



Hybrid energy efficient static routing protocol for homogeneous and heterogeneous large scale WSN

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Abstract

Wireless sensor networks consist of a large number of nodes deployed randomly in an area of interest. These nodes have sensing, computation, and wireless communications capabilities. In another hand nodes have energy constraints since they are equipped by non-rechargeable batteries. To handle this issue, routing protocols consist of designing the network in order to collect and transmit data with less energy consumption. In this paper we presented a new Hybrid Energy Efficient Static routing protocol (HEESR), combining between clustering and multi-hop routing techniques. HEESR is dividing the network into several levels. For each round, it creates clusters, route the collected data through gateways called Independent Nodes, elected using a new dynamic approach and introduces Dormant nodes. Finally, the proposed HEESR have improved network's life time, throughput and other compared metrics, in both homogeneous and heterogeneous networks, and prolonged network's stability zone up to 98.4% compared to LEACH, 98% compared to DEEC and up to 40.5% compared to SMR.

Keywords WSN · Hybrid routing · Energy consumption · Network lifetime · Throughput

1 Introduction

WSN has become a significant technology in the field of ubiquitous living and stays to be active research in many applications [1]. WSNs can give many benefits over traditional communications used in existing electrical power systems [2]. This type of networks have been increasingly adopted as a useful technology to improve different areas of electric power systems [3] and in IoT which is based on Low-Power Wireless Personal Area Networks [4]. In another hand, the energy harvesting problem in WSNs is attracting the attention of many researchers. This problem is caused by the fact that nodes are equipped with non-rechargeable batteries and often deployed in non-reachable areas. Many routing, power management, and data dissemination protocols have been specially designed for

WSNs where energy awareness is an essential design issue [5].

Although, routing protocols defines the structure of the network and data transmission strategy. For this reason, SMR [6] divided the network into levels, counted from the BS, and introduces another type of nodes called independent nodes INs, created by limiting the number of cluster members to N_0 , as in EDMHT-LEACH [7]. In addition, the cluster is divided into two levels, for that reason SMR consider inter and intra-cluster communication.

The remainder of the paper is organized as follow: Sect. 1 illustrates the introductory part of the WSN and the routing techniques, Sect. 2 outlines some related works, inspired by to develop the proposed method. The radio model used in the paper is presented in Sect. 3. Section 4 describes the proposed HEESR protocol, while Sect. 5 deliberates the results compared to some existing techniques, and Sect. 6 concludes the paper.

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2 Related work

In the last decades, energy harvesting was seen as the most challenging problem in WSNs. A lot of researches were done in order to handle this issue for both homogeneous and heterogeneous networks. Homogeneous networks are considered to be as the networks where the nodes have identical amount of energy [8]. For heterogeneous networks, initial energy of sensor nodes is randomly distributed over the close set $[E_o, E_o(1 + a)]$, where E_o is the lower bound and a determine the value of the maximal energy [9]. Thus a variety of protocols have been developed to handle this problem. Between those solution we find LEACH [10], based on a hierarchical process by selecting CHs periodically and drains energy uniformly by role rotation. Each node decides itself whether being a CH or not, distributed by a probability. Under homogeneous network, LEACH performs well, but its performance become badly in the heterogeneous network [9]. Ali et al. [11] proposed A-LEACH, which uses the initial energy and current energy of nodes for calculating the energy factor. In [12], C-LEACH balanced the energy consumption, considering the minimum and maximum number of members in each cluster and sets a threshold value for them. In [13] a Hybrid LEACH (H-LEACH) is proposed, it uses the number of clusters and total number of nodes in determining the selection of cluster heads and calculates the differences between the current and initial energy [2].

HEED [14] takes residual energy and communication cost into consideration when selecting a CH. In contrast with LEACH, HEED uses multi-hop communications between CHs and the BS. Moreover, HEED also provides guaranteed coverage of nodes in WSNs. However, it assumes that nodes can control their transmission power level. This is not always a realistic assumption [15]. In PEGASIS [16], nodes organizes theirs self to form a chain. This method is difficult to implement due to the requirement of global knowledge of the network topology. In a heterogeneous environment, SEP [17] considers that in the network there is two types of nodes, *normal nodes* and *advanced nodes* whom have an exceed of energy than normal nodes. SEP uses the same election process of LEACH except that each type of nodes has a specified election probability based on the proportion of each type in the network. DEEC [9], is an election energy aware protocol. It uses the same technique of LEACH, it introduce nodes residual energy in CHs election process so that nodes with more energy have more chance to be CHs than nodes with less energy. This process distribute consumption of energy in the network.

In another sens, the main principle of MHT-LEACH [18] is to dived the network into levels, counted from the

BS, where a CH located in a level (k) send its data to CHs located in lower levels ($k' < k$) and so one till the BS. EDMHT-LEACH [7] introduces another type of nodes called independent nodes INs, appeared by having a threshold value, N_o , of the number of cluster members. SMR [6] is based on the same clustering process used in EDMHT-LEACH, but with another election threshold vale. SMR considers two types of communications based on the leveling topology discussed before. The intra-communication topology considers routing data from cluster members to theirs CH, and the inter-communication topology describing routing data from CHs to the BS passing by INs. Al thought, The main problem of SMR is that the deployment and clustering processes are random, INs may be scattered in upper levels, so they will not help in routing data to the BS, resulting an exceed of energy consumption in the network.

In this paper, a hybrid energy efficient static routing technique is proposed for energy efficiency and energy balanced consumption (HEESR). This protocol is based on the same topology of communication used in SMR. To handle the problem of unused INs. HEESR, elects a pre-defined number of INs depending on the number of CHs in the upper levels and introduces a new kind of nodes called Dormant Nodes (DNs). INs election process is the one used to elect CHs in LEACH. Using this technique, INs are only elected if needed. As a result this technique reduces and balances energy consumption in the network.

