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Analysis of energy efficiency for the extended WSN using a multilevel HEED protocol

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ABSTRACT: The energy consumption is always unbalanced between nodes in any wireless network. That decreases its lifetime and its performance. Deployment of nodes, as an essential operation that can prolong the network lifetime and improves its functioning, can be influenced by the residual energy of these nodes. In order to solve this problem, we combine in this paper, the scheme effect of this deployment with a good chosen hierarchy protocol in wireless sensor networks. We take residual energy into consideration in our improved HEED algorithm to balance the energy consumption of the network. For n level of energy, this protocol is denoted by MLHEED-E. Thus, it's denoted by MLHEED-S for n level of space. For all level heterogeneity, this protocol becomes MLHEED-SE. It's depended on space and energy. We illustrate therefore a network model up to five levels. Experimentally, as the level of heterogeneity increases, the rate of energy dissipation decreases and hence the nodes stay alive for longer time. In best situations, the protocols MLHEED-S, MLHEED-E and MLHEED-SE increase the network lifetime by 25%, 50% and 44.44% respectively. They increase the network's packets sent between 8% and 101%, compared to the original HEED protocol.

KEY WORDS: Heterogeneity, Network lifetime, HEED, Multilevel, Energy efficiency, WSN

I. INTRODUCTION

A WSN is a collection of autonomous self-organized sensor nodes that communicate via wireless medium [1]. Each node in WSNs has limited resources, including low wireless communication bandwidth, low processing capability, small memory, and an inadequate non-rechargeable battery [2]. Each sensor has a function to sense an event measure, such as temperature, pressure or vibration and send their measurements toward a processing center called sink [3, 4]. Nodes clustering are an effective technique for improving the energy efficiency and prolonging the lifetime of a WSN [5]. The cluster head is responsible for reducing redundant data and apply aggregation techniques that minimizing the data size and forward it to the BS [6].

One of the dominant issues in a WSN is to develop an energy efficient protocol, which can have a momentous impact on the network lifetime and stability [2,7,8]. In extended spaces, the homogenous wireless sensor networks suffer of great energy leakages [9]. Therefore, multilevel scheme has been created in order to decrease energy consumption of network and to improve the performance of protocols [10,11].

The rest of the paper is organized as follows. Section 2 shows a brief description of the related work performed on the HEED protocol. Section 3 presents network model and assumptions. Simulation results and analysis are discussed in Section 4. Finally, the conclusion is introduced in Section 5.

II. COMPREHENSIVE THEORETICAL BASIS

In [9], authors study the protocol LEACH, applied in an homogeneous WSN with two-level of nodes density. In [10], they discuss the MLHEED, a multilevel heterogeneous network model applied in HEED protocol. In the paper [11], they examine the LEACH-*n*Level, which considers the homogeneous WSN, in extended spaces and with multilevel of nodes density. In the paper [12], they discuss the LEACH-C, an enrichment over the LEACH protocol, by diffusing the cluster heads all over the network so that it can produce better performance.

ISSN: 2350-0328
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Some heterogeneity-aware protocols such as SEP [13,14] and DEEC [15] are specially designed for heterogeneous WSNs. SEP is aimed at prolonging the stability period of two-level heterogeneous networks, which consist of two types of nodes according to the initial energy, i.e., normal nodes and advanced nodes. For SEP, the CH rotating epoch and election probability are directly related to the initial energy of nodes. As opposed to SEP, DEEC further improves the functions of election probability by considering both the initial and residual energy of the network. It achieves better performance than SEP in a multi-level heterogeneous WSN. Unfortunately, DEEC can't be used when the sink node is located far from the sensor nodes since it is working under the assumption that sink node is located in the center of the WSN.
Farouk et al. discuss a stable and energy-efficient clustering (SEEC) protocol and extend it to multi-level SEEC [16]. It depends on network structure that is divided into clusters. Each cluster has a powerful advanced node and some normal nodes deployed randomly in this cluster. In the multi-level architectures, more powerful supper nodes are assigned to cover distant sensing areas. Each type of nodes has its role in the sensing, aggregation or transmission to the base station. Singh et al. discuss an energy efficient clustering protocol using fuzzy logic for heterogeneous WSNs [17]. It considers four parameters, i.e., residual energy, node density, average energy, and distance. It applies fuzzy logic to determine the cluster heads. In this protocol data may be lost if cluster heads are not able to communicate with each other. Paper [18] presents a new approach for splitting the whole sensor network into several levels using two techniques, a static one and a dynamic one. The paper [19] takes residual energy into consideration in improved CFSFDP-E algorithm so as to ultimately balance the energy consumption of the network. It analyzes different forms of energy and chooses a dynamic threshold for each round in the CFSFDP-E algorithm.

