Performance Improvement of Heterogeneous Wireless Sensor Networks Using a New Clustering Algorithm

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Abstract—**This paper proposes and evaluates a new clustering algorithm: Weighted Election Probabilities Clustering Scheme (WEPCS) for Heterogeneous Wireless Sensor Networks (HWSNs). WEPCS is an improvement of the Energy Efficient Heterogeneous Clustered (EEHC) protocol. The modification proposed allows the election of Cluster Heads (CHs) using different weighted probabilities. The WEPCS algorithm aims mainly to improve network stability period and the network throughput. An Experimental evaluation is presented and the results show that the WEPCS achieves longer life time and more throughput than the existing clustering protocols in heterogeneous environments.**

Keywords-Wireless Sensor Network; Heterogeneous; Clustering; Energy Consumption; Network Stability Period.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) are an example of the paradigm shift-taking place in wireless network architectures. Recent advances in computing and communication have caused a significant shift in sensor network research.

WSN is composed of a Base Station (BS) and a number of wireless Sensor Nodes (SNs). These SNs are characterized as low-cost and low-power entities and are capable of communication at very short distances, also, they perform limited computation. All SNs, communicate wirelessly, and form a sensor field [1,2]. Typically, BS serves as an access point for the user, or as a gateway to another network.

The main task of the SN is to sense and collect data from a certain region, process it, and transmit it to the BS, where further processing on the collected data can be performed. So, WSN can be used in a wide variety of civilian and military applications, e.g., environmental monitoring, battlefield surveillance, industry process control, and health.

Depending on the application of WSNs, certain routing protocols are required in order to establish the communication among SNs and the BS [3]. WSNs consume their limited energy while collecting data, performing calculations, and routing the received data. Nevertheless, in most applications, each SN is expected to last for a long time. For these reasons, both efficient routing schemes and efficient use of energy are highly important in WSNs.

Different techniques have already been proposed to improve energy consumption rate and network's lifetime, such as: clustering and data aggregation.

Clustering is a key technique used to extend the lifetime of WSN by organizing SNs into clusters. Each cluster has a leader called Cluster Head (CH). Each SN transmits its data to the closest CH to minimize energy consumption. Then the CH manages communication within a cluster, and forwards collected data from its Cluster Members (CMs) to the BS.

In clustered WSNs, CH has a higher burden than its CMs The CH drains its energy much more quickly than the CMs. Rotating the CH's role distributes this higher burden among SNs, thereby preventing CH from dying prematurely [4,5]. Hence, an important design issue in WSNs is to lessen the energy consumption in WSN for sake of the network lifetime.

One of the ways for saving energy is to insert a percentage of SNs equipped with additional energy resources in the sensing field, i.e., making WSN heterogeneous in terms of energy.

Many existing schemes for Heterogeneous Wireless Sensor Networks (HWSNs), such as SEP [6], DEEC [7], and EEHC [8], demonstrate that HWSNs are supposed to survive for a longer time compared to homogeneous WSNs.

This paper proposes and evaluates a new clustering algorithm: Weighted Election Probabilities Clustering Scheme (WEPCS) for HWSNs. It takes advantages from previous developed algorithms and studies the impact of heterogeneity of SNs on the network performance, based on their energy levels. The main issue of our interest is to maximize the lifetime of HWSN and throughput.

The rest of this paper is organized as follows. Section II discusses the related work. Section III presents the proposed algorithm. Section IV provides the experimental results. Section V concludes the paper and discusses the future work.

II. RELATED WORK

Most of the clustering algorithms, e.g., LEACH [9], assume WSNs are homogeneous, where all SNs have the same initial energy. These algorithms perform poorly in heterogeneous environments, where all SNs of WSN are equipped with different amounts of energy. HWSNs are very much useful in real deployments because they are more close to real life situations; so the work presented in this paper emphasizes upon HWSNs where two or more types of SNs are considered [10,11,12,13].

Low-Energy Adaptive Clustering Hierarchy (LEACH) [9] is one of the most simple and effective widely deployed clustering solutions for WSN. In LEACH, each SN is given equal chance to be a CH. The clusters are re-established and new CHs are elected in each "round", so that the load is distributed and balanced among SNs of the network.

Distributed Energy-Efficient Clustering (DEEC) [7] is a cluster-based scheme for two level and multilevel

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energy HWSNs. DEEC is based on LEACH. In this scheme, CHs are selected using the probability based on the ratio between the residual energy of each SN and the average energy of the network. Thus, DEEC can prolong the stability period. SNs with high initial and residual energy will have more chances to be CHs than low energy SNs. However, this choice penalizes always advanced SNs, because these SNs will be continuously CHs. In this situation, the advanced SNs die quickly than the others.

Energy Efficient Heterogeneous Clustered (EEHC) [8] is developed for the 3-level heterogeneous networks, which include three types of nodes according to the initial energy, i.e., the super nodes, the advance nodes and the normal nodes. The rotating epoch and election probability is directly correlated with only the initial energy of nodes. EEHC performs poorly when heterogeneity is a result of operation of the sensor network.