3 Radio model

In this paper we use the common radio model of a node to represent consumed energy in different transmissions of collected data through the network to the BS (see Fig. 1). To compute the consumed energy, we use the energy dissipation model proposed in [19]. The required energy to transmit and receive a L -bits message is calculated using the following equations [19]:

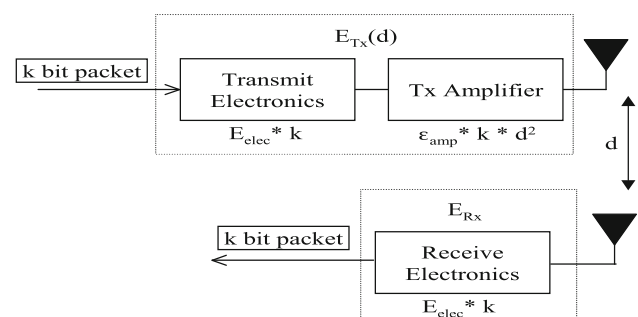


Fig. 1 Radio model of a node

$$E_{Tx}(d) = LE_{ele} + \begin{cases} L\epsilon_{fs}d^2 & \text{si } d < d_0 \\ L\epsilon_{amp}d^4 & \text{si } d \geq d_0 \end{cases} \quad (1)$$

$$E_{Rx} = LE_{ele} \quad (2)$$

With d is the distance between the two nodes, E_{TX} is the energy dissipated during transmission and E_{RX} is the consumed energy in reception. ϵ_{fs} is the transmission power in the free space transmission model, ϵ_{amp} is the transmission power in the multi-hop transmission model. d_0 is the limit value between free space and multi-hop transmission models, it's expression is giving in [19, 20] as follow:

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{amp}}} \quad (3)$$

4 Proposed method

This paper outlines a new Hybrid Energy Efficient Static Routing technique (HEESR). We suppose that network's life time is divided into rounds, in each round, we denote three phases: the set-up phase, path selection phase and the routing phase. We suppose, in this study, that all nodes are static and randomly deployed, in a region of interest (ROI).

4.1 Set-up phase

In this phase, the network is divided into levels, CHs are elected, INs are placed and clusters are formed. The network will be divided into levels starting from the BS, the

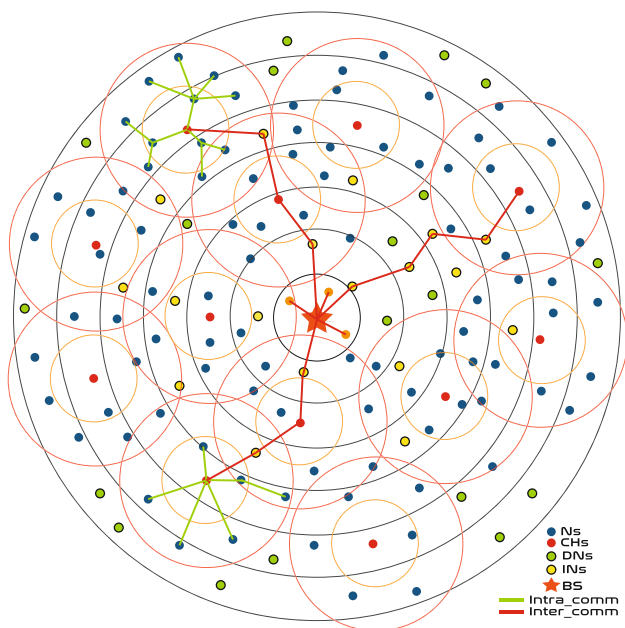


Fig. 2 Network leveling process with Intra and inter communications

length of each level is $d_0/2$ (see Fig. 2). Each node calculate it's level based on the distance to the BS. For example, a node located with a distance less than $d_0/2$ from the BS will belong to the first level, whereas the node with a distance equal or larger than $d_0/2$ but less than d_0 will belong to the second level and so on [6]. Same, clusters are divided into two levels of $d_0/2$ from the CH.

4.1.1 Cluster heads election

The election process adopted in this paper uses an improved threshold expression. Each node in the network chooses a random number between 0 and 1. If the chosen number is less than the threshold value $T(n)$, expressed, as in [21], in Eq. (4), the node becomes a CH. Otherwise, the node remains a normal node, for the current round.

$$T(n_i) = \begin{cases} \max\left(\frac{p_i}{1 - p_i \cdot \left(\text{rmod} \frac{1}{p_i}\right)} \times \frac{E_{res}}{E_{init}}, T_{min}\right) & \text{si } \{n_i\} \in G \\ 0 & \text{Otherwise.} \end{cases} \quad (4)$$

Here, the E_{res} is the residual energy of the node. E_{init} denotes the initial energy given to each node before starting its activity. T_{min} refers to the minimum value of the threshold, which can be used if the E_{res} value has descended to low values. After finishing electing the CHs, the clustering formation process begins.

Algorithm 1 CHs election process

SN : Set of normal sensor nodes
T : CHs election threshold
Require: *q* : Random number between 0 and 1
E(S) : Residual energy of the sensor node S

begin:

```

1: for each S ∈ SN do
2:   if (E(S) > 0) then
3:     S choose a number q between 0 and 1
4:     if q < T then
5:       S is a CH for the current round
6:     else
7:       S is a normal node for the current round
8:     end if
9:   end if
10: end for
11: Calculate Nbr.CHk(r) and Nbr.Nk(r) end;
```

Hence, in what follows, we introduce a number of concepts useful for clusters formation and the network topology.

4.1.2 Independent nodes election

As expressed in Eq. (1), dissipated energy depends on transmission distance. It is clear that minimizing transmission distance reduces energy consumption. To handle this problem, an other type of nodes called INs is introduced (as in [6]). Those nodes are responsible of routing data sent from CHs or INs, located in upper levels, to the BS. To well distribute the INs in the network, in each level the number of INs is determined based on the number of CHs in the upper level, as expressed in Eq. (5).

$$T'(S_i^k) = \begin{cases} \frac{p_i^k(r)}{1 - p_i^k(r) \left(r \bmod \frac{1}{p_i^k(r)} \right)} & \text{if } \{S_i^k\} \in G' \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

With G' is the set of sensor nodes, legitimate to be an INs for the round r , that means, nodes which have not been INs in the last $1/p_i^k$ rounds.