III. PROPOSED AND RESEARCH METHOD

In this paper, we have focused on the concept underlying the multilevel deployment scheme in the 11th reference and the multilevel energy scheme developed by S. Singh [10]. We have extended their work to evaluate the influence on performance of over the HEED protocol. Therefore, we have proposed new protocols. They are depended on [11] for 2D dense WSN (MLHHED-S), on [10] in extended space (MLHEED-E) and finally on the combination of the two previous protocols (MLHEED-SE).The basic assumptions made for the network in our model, are as follows (see figure 1):

- All sensor nodes and base station are stationary after deployment; each is identified by a unique ID.
- Nodes are location unaware, i.e. they are not equipped withGPS-capable antennae.
- All nodes have similar capabilities, but are different in terms of energies in case of heterogeneity.
- Nodes are left unattended after deployment, meaning thereby the battery recharge is not possible.
- There is only one BS located at the center in network, which has a constant power supply; thus, there is no energy, memory and computation constraint.
- Each node has the ability to aggregate data; as a result several data packets can be compressed as one packet. The distance among the nodes can be computed based on the received signal strength.
- Nodes have the capability of controlling the transmission power, according to the distance of receiving nodes. The failure of each node is only considered due to depletion of its energy.
- The radio link is symmetric such that energy consumption of data transmission from node A to node B is the same as that of from node B to node A.
- Nodes in the network can be homogeneous or heterogeneous, but not chargeable.
- Unlike the authors in [10], we will take into consideration that all networks start with the same initial energy. This could be the preferred condition to evaluate the ability of network to manage this energy until the end of operation.

The multilevel deployment in space for HEED (MLHEED-S) describes a homogeneous wireless sensor network that consists of *n* levels of deployment of sensor nodes in space, based on the distance from base station. The levels having larger distance of base station are supposed to have less density of nodes than those having shorter distance. We assume that the WSN has N as a number of nodes out of which $\delta_i * N$ nodes exist in level *i* of space, where: $0 < \delta_i < 1$ and $\sum_i^n \delta_i = 1$.

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Vol. 6, Issue 3, March 2019

Here too, the multilevel deployment in energy for HEED (MLHEED-E) describes a heterogeneous wireless sensor network that consists of *m*levels of heterogeneity of sensor nodes based on the distance of base station. The levels having larger distance of base station are supposed to have more energy than those having shorter distance. We assume that the WSN has N as a number of nodes out of which $\phi_j * N$ nodes exist in level *j* of energy, where: $0 < \phi_j < 1$ and $\sum_j^m \phi_j = 1$.
And here, the multilevel deployment in space and energy for HEED (MLHEED-SE) describes a heterogeneous wireless sensor network that consists of *k* levels of heterogeneity and deployment of sensor nodes based on the distance of base station. The levels having larger distance of base station are supposed to have more energy and less density of nodes, than those having shorter distance. We assume that the WSN has N as a number of nodes out of which $\psi_l * N$ nodes exist in level *l* of space, where: $0 < \psi_l < 1$ and $\sum_l^k \psi_l = 1$.