III. THE WEIGHTED ELECTION PROBABILITIES CLUSTERING SCHEME (WEPCS)

After studying the operation of LEACH [9], DEEC [7], and EEHC [8], the following facts were noticed:

First, SN nearer to BS than to any CH may send its data to far CH, as shown in Fig. 1. As a result, it will lose more energy compared to the case of sending its data directly to BS, as shown in Fig. 2.

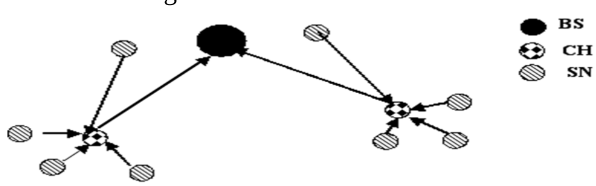

Figure 1. The Network Model for the General Clustering Algorithms.

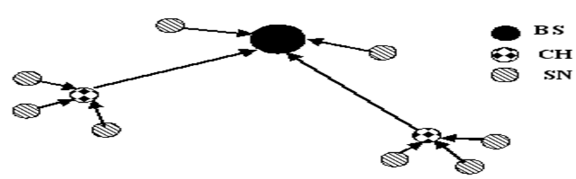

Figure 2. The Network Model for the WEPCS Algorithm.

Second, when no SN elects itself as CH, and at the same time there are some SNs still alive and has enough energy to send data to BS, then SNs usually will turn off to sleep mode. In turn, the packets of these live SNs will not be sent to BS. This great disadvantage influences the transmission reliability in the networks, especially for some important real-time tasks, e.g., fires and volcanoes.

Third, in EEHC, the "CH weighted election probability" equation does not consider the residual energy of the SNs, the residual energy of the network, and the number of live SNs, i.e., EEHC depends only on the initial parameters of the network. In addition, EEHC considers three types of SNs only (normal, advanced, and super) instead of Multi-Level type that can be encountered in HWSN after a significant amount of time of operation.

Thus, in this paper, we will consider the previous notes in the proposed algorithm.

A. Goals of WEPCS

- Improving network stability period in terms of the Death of First SN (FND), by increasing the time until a SN breaks down
- Increasing HWSN lifetime in terms of the Death of Half SNs (HND), by increasing the half-life period of the network
- Increasing total throughput, by increasing the total number of packets that sent to BS.

To achieve these goals, WEPCS includes the following modifications:

BS will act as if it is one of CHs thus,

- Non CH (NCH) is allowed to send its packets directly to BS when it has no CH, i.e., when no SN elects itself as CH and there are some SNs still alive. Hence, in WEPCS, loss of data due to inability to reach BS is avoided. This enhances WSN efficiency.
- NCH is allowed to choose its nearest leader (CH or BS), i.e., if any NCH is nearer to BS than any CHs, it will contact directly to BS. Moreover, accordingly, the power dissipation due to the distance will be decreased, and more communication energy will be saved.

CH selection will depend on three basics:

- The weighted election probability equation, which is used in threshold and epoch calculations, is based on the residual energy of SNs, the actual residual energy of the network, and the number of alive SNs.
- The scheme of WEPCS is implemented along three scenarios for sending the remaining energy information of SN to BS along three different rates: none in implementation-a (Impl-a), every round in implementation-b (Impl-b), and every epoch in implementation-c (Impl-c).

We consider different models of HWSN, which are Two Level, Three-Level, and Multi-Level in terms of the SN initial energy.

B. Phases of the WEPCS Algorithm

The operation of each round of WEPCS is divided into three phases, as shown in Fig.3.

Set-Up Phase: SNs will organize themselves into local clusters, with one SN acts as CH. SNs elect themselves as CHs with respect to their energy levels, autonomously. Then, BS selects CHs based on suggestions of requesting SNs to be CHs, i.e., the proposed algorithm is a combination between distributed and centralized clustering algorithms. Fig. 4 gives an overview of the formal description of the Set-Up phase.

Steady-State Phase: The sensed data packet will be collected from all CMs by its leader (CHs or BS). CHs

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perform processing functions on the received data (e.g., data aggregation and compression). Then CHs send the compressed data to BS.

BS has two types of data: one from CHs, and another from SNs that sent directly to BS. BS performs another data aggregation function, which aggregates both types of data.

Maintenance phase: The "*network status*" information, which contains the real number of live SNs and the total remaining energy of the network, will be updated for all SNs.

CMs send their "*remaining energy*" information to their leaders (CH or BS). The leaders aggregate remaining energies and calculate the real number of live SNs in their clusters, and then CHs send this "*energy level*" information to BS.

After that, BS aggregates the real number of live SNs and the total remaining energy of the network. Then, BS broadcasts "*network status*" to all SNs in the network. Finally, SNs receive this information, and update their stored "network status".

This "*network status*" will be used in three different ways, according to the implementation scenarios of WEPCS: Impl-a, Impl-b, or Impl-c.

After this phase, the next round begins, and the algorithm reforms the CH selection process.