Algorithm 2 INs election process

Nbr_CH^k : Number of CHs in each level k
Nbr_N^k : Set of CHs
Require: T' : INs election threshold
 $E(S)$: Residual energy of the sensor node S
 G' : Set of legitimate nodes to be INs for the current round

begin:

- 1: **for** each $S \in SN$ **do**
- 2: **if** ($S \in G' \& E(S) > 0$) **then**
- 3: **for** each level k **do**
- 4: calculate $Nbr_IN^k(r)$ and $p_i^k(r)$
- 5: S choose a number q' between 0 and 1
- 6: **if** $q' < T'$ **then**
- 7: S is an IN for the current round
- 8: **else**
- 9: S is a normal node for the current round
- 10: **end if**
- 11: **end for**
- 12: **end if**
- 13: **end for**

end;

$$Nbr_IN^k(r) = \alpha Nbr_CH^{k+1}(r) \tag{5}$$

With $Nbr_IN^k(r)$ is the number of INs, to elect for the level k , Nbr_CH^{k+1} is the umber of CHs in the leve $lk + 1$ during the round r and α is a weight.

To balance energy consumption in each level, INs are elected using same process of CHs but with another probability and threshold expressions.

The probability $p_i^k(r)$ of a node S_i^k to be an IN for the round r is expressed as follow:

$$p_i^k(r) = \frac{Nbr_IN^k(r)}{Nbr_N^k(r)} \tag{6}$$

$Nbr_N^k(r)$ is the number of nodes alive located in the level k during the round r .

INs election process is the same as the one used for CHs election in LEACH [10], but with different optimal election probability. The threshold value is expressed as follow:

4.1.3 Clustering

After CHs election process, each one broadcasts messages to declare themselves to other nodes in the network. Each announcement message includes the CH identification (CH ID) and the coordinates of its position [6]. To balance energy consumption, in the network, the number of nodes in each cluster is limited to N_o :

$$N_o = \frac{Nbr_NA(r)}{Nbr_CH_t(r)} \tag{8}$$

With $Nbr_NA(r)$ denotes the number of total nodes alive and $Nbr_CH_t(r)$ stands for the number of CHs elected in the current round r .

On the other side, each normal node calculate the distance to each CH, based on received messages. After calculating different distances to all CHs, each normal node transmit a JOIN-REQ message toward the CH that owns the lowest distance value and that the distance is less or

equal to d_o . The CH, in turn, creates a TDMA schedule, based on the number of nodes wanting to join the cluster. Once the Schedule is created, CH broadcast it to the cluster members, so that every node knows the time reserved to transmit their data (See Algorithm 3).

Algorithm 3 Clustering process

SN : Set of normal sensor nodes
 SCH : Set of CHs
Require: d_{S-CH} : distance between node and CH
 C_d_{S-CH} : closest distance between node and CH
 N_o : Optimal number of nodes in each cluster
 $Curr_n$: Current number of nodes in the cluster.

begin:
 1: **for** (each $CH \in SCH$) **do**
 2: CH broadcast an announcement messages to the rest of the network.
 3: CH wait for JOIN-REQ messages
 4: **end for**
 5: **for** (each $S \in SN$) **do**
 6: calculate d_{S-CH} .
 7: **if** ($d_{S-CH} \leq d_o$) **then**
 8: **if** ($d_{S-CH} == C_d_{S-CH}$) **then**
 9: SN send a JOIN-REQ to the closest CH
 10: **end if**
 11: **end if**
 12: **end for**
 13: **for** (each $CH \in SCH$) **do**
 14: **if** ($Curr_n < N_o$) **then**
 15: CH send a REQ- ACCEPTED message to the SN
 16: CH create a TDMA schedule and send it to it's cluster members.
 17: **else**
 18: CH send a REQ-REFUSED message to the SN
 19: **end if**
 20: **end for**
end;

Sensor nodes who have not been able to join any cluster are called Dormant nodes (DNs). It should be noted that, DNs do not participate at all in the process of communication. Those nodes will turn off their sensors and transceivers for the current round.

4.2 Path selection phase

In this phase each node in the network select it's next hope if necessary. Two steps are considered, the *advertising phase*, were all nodes declares them self in the network and the *path selection* phase where every node choose it's next hop.

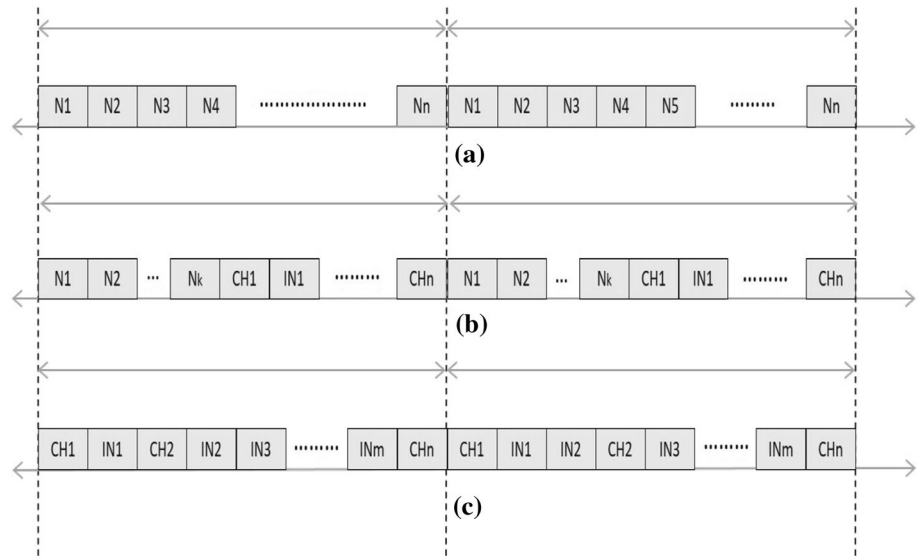
4.2.1 Advertising

After clustering process, each node declare itself in the network broadcasting an advertising message. Normal nodes broadcast messages containing their IDs, cluster IDs, levels, and coordinates. Furthermore, the CHs and INs broadcast their IDs, levels, and coordinates.

4.2.2 Path selection

At this stage, all nodes are able to generate their routing tables (RT), In both approaches. In this paper we use the same concept of RTs used in [6]. Based on the advertising messages, for intra-cluster communication, nodes located in a distance greater than $d_o/2$ from the CH, creates a RT.