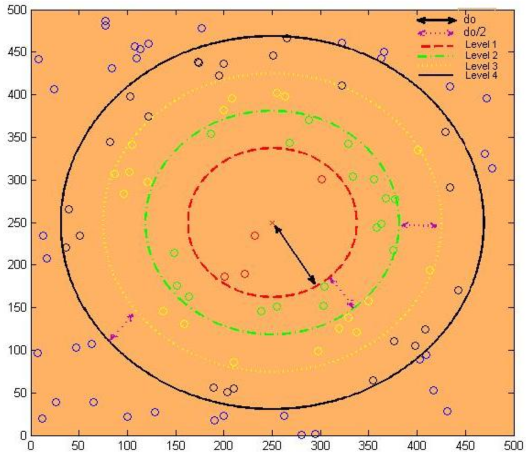

Fig 1. Deployment over 500mx500m with five levels

A. The total energy of network in t_0

MLHEED-S

$$TotEn_{HEED-S} = \delta_1 * N * E_1 + \delta_2 * N * E_2 + \cdots + \delta_n * N * E_n = N * \sum_i^n \delta_i * E_i \quad (1)$$

WSN is homogeneous: E_i=E_0 and: $\sum_i^n \delta_i = 1$

$$TotEn_{HEED-S} = N * E_0 \sum_i^n \delta_i = N * E_0 \quad (2)$$

MLHEED-E

$$TotEn_{HEED-E} = \phi_1 * N * E_1 + \phi_2 * N * E_2 + \cdots + \phi_m * N * E_m = N * \sum_j^m \phi_j * E_j \quad (3)$$

Distribution of nodes is uniform: $\phi_1 \approx \phi_2 \ldots \approx \phi_m = \frac{1}{m}$

$$TotEn_{HEED-E} = N * \phi \sum_j^m E_j = N * \frac{1}{m} \sum_j^m E_j \quad (4)$$

WSNs start with the same total energy network in T_0

$$TotEn_{HEED-E} = N * E_0 \Leftrightarrow \sum_j^m E_j = mE_0 \quad (5)$$

MLHEED-SE

$$TotEn_{HEED-SE} = \psi_1 * N * E_1 + \psi_2 * N * E_2 + \cdots \psi_k * N * E_k = N * \sum_l^k \psi_l * E_l \quad (6)$$

WSNs start with the same total energy network in T_0

$$TotEn_{HEED-SE} = N * E_0 \Leftrightarrow \sum_l^k \psi_l * E_l = E_0 \quad (7)$$

ISSN: 2350-0328
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Vol. 6, Issue 3, March 2019

B. Network applications

Case of two levels

In the table below, we illustrate the parameters which the MLHEED needs of WSN deployment over the space of 200 meters:

Table 1. Two level case parameters

Protocol	δ		ϕ		ψ		$E_0(J)$	
MLHEED-S	Level 1 0.9	Level 2 0.1	N/A		N/A		Level 1 0.2	Level 2 0.2
MLHEED-E	N/A		Level 1 0.5	Level 2 0.5	N/A		Level 1 0.2	Level 2 0.2
MLHEED-SE	N/A		N/A		Level 1 0.9	Level 2 0.1	Level 1 0.2	Level 2 0.2

Case of three levels

In the table below, we illustrate the parameters which the MLHEED needs of WSN deployment over the space of 300 meters:

Table 2. Three level case parameters

Protocol	δ			ϕ			ψ			$E_0(J)$		
MLHEED-S	Level 1 0.7	Level 2 0.2	Level 3 0.1	N/A			N/A			Level 1 0.2	Level 2 0.2	Level 3 0.2
MLHEED-E	N/A			Level 1 0.33	Level 2 0.33	Level 3 0.33	N/A			Level 1 0.15	Level 2 0.25	Level 3 0.3
MLHEED-SE	N/A			N/A			Level 1 0.7	Level 2 0.2	Level 3 0.1	Level 1 0.15	Level 2 0.25	Level 3 0.45

Case of four levels

In the table below, we illustrate the parameters which the MLHEED needs of WSN deployment over the space of 400 meters:

Table 3. Four level case parameters

Protocol	δ				ϕ				ψ				$E_0(J)$			
MLHEED-S	Lev1 0.4	Lev2 0.3	Lev3 0.2	Lev4 0.1	N/A				N/A				Lev1 0.2	Lev2 0.2	Lev3 0.2	Lev4 0.2
MLHEED-E	N/A				Lev1 0.25	Lev2 0.25	Lev3 0.25	Lev4 0.25	N/A				Lev1 0.15	Lev2 0.15	Lev3 0.15	Lev4 0.15
MLHEED-SE	N/A				N/A				Lev1 0.4	Lev2 0.3	Lev3 0.2	Lev4 0.1	Lev1 0.15	Lev2 0.15	Lev3 0.15	Lev4 0.15

Case of five levels

In the table below, we illustrate the parameters which the MLHEED needs of WSN deployment over the space of 500 meters:

Table 4. Five level case parameters

Protocol	δ					ϕ					ψ					$E_0(J)$				
MLHEED-S	1 0.35	2 0.25	3 0.2	4 0.15	5 0.05	N/A					N/A					1 0.2	2 0.2	3 0.2	4 0.2	5 0.2
MLHEED-E	N/A					1 0.2	2 0.2	3 0.2	4 0.2	5 0.2	N/A					1 0.15	2 0.2	3 0.25	4 0.3	5 0.05
MLHEED-SE	N/A					N/A					1 0.35	2 0.25	3 0.2	4 0.15	5 0.05	1 0.15	2 0.2	3 0.25	4 0.3	5 0.05

IV. RESULTS AND DISCUSSION

Table 5. Simulation parameters

Parameter	E_0	d_0	N	E_{elec}	E_{DA}	ϵ_{fs}	ϵ_{mp}	l	P	Rounds	E_0(WSN)
Value	0.2 J	87.7 m	100	50 nJ/bit	5 pJ/bit	10 pJ/bit/m^2	0.0013 pJ/bit/m^2	4000 bits	0.05	1000	20 J

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 6, Issue 3, March 2019

In this section, we study the performance of MLHEED-S, MLHEED-E and MLHEED-SE protocols under different scenarios using MATLAB. We consider a model illustrate in the figure 1 with (N=100) nodes randomly distributed in a different space dimensions and divided in a levels. To compare the performance of the three protocols, we use the parameters shown in table 5 for each level.

A. Network lifetime

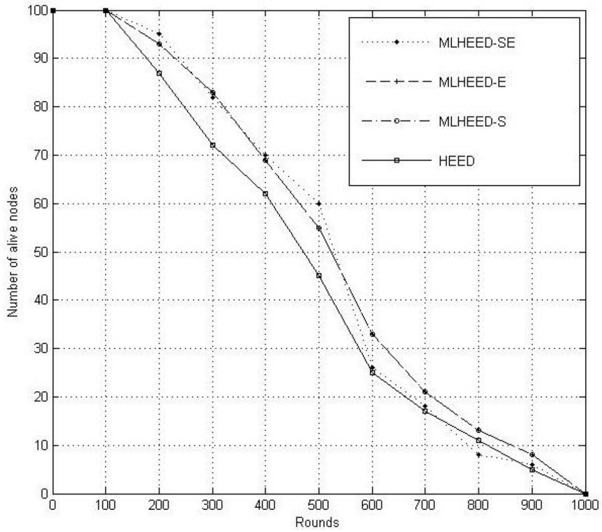


Fig 2. Network lifetime in terms of number of alive nodes vs number of rounds for space dimension of 200m.