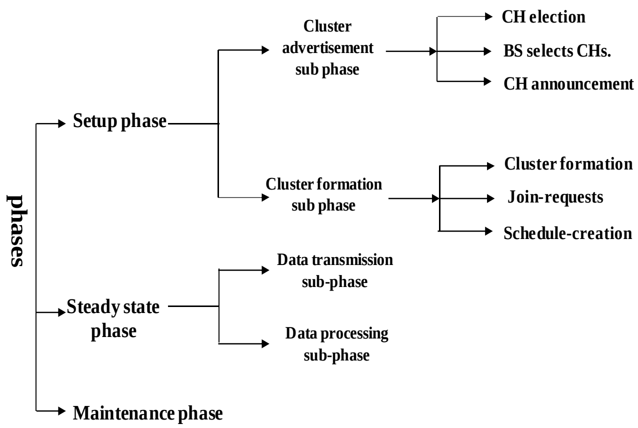

Figure 3. Phases of the Proposed Algorithm

C. Cluster Head Selection for WEPCS

When a new round begins, each SN decides whether to become CH or not. This decision is made by SN choosing a random number between 0 and 1.

SN becomes a CH for the current round, if the number is less than the following threshold [8]:

$$T(s_i) = \begin{cases} \dfrac{P_{s_i}}{1 - P_{s_i} * r \bmod \left(\frac{1}{P_{s_i}}\right)}, & \text{If } s_i \in G \\ 0, & \text{Otherwise} \end{cases} \tag{1}$$

where P_{s_i} is the weighted election probabilities of SN in the current round r, and G is the set of SNs that are eligible to be CHs at round r.

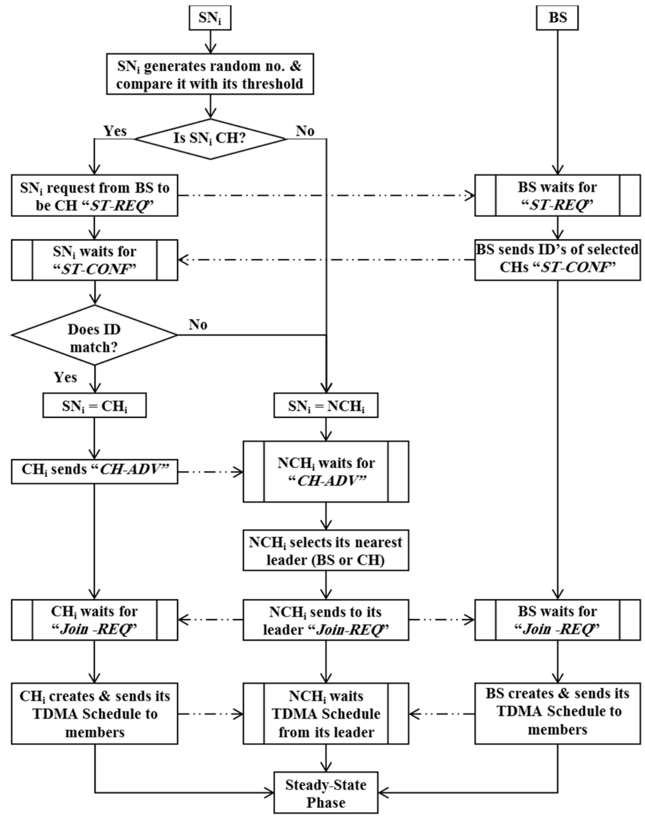

Figure 4. Formal Description of the Set-Up phase

After SN works as CH in current round, it will not belong to the set G, i.e., it will be prevented from being elected again during next rounds until it passes its individual rotating epoch (m_{Si}= $1/P_{s_i}$). After a new epoch starts, SN will belong again to the set G.

Weighted Election Probabilities: WEPCS makes more control on the threshold. This control is achieved based on the weighted election probability, $\mathbf{P_{s_i}}$. According to the implementation scenarios of WEPCS, $\mathbf{P_{s_i}}$ is computed as follows:

a) *Implementation-a of WEPCS (Impl-a)*

The weighted probability for Impl-a scenario is:

$$P_{s_i} = \frac{n_{initial} \times P_{opt} \times E_{s_i}(r)}{E_{total-initial}} \tag{2}$$

where P_{opt} is optimal percentage of SNs to become CHs, $E_{s_i}(r)$ is current energy of SN per round, $n_{initial}$ is the total number of SNs at the start of the network operation, and $E_{total-initial}$ is the total initial energy of HWSN.

b) *Implementation-b of WEPCS (Impl-b)*

The weighted probability for Impl-b scenario is:

$$P_{s_i} = \frac{n(r) \times P_{opt} \times E_{s_i}(r)}{E_{total}(r)} \tag{3}$$

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where $n(r)$ is total number of SNs in the network at the start of each round and $E_{total}(r)$ is total energy of HWSN at the start of each round. These two values are updated every round by using network status information.

c) Implementation-c of WEPCS (Impl-c)

The weighted probability for Impl-c scenario is:

$$P_{s_i} = \frac{n(m) \times P_{opt} \times E_{s_i}(r)}{E_{total}(m)} \quad (4)$$

where $n(m)$ is total number of SNs at start of each optimal epoch and $E_{total}(m)$ is total energy of HWSN at the start of each optimal epoch. These two values are updated every optimal epoch ($m_{opt}=1/P_{opt}$).