Fig. 3 The time division multiple access (TDMA) schedule of **a** normal node; **b** CH; and **c** IN



The entry of this RT is a list of next probable hops, nodes existing in the 1st level of the cluster, based on the distance.

Afterward, each node transmits a JOIN-REQ to all nodes of the first level of the cluster. In the other hand, the normal node that receives the request checks for a empty slot in its TDMA scheme. If there is one, it allocates for the requester. Then, it transmits an affirmation message to the sender. Thus, all nodes that send approvals are added to the RTs. The TDMA schedule of normal nodes is only dedicated for its neighboring nodes at the same cluster (See Fig. 3).

Furthermore, for inter-cluster communication, CHs and INs located in a distance greater than $d_o/2$ from the BS create a RT. The entry of the RT are CHs and INs located in lower levels from the BS. Thus, the CHs and INs transmit the JOIN-REQ messages to each other and they wait for the approval to enable them to create their RTs. Accordingly, all messages, which are received from the same and upper levels, will be neglected. As in [6]. The TDMA schedule of the CH has been divided into two sections: the first part is allocated to cluster members and the second part is allocated to other neighboring CHs and INs. Finally, the slots of the TDMA schedule of the IN are only assigned to the neighboring CHs and INs. (See Fig. 3).

4.3 Routing phase

This phase represent the real communication step, where every node monitor its environment and send data to the BS through the optimal selected path using RTs. Routing data is essentially based on the distance between sender and receptor. It can happen that the distance to the node chosen, using RTs is larger than the distance, either to the CH, or to the BS. In this case the node send directly to its

superior. The proposed method is considered static because, for each round, each node chooses a single path to transmit data. In the proposed method, we have two communication schemes. For both cases, lets denote a receptor node as RN, and the sender node as SN. In both types, each node selects the route with minimum distance to conserve energy while transmission (See Fig. 2).

4.3.1 Static intra-communication routing process

Each cluster member computes its distance to the CH (d_{SN_CH}) to determine its level. SNs in the first level send their collected data to the CH directly. On the other hand, the SNs of the second level use their RTs to select their routes. The details of the intra-cluster routing process are developed by the following pseudo-code (See Algorithm 4).

Algorithm 4 Intra-cluster communication

```

    SN      : Sender node
    RN      : Receptor node
Require: RT      : Routing table
     $d_{SN\_CH}$  : distance to CH
     $d_{SN\_RN}$  : distance to the node selected from the RT.

    begin:
1: if ( $d_{SN\_CH} \geq d_{SN\_BS}$ ) then
2:   SN sent directly to the BS
3: else
4:   if ( $d_{SN\_CH} \geq \frac{d_o}{2}$ ) then
5:     SN select  $RN \in RT$ .
6:     if ( $d_{SN\_RN} \geq d_{SN\_CH}$ ) then
7:       SN send directly to it's CH.
8:     else
9:       SN send the data to the CH through RN.
10:    end if
11:  end if
12: end if

    end;

```

4.3.2 Static inter-communication routing process

In the inter-cluster communication, CHs and INs located in the first level send their data, directly, to the BS. In the other hand, CHs and INs, located in upper levels send data to the nodes selected, based on the distance and availability, in their RTs. As mentioned before, for inter-cluster communication, CHs and INs passes their data through CHs and INs located in lower levels based on the distance.

Algorithm 5 Inter-cluster communication

```

Require:
    SN      : Sender node( CH, IN )
    RN      : Receptor node(CH, IN)
    RT      : Routing table
    dSN_BS : distance to BS
    dSN_RN  : distance to the node selected from the RT.

begin:
1: if (dSN_BS ≥  $\frac{d_0}{2}$ ) then
2:   SN select RN ∈ RT.
3:   if (dSN_RN ≥ dSN_BS) then
4:     SN send directly to the BS.
5:   else
6:     SN send the data to the BS through RN.
7:   end if
8: end if

end;
```

5 Simulation results

5.1 Simulation model and parameters

A MATLAB program is used to evaluate the performance of HEESR in a network of 200 nodes randomly deployed in an area of 300 × 300 m with the BS location is variable. Analysis will be divided into two experiments, in the first experiment, we will discuss the performance of HEESR in a homogeneous network. In the second experiment, HEESR performance is evaluated in a heterogeneous network. Common parameters used in the simulations, are mentioned in Table 1.

5.2 Performance metrics

HEESR is evaluated in homogeneous and heterogeneous networks compared to SMR, DEEC and LEACH. We evaluate the performance according to the following metrics.

- *Life-time* Number of nodes alive.
- *Throughput* Number of packets sent to the BS.
- *Network’s residual energy* Total energy consumption in the network.
- *FND* First node dead round.
- *HND* Half node dead round.

Table 1 The essential simulation parameters

Parameters	Value
a	1 or 0
α	0.8
Énergie initiale(E_0)	0.5 J
p	0.2%
d_0	70 m
E_{elec}	50 nJ/bit
E_{fs}	10 pJ/bit/m ²
E_{amp}	0.0013 pJ/bit/m ⁴
E_{data}	5 nJ/bit
T_{min}	0.03
L	6400 bit

- *AND* All node dead round.
- *SZI* Stability Zone Improvement compared to HEESR.

In order to determinate the effect of the BS location on compared metrics, two cases are discussed in each type of networks. The first case is where the BS is located in the center of the network, and the second one is where the BS is located far from the network, which represents a realistic case especially when the ROI is hard to achieve (See Table 2).

5.3 Results

5.3.1 Homogeneous network

For both BS locations, network’s life-time and the number of packets sent to the BS are illustrated in Fig. 4. We can observe that the stability zone, wish represent the number of rounds till the death of the first node, is extended using HEESR compared to SMR, DEEC and LEACH (See Fig. 4a, b). Consequently, the number of packets sent to the BS has increased using HEESR compared to SMR, DEEC and LEACH (See Fig. 4c, d).

In the other side, HEESR and SMR’s life-time and throughput have not been affected by the large distance to the BS. This can be explained by the fact that CHs in LEACH and DEEC send directly their data to the BS.