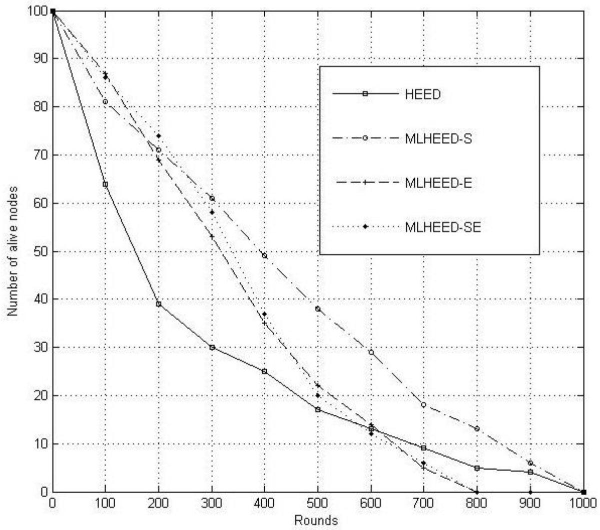


Fig 3. Network lifetime in terms of number of alive nodes vs number of rounds for space dimension of 300m.

ISSN: 2350-0328

International Journal of AdvancedResearch in Science, Engineering and Technology

Vol. 6, Issue 3, March 2019

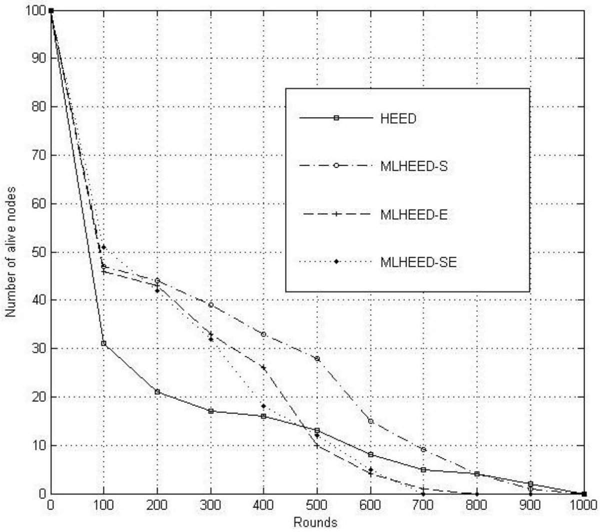


Fig 4. Network lifetime in terms of number of alive nodes vs number of rounds for space dimension of 400m.

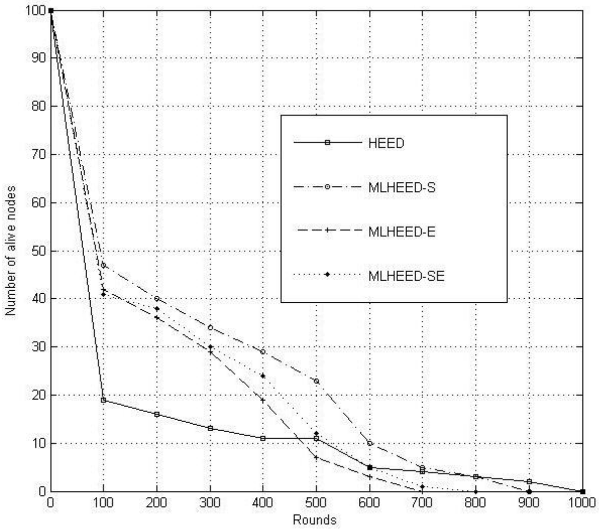


Fig 5. Network lifetime in terms of number of alive nodes vs number of rounds for space dimension of 500m.

Table 6. Number of rounds when first and last nodes are dead for all proposed protocols

Dimension	MLHEED-S				MLHEED-E				MLHEED-SE			
	FND	Inc/Dec(%)	LND	Inc/Dec(%)	FND	Inc/Dec(%)	LND	Inc/Dec(%)	FND	Inc/Dec(%)	LND	Inc/Dec(%)
200	109	-7,63	1000	0,10	109	-7,63	1000	0,10	157	33,05	996	-0,30
300	20	-23,08	995	-0,20	23	-11,54	776	-22,17	31	19,23	798	-19,96
400	8	-11,11	952	-4,23	13	44,44	714	-28,17	13	44,44	689	-30,68
500	5	25,00	881	-11,10	6	50,00	661	-33,30	5	25,00	722	-27,14

We remark really the increase in lifetime, with respect to the original HEED for all proposed protocols and spaces dimensions. The MLHEED-E and MLHEED-SE provide maximum network lifetime, i.e., increasing by 50% (500m) and 44.44% (400m) respectively.