D. Network Model

We have considered the following assumptions:

- All SNs are randomly distributed in a (M * M) square sensing field.
- All SNs and BS are stationary, after deployment.
- All SNs have unique IDs and they are location-unaware.
- BS is located at the center of the square field.
- BS location is known by each SN in the network.
- Type of communication is single hop.
- Communication is symmetric and SN can compute the approximate distance based on the received signal strength.
- The communication environment is contention and error free. Hence, SNs do not have to retransmit any data.

In the work presented in this paper, WEPCS is applied on several types of HWSN, including Two-Level, Three-Level, and Multi-Level in terms of the SN initial energy. Next, the total initial energy of each network level is calculated. This total energy is used in computing P_{s_i} in Eq. (2), (3) and (4) to elect CH at the start of WEPCS within the three scenarios of implementation.

Two-Level HWSN

There are two types of SNs : advanced and normal SNs. Let's assume that E_0 is the initial energy of normal SNs, and m is the fraction of advanced SNs, which own α times more energy than the normal ones.

Thus there are n*m advanced SNs equipped with initial energy of $(1+\alpha)*E_0$, and n*(1-m) normal SNs equipped with initial energy of E_0. The total initial energy of the Two-Level HWSN [6,7,12] is:

$$E_{total} = n*(1-m)*E_0+n* m*(1+ \alpha) *E_0= n* E_0*(1+ \alpha m) \quad (5)$$

Three-Level Network

There are three types of SNs: super, advanced, and normal SNs. Assuming that E_0 is the initial energy of normal SNs, m is the fraction of advanced SNs, which own α times more energy than the normal ones, and m_0 is the fraction of super SNs, which own β times more energy than the normal ones.

Thus there are $n*m*m_0$ super SNs equipped with initial energy of $(1 + \beta)*E_0$, $n*m*(1–m_0)$ advanced SNs equipped with initial energy of $(1 + \alpha)*E_0$, and $n*(1 – m)$ normal SNs equipped with initial energy of E_0. The total initial energy of the Three-Level HWSNs [8,10,11] is :

$$E_{total} = n *m*m_0*(1+ \beta) E_0 + n*m*(1–m_0)*(1+ \alpha) E_0 +n*(1–m)*E_0$$
$$E_{total} = n*E_0*(1+ m*(\alpha –a*m_0+m_0* \beta)) \quad (6)$$

Multi-Level Network

There are many different types of SNs. Let assume the initial energy E_0 is randomly distributed over the close set $[E_0 , E_0*(1 + \alpha_{max})]$, where E_0 is the lower bound and α_{max} determines the value of the maximal energy. Initially, the node s_i is equipped with initial energy of $E_0*(1 + \alpha_i)$, which is α_i times more energy than the lower bound E_0. The total initial energy of Multi-Level HWSNs [7] is:

$$E_{total} = E_0 (1+ \alpha_1) + E_0 (1+ \alpha_2) + ...+ E_0 (1+ \alpha_n)$$
$$E_{total} = \sum_{i=1}^{n} E_0 * (1+\alpha_i) = E_0(n + \sum_{i=1}^{n}\alpha_i) \quad (7)$$

E. Energy Model

The work presented in this paper adopts the same energy model proposed in [9,14]. The free space energy model used because SNs are randomly distributed over the sensing field and BS is at the center, as a result, the distance from any SN to the BS or its CH is small. Table 1 describes the energy dissipation in CHs during each phase and Table 2 describes the energy dissipation in NCHs (CMs) during each phase.

TABLE 1. ENERGY DISSIPATION IN CHS

Operation	Energy Dissipated
Set-Up Phase	
When CH sends its status “ST-REQ” request to BS	$L_1 E_{elec}+ L_1 e_{fs} d^2_{to BS}$
When CH receives its confirmation “ST-CONF” message from BS	$L_1 E_{elec}$
When CH broadcasts “CH-ADV” message to all SNs	$L_1 E_{elec}+ L_1 e_{fs} d^2_{range}$
When CH receives “Join-REQ” messages from CMs.	$N_c L_1 E_{elec}$
When CH transmits its TDMA schedule to CMs.	$L_1 E_{elec}+ L_1 d^2 e_{fs}$
Steady-State Phase	
When CH receives sensed data packet from its CMs (E_{Rx})	$L_2 E_{elec}$
When CH aggregates the sensed data packet of its CMs (E_{DA})	L_2E_{aggr}
When CH transmits aggregated data to BS (E_{Tx})	$L_2 (E_{elec} + e_{fs} d^2_{to BS})$
Maintenance Phase	
When CH receives “remaining energy” information from its CMs	$N_cL_3 E_{elec}$
When CH aggregates this information	$(N_c + 1) L_3 E_{elec}$
When CH transmits this “energy level” information to BS	$L_3 (E_{elec} + e_{fs} d^2_{to BS})$
When CH receives the “network status” information from BS	$L_4 E_{elec}$