Table 2 Experiments specifications

Experiment	Nbr. nodes	BS coordinates	Network’s type
1	200	150 × 150	Homogeneous (a = 0)
	200	150 × 350	Homogeneous (a = 0)
2	200	150 × 150	Heterogeneous (a = 1)
	200	150 × 350	Heterogeneous (a = 1)

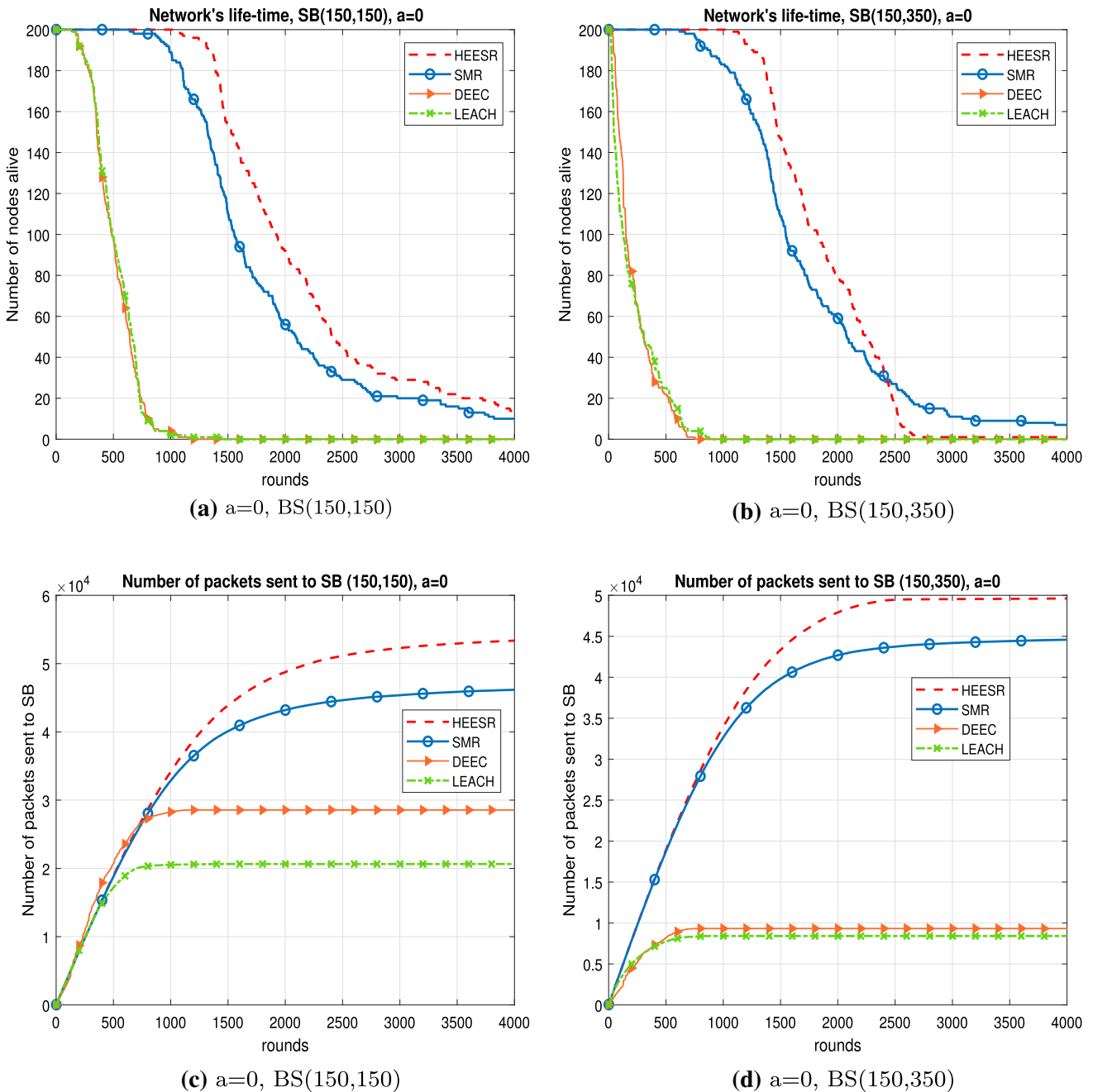


Fig. 4 Network’s life-time and throughput of compared protocols in a homogeneous network in both BS’s locations

However, In HEESR and SMR, introducing INs and DNs for multi-hop routing techniques is used to handle this problem.

In term of energy, heterogeneity will appear in the network rather it was homogeneous at the beginning. This heterogeneity is caused by the different amount of consumed energy of each node per round, which is not the same. So, at this stage, each node will have a unique

residual energy. For this reason, HEESR is evaluated in a heterogeneous network.

5.3.2 Heterogeneous network

To create an heterogeneous network, each node will have a specific energy equal to $E_0(1 + a_i)$, with $0 < a_i \leq a$ [9]. In this case each node will have a specific exceed of energy that makes it unique in the network.

