy decreasing of the NN, AN and total nodes;
b) Number of reaming NN, AN, and total nodes;
c) Radius of the clusters and average of the distances between the CH and Sink.

5) The necessary energy to transmit aggregated frames to the Sink becomes smaller as the time elapses because the remaining active nodes are closer to the Sink node. At the beginning of the frame transmissions a relatively constant energy consumption exits, then this consumption enters into another smaller and decreasing consumption phase. Far nodes die first (see Figure 6.b).



a) b)

Figure 6. Behavior of the LEACH WSN system and comparison to the Direct Sequence WSN (N = 200; p = 10%, b = 2.5; m = 0.4; a = 3).
a) Number of clusters and number of frames received by the Sink node (LEACH WSN);
b) Dependence of the operational nodes and the remaining energy (DS WSN).

6) The message transmissions by the Direct Sequence (DS) WSN are executed much slowly (30,067 epochs) representing 423% of the LEACH WSN transmissions (7,095 epochs). For the same initial energy of the both WSN systems (LEACH and DS) the number of transmitted frames for DS is just 60 k, representing just 35 % of the 17 k frames sent by the LEACH mechanism (see Figure 7.a).

7) DS WSN is not able to use all the own energy because far nodes from the Sink cannot transmit their frames with the last fragment of their energies. At the end of 30 k epochs the consumed energy of the DS WSN is just 95 % of the initial energy. After a quick decrease to 50% of the DS operating nodes transmission of frames is executed with

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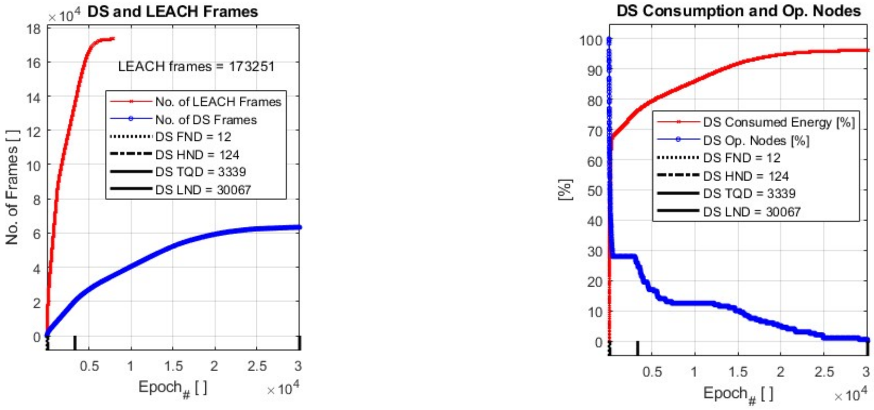
constant number of nodes, then the last 25 % of thesenodes decreases uniformly (see Figure 7.b).



a) b)

Figure 7. Comparison of the LEACH WSN and DS WSN systems
(N = 200; p = 10%, b = 2.5; m = 0.4; a = 3).
a) Number of frames received by the Sink for LEACH WSN and DS WSN;
b) Energy consumption and No. of nodes for DS WSN.

8) The initial energy factor a of the AN advanced nodes has no effect to the number of operational nodes at the beginning of the simulation, but its influence becomes considerable for the last 10% of the live LEACH WSN nodes. Ratio m of the AN nodes to the total number of nodes has lower impact as parameter a to the total number of operational nodes.(see Figure 8).

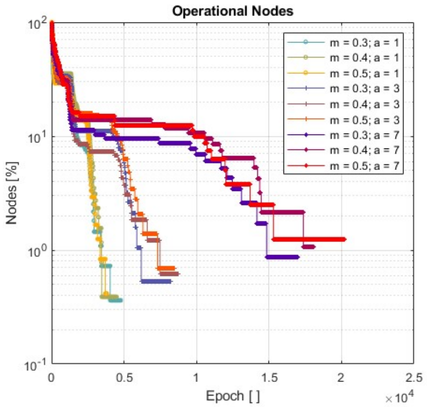


Figure 8. Behavior of the LEACH WSN system for different parameters
(p = 10 %; b = 2.5; m = 0.3, 0.4, 0.5; a = 1, 3, 7).

9) The greater is the initial energy factor a of the AN advanced nodes, the longer is the live cycle of the LEACH WSN system. The lower is the ratio m of the AN nodes to the total number of nodes, the shorter is the live cycle of the LEACH WSN system. This is caused by the larger initial number of nodes providing same initial energy of the system(see Figure 8).

5. CONCLUSIONS

In this paper we analyses the heterogeneous LEACH WSN protocol with own developed software. We included two classes of nodes having different initial energy, Normal node (NN) and Advanced Node (AN) in order to find behaviorinfluences of different parameters (number of nodes, ratio of the number of AN to the total number of nodes, ratio of CH nodes, path loss exponent, etc.). There were found important characteristics of the usage efficiency of the communication energy, dependency on the spatial distribution of the sensor nodes. Because the basic LEACH protocol does not take in consideration the remaining energy of the nodes during the cluster head election, nodes with small amount of energy may become CH with extra energy consumption making faster the battery flatting of such nodes. These enhancements of the LEACH performance are induced by the aggregation possibility, as well. It is necessary to extend the intelligence of the basic CH election mechanism and to find the optimal level of cluster hierarchies as a continuation of this work in the next research time period.

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