TABLE 2. ENERGY DISSIPATION IN NCHS

Operation	Energy Dissipated
Set-Up Phase	
When NCH receives "CH-ADV" message from CHs	$L_1 E_{elec}$
When NCH transmits "Join-REQ" message to its leader	$L_1 E_{elec}+ L_1 e_{fs} d^2$
When NCH receives TDMA schedule from its leader	$L_1 E_{elec}$
Steady-State Phase	
When NCH (CM) transmits sensed data packet to its leader (E_{Tx})	$L_2 E_{elec} + L_2 e_{fs} d^2_{to\ CH}$
Maintenance Phase	
When NCH transmits "remaining energy" information to its leader	$L_3 (E_{elec} + e_{fs} d^2_{to\ leader})$
When NCH receives the "network status" information from BS	$L_4 . E_{elec}$

where, E_{elec} is the energy dissipated per bit to run the transmitter or the receiver circuit, d is the distance between CM and its leader, d_{toBS} is the distance between CH and BS, d_{range} is the CH radio range distance, N_c is the number of CMs in each cluster, L_1 is the number of bits in each set up message, L_2 is the number of bits in each data message, L_3 is the number of bits of "energy level" information and "remaining energy" information, L_4 is the number of bits of "network status" information, e_{fs} depends on the transmitter amplifier of the free space model, and E_{aggr} is the processing energy cost of a reported bit to BS.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

A. Simulation Environment and settings

The simulation has been done using MATLAB. The parameters used in our simulation are shown in Table 3.

The SN is considered dead when it has energy less than the energy needed for transmitting L_1-bit packets to its leader. In addition, the optimal percentage of SNs that will be CHs P_{opt} is equal to 5% of the total number of SNs in the network as in [9, 14].

B. Simulation Metrics

- *Overall network performance view:* The lifetime of HWSN is defined by three metrics [15]:

TABLE 3. SIMULATION PARAMETERS

Parameter	Value
Square Sensing field.	(100,100)
n: total number of SNs in the network.	Init.: 100
E_{elec}: energy dissipated per bit to run the transmitter or receiver circuit.	50 nJ/bit/ packet
e_{fs}: energy consumed by the amplifier to transmit at a short distance.	10 pJ/bit/m2
E_0: initial energy of normal SN	0.5 J
E_{DA}: data aggregation energy is the processing cost of a bit report to BS.	5 nJ/bit/ report
L_1: number of bits in each set up packet	200 bits
L_2: number of bits in each data packet	4000 bits
L_3: number of bits in each network status packet	200 bits
P_{opt}: optimal probability of SN to become CH.	Init:0.05
BS Location	(50,50)

  - First Node Died (FND), which indicates the period from the start of the network operation and the first dead SN (stability period).
  - Half Nodes Died (HND), which indicates an estimated value for the half-life period of HWSN.
  - Last Node Died (LND), which indicates an estimated value for the overall lifetime of HWSN. This research finds LND when all nodes die-if possible; but this measure is not of interest here.

  In this paper, we limit the discussion of algorithms to the metrics FND and HND.
- *Overall network status*: These metrics reflect the total number of alive SNs per round and the total number of dead SNs per round.
- *Throughput:* This metric reflects the total number of data packets sent over the network to BS per round.
- *Improvements along the metrics*: The improvement of FND, HND, and Throughput will be calculated by:

$$\text{Improvement} = \frac{\text{Value of WEPCS metric} - \text{Value of other algorithm metric}}{\text{Value of other algorithm metric}} \tag{8}$$

C. Simulation Results

This section provides a limited set of results, obtained using simulation. The simulation results compare the performance of WEPCS to the three previously developed algorithms: LEACH (Homogeneous LEACH, and heterogeneous LEACH), DEEC, and EEHC. Homogeneous LEACH schemes are obtained assuming that the SNs of WSN are equipped with the same amount of energy. Also, heterogeneous LEACH schemes are considered assuming that a percentage of the SNs' population is equipped with more energy than the rest of SNs in the same network. We extended LEACH, DEEC, and EEHC to be tested under Two-level, Three-level, and Multi-level HWSNs.

1) Results Under Two-Level HWSN

For two-level heterogeneous networks, Fig. 5 and Table 4 show the results of the case with $m=0.3$, and $a=1.5$. This mean that the total number of normal SNs (N_n) is equal to 70, initial energy of normal SNs (E_{in}) is equal to 0.5 J, total number of advanced SNs (N_a) is equal to 30, initial energy of advanced SNs (E_{ia}) is equal to 1.25 J, and total initial energy of network (E_{total}) is equal to 72.5 J.

TABLE 4. PERCENTAGE OF IMPROVEMENT BETWEEN THE PROPOSED ALGORITHM AND OTHER ALGORITHMS FOR TWO-LEVEL HWSN

	Metrics	Hetero. LEACH	DEEC	EEHC
Impl-a	Stability period (FND)	66.7%	4%	39%
	HND	47%	5%	26.6%
	Throughput	41%	40%	38%
Impl-b	Stability period (FND)	62.8%	1.7%	36%
	HND	31.6%	-6%	12.7%
	Throughput	19%	18.5%	16.5%
Impl-c	Stability period (FND)	72.8%	8%	44%
	HND	42.9%	1.68%	22%
	Throughput	28%	27.5%	25%