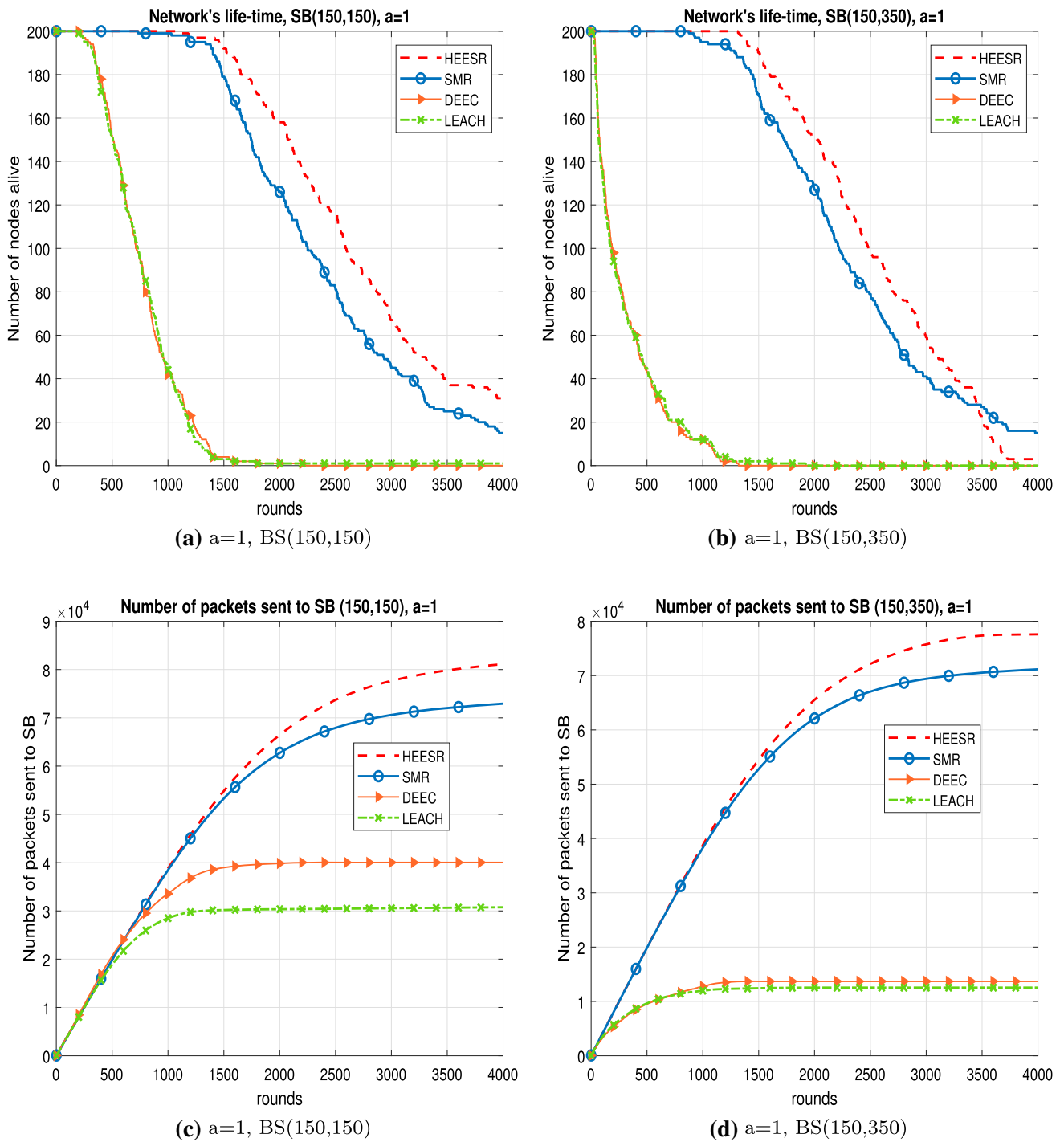


Fig. 5 Network's life-time and throughput of compared protocols in a heterogeneous network in both BS's locations

Figure 5 present our protocol performance in an heterogeneous network, compared to SMR, DEEC and LEACH. Interestingly, as in homogeneous networks, HEESR performs very well in term of stability zone, network's life-time (See Fig. 5a, b) and throughput (See Fig. 5c, d), in both BS's locations.

5.3.3 Energy consumption

Another important metric to care about is network's total energy consumption. Figure 6, illustrates Network's total energy consumption during life-time in all cases.