The MLHEED-S increases the lifetime of space dimension of 500 meters, by 25% compare to original HEED.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 6, Issue 3, March 2019

B. Total energy consumption

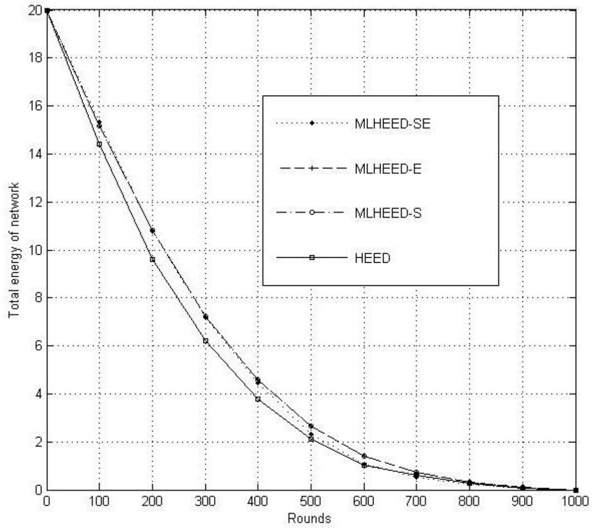


Fig 6. Total energy dissipation vs number of rounds for space dimension of 200m

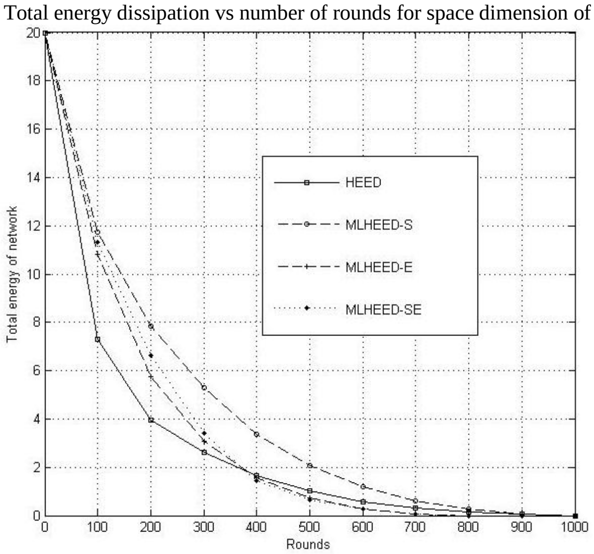
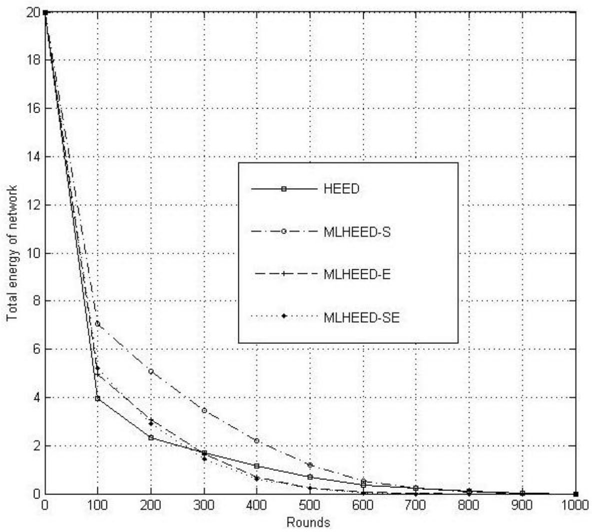


Fig 7. Total energy dissipation vs number of rounds for space dimension of 300m



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International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 6, Issue 3, March 2019