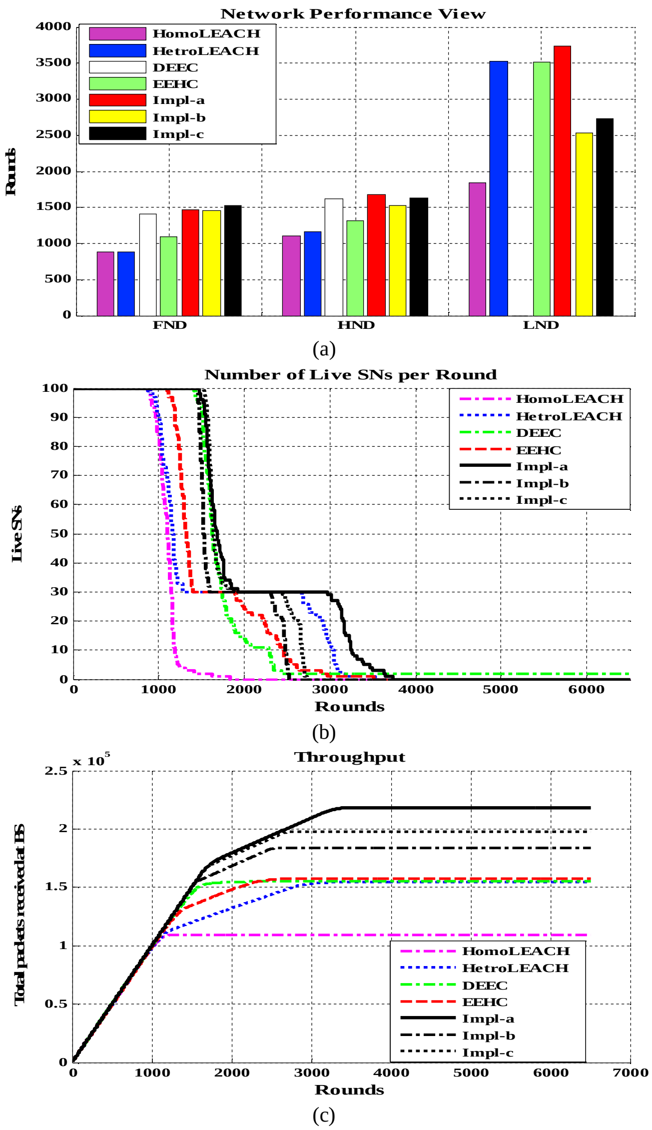


Figure 5. Results for Two-level HWSN.

2) Results Under Three-Level HWSN

For three-level heterogeneous networks, Fig. 6 and Table 5 show the results of the case of $m=0.2$, $m_0=0.5$, $\alpha=2$, and $\beta=1$. This means that 10% of SNs are advanced which are equipped with 200% more energy than normal SNs, and 10% of SNs are super which are equipped with 100% more energy than normal SNs.

3) Results Under Multi-Level HWSN

In this case, we consider that the initial energies of SNs are randomly distributed in [E_0,=0.5 2E_0=1]. The results are in Fig. 7 and Table 6. In addition, Figs. 8, 9, and 10 show the effect of changing initial energy of SN, packet size of SN, and number of SNs.

From our simulations, we observed the followings:

1. The stability period of WEPCS is prolonged compared to that of LEACH, DEEC, and EEHC in heterogeneous settings.
2. The instability period was shortened for WEPCS compared to that of LEACH, DEEC, and EEHC.
3. The number of packets received by BS (Throughput) during the lifetime of the network are more than that of LEACH, DEEC, and EEHC. This is because WEPCS has more number of alive SNs as shown in Figs. 5(b), 6(b), 7(b).

TABLE 5. PERCENTAGE OF IMPROVEMENT BETWEEN THE PROPOSED ALGORITHM AND OTHER ALGORITHMS FOR THREE-LEVEL HWSN

	Metric	**Hetero. LEACH**	**DEEC**	**EEHC**
Impl-a	Stability period (FND)	60.%	9.5%	35.5%
	HND	40.5%	3.5%	25%
	Throughput	38.9%	40%	37%
Impl-b	Stability period (FND)	50.9%	3.%	27.6%
	HND	24.8%	-8%	11%
	Throughput	14%	15%	12.7%
Impl-c	Stability period (FND)	63.9%1	12%	38.6%
	HND	34.9%	-0.5%	20%
	Throughput	22.7%	23.9%	21%