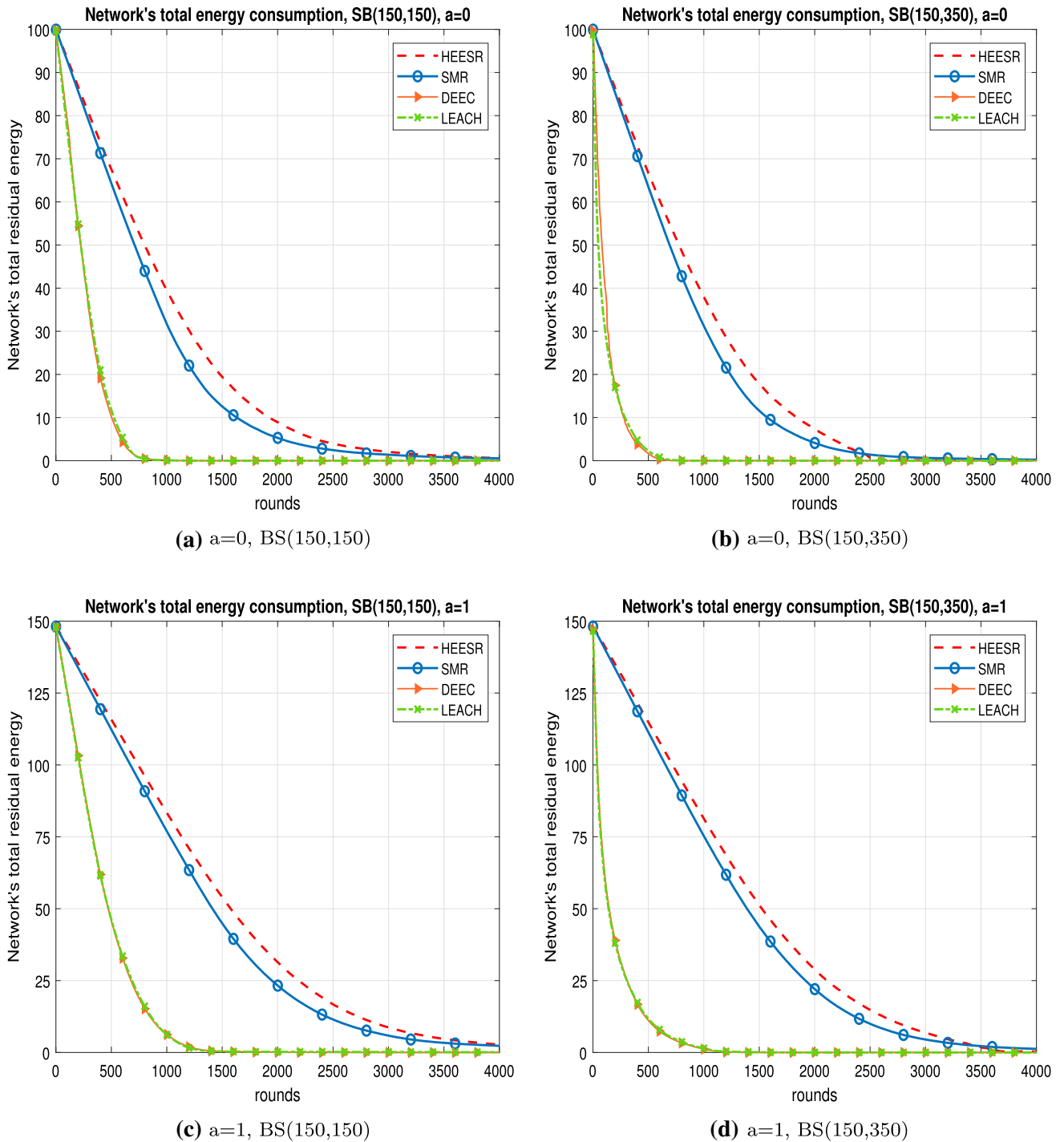


Fig. 6 Network’s total energy consumption using HEESR, SMR,DEEC and LEACH in all simulation cases

It is remarkable that energy harvesting is less using HEESR compared to other protocols in all cases. This result justify the benefit of the modification added by HEESR, of well distributing INs in the network and not choosing them randomly as in SMR.

5.3.4 Statistics

To know more about the evolution of the network using different protocols, more statistics presenting information about significant rounds of all compared protocols are resumed in Table 3.

Table 3 FND, HND, AND and SZI of HEESR compared to SMR, DEEC and LEACH in all simulations

Exp.	Technique	FND	HND	AND	SZI
(a = 0,150,150)	HEESR	1047	1920	> 4000	***
	SMR	642	1553	> 4000	38.7%
	DEEC	133	485	1155	87.3%
	LEACH	139	486	1448	86.7%
(a = 0,150,350)	HEESR	1037	1822	> 4000	***
	SMR	618	1544	> 4000	40.5%
	DEEC	24	150	753	97.7%
	LEACH	23	126	878	97,8%
(a = 1,150,150)	HEESR	1077	2588	> 4000	***
	SMR	731	2249	> 4000	32%
	DEEC	214	710	2201	80%
	LEACH	193	727	1921	82%
(a = 1,150,350)	HEESR	1315	2480	> 4000	***
	SMR	874	2215	> 4000	33%
	DEEC	26	187	1319	98%
	LEACH	21	172	1921	98.4%

SZI is the improvement in stability zone of the HESSR compared to other protocols. *** indicates that it cannot be compared HESSR with itself

The stability zone of HEESR is larger by a minimum of 32% compared to all protocols, this justifies used routing topology.

5.4 Results discussion

Analyzing obtained results, HEESR showed a remarkable improvement, in stability zone, network's life time, throughput and energy consumption, compared to SMR, DEEC and LEACH. This improvement, has been achieved because the proposed approaches suppose that all nodes are ranged on levels around the BS, and that each node calculate it's levels according to the distance to the BS. Particularly, the CHs and the INs determine their levels around the BS, whereas the cluster members of each cluster will identify their levels based on the distances to its CH. Furthermore, Thus, all sensor nodes of the network use multi-hop routing to deliver the data to the destinations either the BS or the CHs.

In addition, we have noted that the HEESR has achieved a larger stability zone and bigger throughput compared to the SMR in all simulations. The reason leading to this result can be related to two facts. The first one is the INs new election process used in our proposed technique. This process elects a predetermined number of INs in each level based on the number of CHs in the upper level. This way INs are elected only if needed and well distributed in the network. Contrary to SMR that considers all nodes not

belonging to any cluster as INs. Knowing that the deployment and clustering processes are random, INs may be scattered in upper levels, so they will not help in routing data to the BS, resulting an exceed of energy consumption in the network.

The second fact is considering nodes not belonging to any cluster as dormant nodes for the current round, this proposal may create holes in the network, in term of useful data, but it preserves the residual energy of the network (See Fig. 6).

We can also observe that HEESR have a longer life-time compared to other protocols when the BS is located in the center of the network, for both network types (See Figs. 4a and 5a). When the BS is far from the network SMR shows a longer life time compared to HEESR in last rounds (See Figs. 4b and 5b) but it didn't affect, neither, the global amount of data sent to the BS witch demonstrates that HEESR have bigger throughput than SMR (See Figs. 4d and 5d), nor energy consumption (See Fig. 6b, d), showing that HEESR have less energy consumption compared to all protocols in all simulation cases.

All compared metrics have been improved passing from an homogeneous to an heterogeneous network, which is related to the exceed amount of energy added to each node, in order to create heterogeneity in the network.

We can also observe that network's life time has not been affected by the large distance to the BS in both network types, using HEESR and SMR, contrary to LEACH and DEEC. This can be only explained by the fact that in LEACH and DEEC, CHs transmit their data directly to the BS, no matter what the distance is. This results a raise in energy consumption specially for far CHs and create an unbalanced consumption of energy. In the other hand HEESR and SMR limited the distance of transmission to $\frac{d_0}{2}$, for both inter and intra communications, using multi-hop transmission and introducing the INs. This solution reduced the energy consumed by nodes during transmission and results prolonging network life time and improving throughput.

6 Conclusion

In this paper, we presented a new Hybrid Energy Efficient Static Routing technique. The proposed HEESR is the modification of the Static Multi-hop Routing technique (SMR), where all nodes could be in one of three situations during the network rounds: CH, IN or Normal nodes. Using network leveling strategy, HEESR adopts two types of data routing: the first type is the intra-cluster data routing and the second type is the inter-cluster data routing. The SMR technique have presented a new approach for disseminating

the data through the network levels. In the other hand, our proposed technique considered that INs are chosen in a dynamic way based on the number of CHs in upper levels, and considers nodes not belonging to any cluster as dormant nodes (DNs) for the current round.

Four simulations were done to evaluate the performance of the HEESR in homogeneous and heterogeneous networks with variable locations of the BS. Simulations results demonstrated that, using HEESR have prolonged the stability zone up to 98.4% compared to LEACH, 98% compared to DEEC and up to 40.5% compared to SMR. The proposed technique have increased life-time and throughput, because the proposed protocols managed to extend the network lifetime and to improve the stability of the network. Energy consumption is reduced by applying network leveling approach, limiting the number of nodes in each cluster and election of INs on demand.