Fig 8. Total energy dissipation vs number of rounds for space dimension of 400m

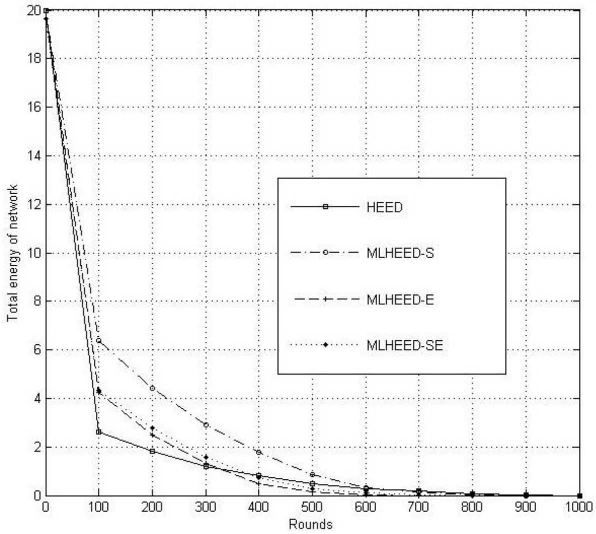

Fig 9. Total energy dissipation vs number of rounds for space dimension of 500m

The amount of energy consumed in the network per round in figure 6 is the same for all proposed protocols with an excess of consumption in the HEED protocol.
As shown in figure 7, 8 and 9, the total energy of network per round of MLHEED-S is higher than that of MLHHED-E, MLHHED-SE and HEED.

C. Number of packets sent to base station

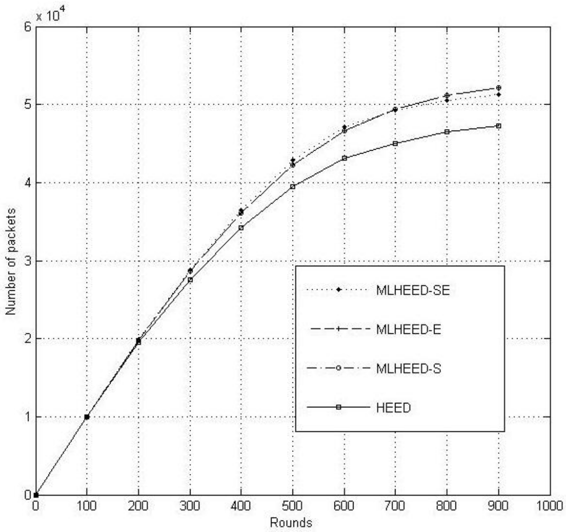

Fig 10. Number of data packets sent to the base station vs number of rounds for space dimension of 200m

ISSN: 2350-0328

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Vol. 6, Issue 3, March 2019

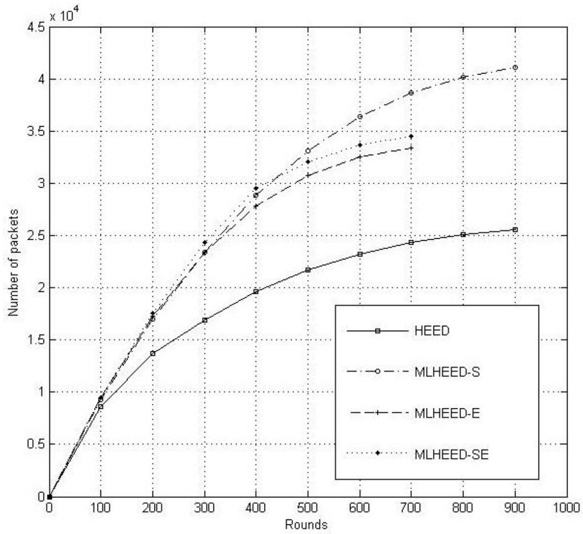

Fig 11. Number of data packets sent to the base station vs number of rounds for space dimension of 300m