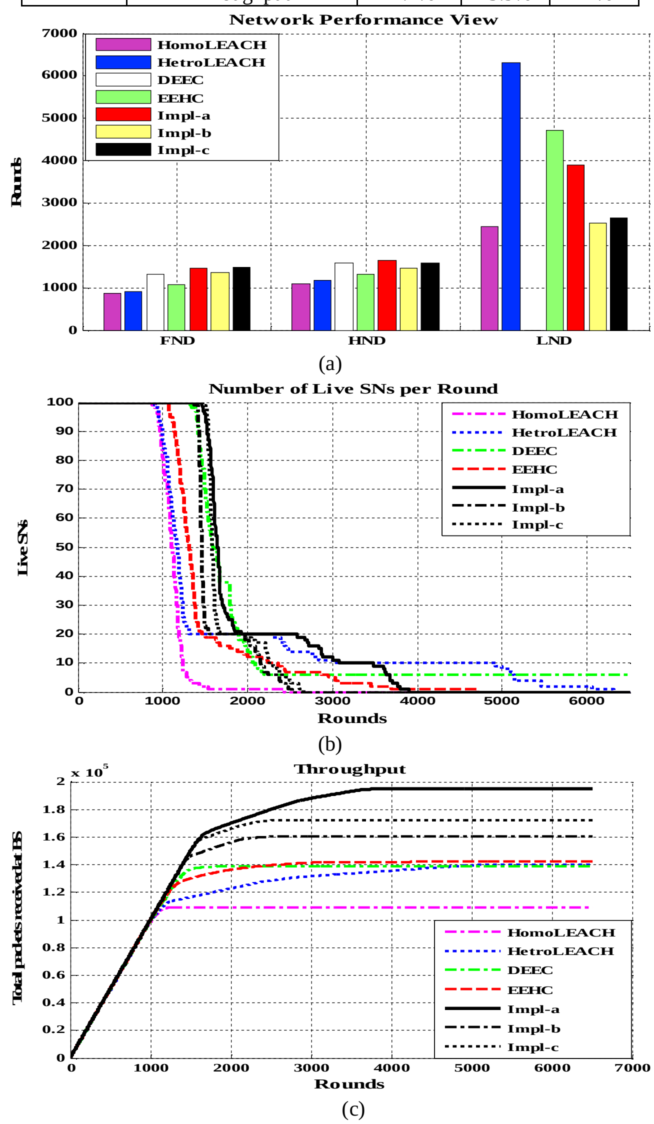
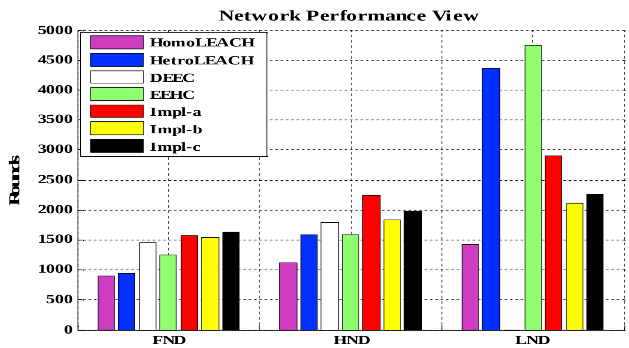


Figure 6. Results for Three-Level HWSN

TABLE 6. PERCENTAGE OF IMPROVEMENT BETWEEN THE PROPOSED ALGORITHM AND OTHER ALGORITHMS FOR MULTI-LEVEL HWSN

	Metrics	Hetero. LEACH	DEEC	EEHC
Impl-a	Stability period (FND)	68%	7.7%	26%
	HND	42%	25.6%	42%
	Throughput	38.7%	44%	38%
Impl-b	Stability period (FND)	64%	5%	23%
	HND	16%	2.9%	16.5%
	Throughput	13.6%	18%	13%
Impl-c	Stability period (FND)	73.6%	11%	30%
	HND	25%	10.6%	25%
	Throughput	22%	27%	21.8%



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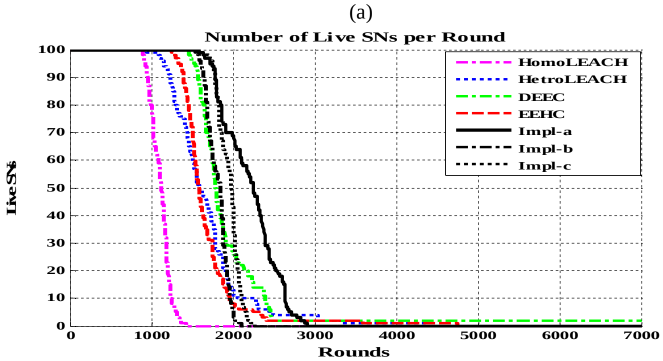

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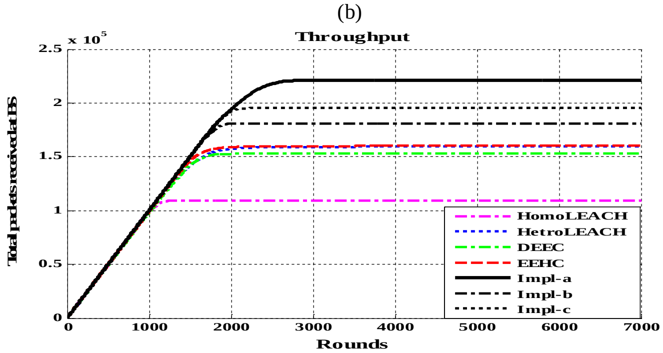
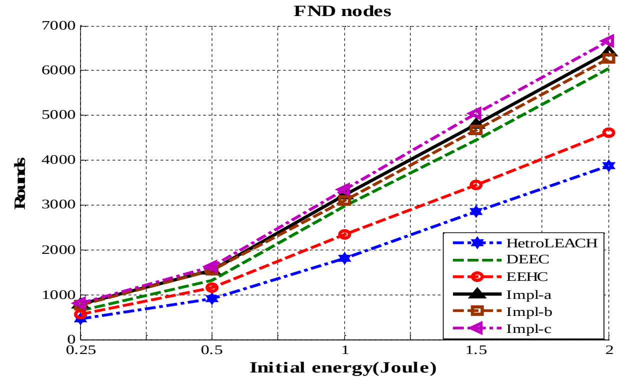
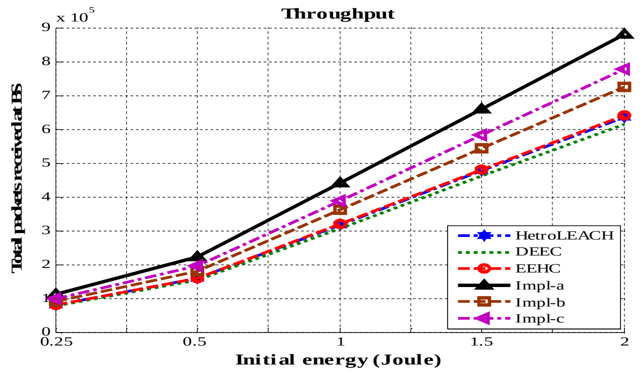