Finally, basing on simulations results, we can conclude that HEESR performs very well, in all networks types and all BS locations, compared to SMR, LEACH and DEEC. This improvement touches all evaluated performance metrics, especially when the BS is located far from the center of the network, which represents a real case, because in a non-reachable zone, nodes are randomly deployed by a plane. Knowing that the BS must have a big computational performances it will be located far from the network.

View the huge development in computer science and artificial intelligence, evolutionary algorithms have been used to find optimal solutions for several problems in different fields, such as automatic control [22] and electronic engineering [23]. As perspectives to this work, it is planed to use evolutionary algorithms in order to have a dynamic CHs election and route selection processes, in order to reduce energy consumption and improve network's life-time and throughput.

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References

- Rodrigues, P., & John, J. (2020). Joint trust: An approach for trust-aware routing in WSN. *Wireless Networks*, <https://doi.org/10.1007/s11276-020-02271-w>.
- Chan, L., Gomez Chavez, K., Rudolph, H., et al. (2020). Hierarchical routing protocols for wireless sensor network: A compressive survey. *Wireless Networks*, <https://doi.org/10.1007/s11276-020-02260-z>.
- Gungor, V. C., Lu, B., & Hancke, G. P. (2010). Opportunities and challenges of wireless sensor networks in smart grid. *IEEE Transactions on Industrial Electronics*, *57*(10), 3557–3564.
- Abdelhadi, E. H., Aicha, S., & Abdelmajid, B. (2019). Assessment of a proactive routing protocol RPL in Ipv6 based wireless sensor networks. In *Third international conference on intelligent computing in data sciences (ICDS), Marrakech, Morocco* (pp. 1–7). <https://doi.org/10.1109/ICDS47004.2019.8942364>.
- Al-Karaki, J. N., & Kamal, A. E. (2004). Routing techniques in wireless sensor networks: A survey. *IEEE Wireless Communications*, *11*(6), 6–28. <https://doi.org/10.1109/MWC.2004.1368893>.
- Alnawafa, E., & Marghescu, I. (2018). New energy efficient multi-hop routing techniques for wireless sensor networks: Static and dynamic techniques. *Sensors Journal, Basel*, <https://doi.org/10.3390/s18061863>.
- Alnawafa, E., & Marghescu, I. (2017). EDMHT-LEACH: Enhancing the performance of the DMHT-LEACH protocol for wireless sensor networks. In *16th RoEduNet conference: Networking in education and research (RoEduNet)* (pp. 1–6). Targu Mures.
- Kumari, C. U., & Padma, T. (2019). Energy-efficient routing protocols for wireless sensor networks. In *Soft Computing and Signal Processing. Advances in Intelligent Systems and Computing* (Vol. 898). Springer, Singapore.
- Qing, L., Zhu, Q., & Wang, M. (2006). Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. *Computer Communications*, *29*, 2230–2237.
- Heinzelman, W. R., Chandrakasan, A., & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In *Proceedings of the 33rd annual Hawaii international conference on system sciences, Maui, HI, USA* (Vol. 2, p. 10). <https://doi.org/10.1109/HICSS.2000.926982>.
- Ali, M., Dey, T., & Biswas, R. (2008). ALEACH: Advanced LEACH routing protocol for wireless microsensor networks. In *IEEE conference on electrical and computer engineering* (pp. 909–914).
- Mehta, R., Pandey, A., & Kapadia, P. (2012). Reforming clusters using C-LEACH in wireless sensor networks. In *International conference on computer communication and informatics* (pp. 1–4).
- Azim, A., & Islam, M. (2009). Hybrid LEACH: A relay node based low energy adaptive clustering hierarchy for wireless sensor networks. In *IEEE conference on communications* (pp. 911–916).
- Younis, O., & Fahmy, S. (2004). HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *IEEE Transactions on Mobile Computing*, *3*(4), 366–379.
- Yan, J., Zhou, M., & Ding, Z. (2016). Recent advances in energy-efficient routing protocols for wireless sensor networks: A review. *IEEE Access*, *4*, 5673–5686. <https://doi.org/10.1109/ACCESS.2016.2598719>.
- Lindsey, S., & Raghavendra, C. S. (2002). PEGASIS: Power-efficient gathering in sensor information systems. In *Proceedings, IEEE aerospace conference, Big Sky, MT, USA* (p. 3).
- Smaragdakis, G., Matta, I., & Bestavros, A. (2004). SEP: A stable election protocol for clustered heterogeneous wireless sensor networks. In *Second international workshop on sensor and actor network protocols and applications (SANPA 2004)*.
- Alnawafa, E., & Marghescu, I. (2016). MHT: Multi-hop technique for the improvement of leach protocol. In *15th RoEduNet conference: Networking in Education and Research, Bucharest* (pp. 1–5).
- Heinzelman, W., Chandrakasan, A., & Balakrishnan, H. (2002). An application-specific protocol architecture for wireless micro sensor networks. *IEEE Transactions on Wireless Communications*, *1*(4), 660–670.
- Zhao, Z., Xu, K., Hui, G., & Hu, L. (2018). An energy-efficient clustering routing protocol for wireless sensor networks based on AGNES with balanced energy consumption optimization. *Sensors (Basel)*, *18*(11), 3938. <https://doi.org/10.3390/s18113938>.

21. Selvakennedy, S. & Sinnappan, S. (2005). A configurable time-controlled clustering algorithm for wireless sensor networks. In *11th International conference on parallel and distributed systems (ICPADS'05)*, Fukuoka (pp. 368–372).
22. Mouhou, A., Badri, A., Ballouk, A., & Sayouti, Y. (2017). Genetic algorithms optimization of tuning parameters of generalized predictive control. In *International conference on electrical and information technologies (ICEIT)* (pp. 1–5). <https://doi.org/10.1109/EITech.2017.8255281>.
23. Bouyghf, H., Benhala, B., Raihani, A., Pereira, P., & Sallem, A. (2017). Optimal design of RF CMOS circuits by means of an artificial bee colony technique. In *Focus on swarm intelligence research and applications* (pp. 221–246). NOVA Science Publishers.

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