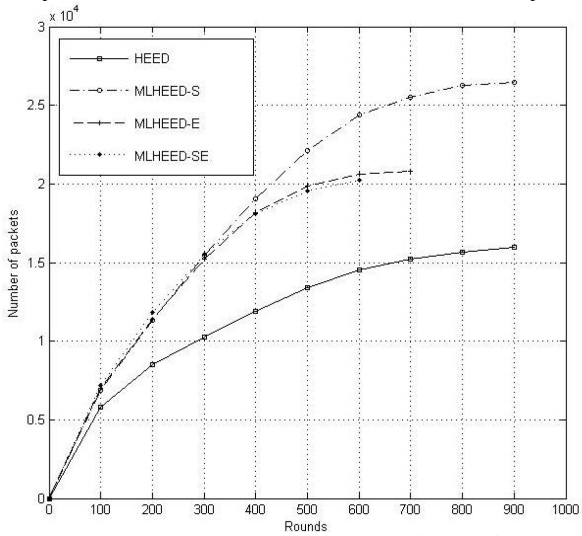

Fig 12. Number of data packets sent to the base station vs number of rounds for space dimension of 400m

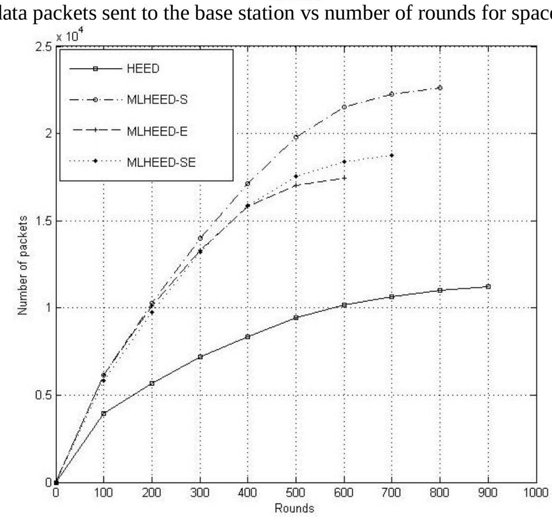

Fig 13. Number of data packets sent to the base station vs number of rounds for space dimension of 500m

Table 7. Percentage increment in number of packets for all proposed protocols

Dimension	MLHEED-S		MLHEED-E		MLHEED-SE	
	Packet	Increase(%)	Packet	Increase(%)	Packet	Increase(%)
200	52214	10,34	52214	10,34	51296	8,40
300	41100	61,06	33400	30,88	34536	35,33
400	26477	65,65	20807	30,17	20268	26,80
500	22640	101,53	17466	55,47	18732	66,74

The amount of information collected by the network from the sensor field is sent to the base station. The MLHEED-S sends maximum number of packets to the base station. That is among all variants as evident from figures 10, 11, 12 and 13. The number of packets transferred to the base station using the HEED, MLHEED-S, MLHEED-E and MLHEED-SE are shown in table 7.

Finally, as noted above, the deployment in energy and spaces (MLHEED-S, MLHEED-E and MLHEED-SE) has a good effect on network lifetime and on information transmission. It saves network energy and increases the packets sent to base station.

V. CONCLUSION

In this paper, we have studied a model of multilevel deployment for WSNs. It can describe any finite level of heterogeneity or space. For experimental validation, we have considered 200, 300, 400 and 500 meters as spaces dimension with two, three, four and five levels respectively. These levels depend on the type of the chosen protocol: MLHHED-S, MLHEED-E or MLHEED-SE. Starting any network by the same initial energy for all its nodes, could be the preferred condition to evaluate the ability of this network to manage this energy until the end of operation. By controlling the density and the heterogeneity in each level, we have prolonged the lifetime of the network in much proportion as compared to the increase of its energy. In case of MLHEED-SE and MLHEED-E with four levels of heterogeneity, the network lifetime has increased by 44.44% for increasing 11% of its energy. We have also computed the number of packets sent with each indicated protocols. The proposed variants of the MLHEED-S significantly increases the number of packets transmitted to base station.

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