(c)

Figure 7. Results for Multi-Level HWSN [E_0, $2E_0$]

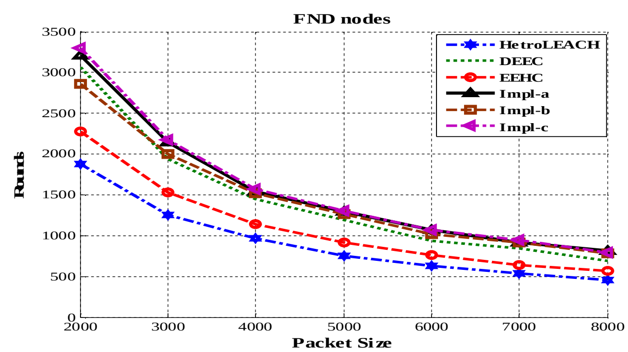


(a)

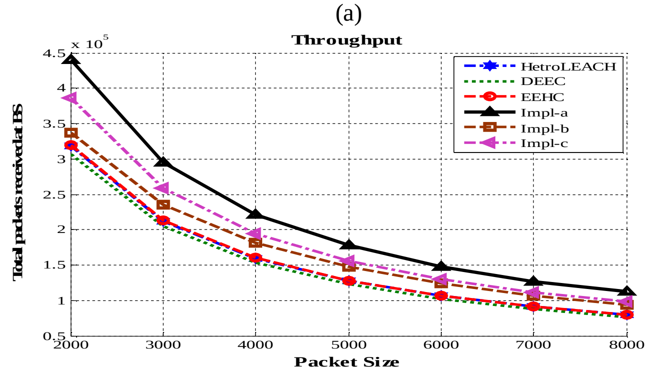


(b)

Figure 8. Performance results for Multi-Level HWSN with different ***initial energies:*** (a) FND and (b) Throughput.



(a)



(b)

Figure 9. Performance results for Multi-Level HWSN with different ***data packet sizes:*** (a) FND and (b) Throughput.

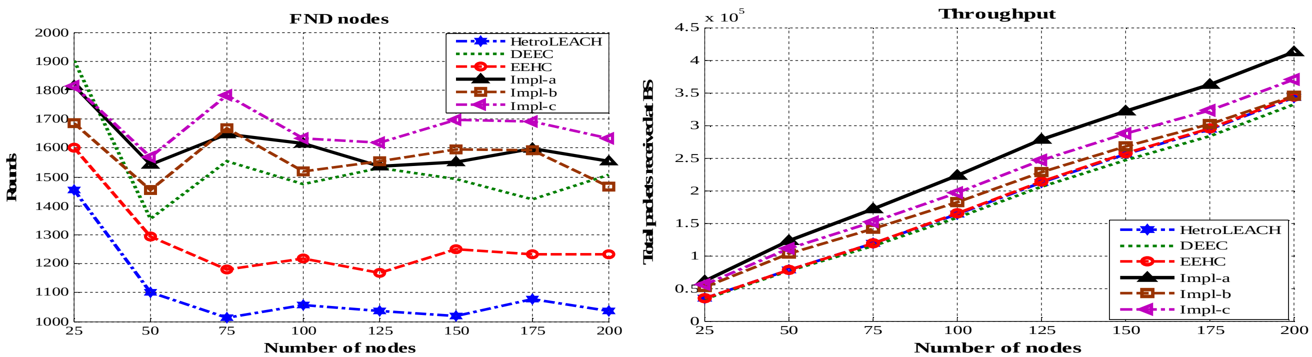


Figure 10. Performance results for Multi-Level HWSN with different ***numbers of SNs:*** (a) FND and (b) Throughput.

V. Conclusion and Future Works

In this paper, we proposed and evaluate WEPCS; a new clustering scheme for heterogeneous wireless sensor networks. WEPCS is an extension of the EEHC. In WEPCS, the election of cluster-heads is based on different weighted probabilities. The epochs of being cluster-heads for nodes are different according to their initial and residual energy. Finally, the simulation results show that WEPCS achieves longer lifetime and more throughput than current important clustering protocols in two-level, three-level, and multi-level heterogeneous environments.

The work done in this paper is based on the assumption that the communication environment is contention and error free.

A future extension of the work may consider the effect of the underlying medium access protocol. Also, the work can be extended by applying the algorithm to multi-hop HWSN.

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