

An Energy Efficient Cluster-heads Re-usability Mechanism for Wireless Sensor Networks

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Abstract—Wireless sensor networks (WSNs) are formed using a cluster of sensor nodes (SNs), deployed randomly to perform sensing operations in an area under observation. Due to the unavailability of an external power source, the energy efficiency considered as one of the critical issues in WSNs. Selection of a sensor node (SN) from a wireless sensor network (WSN) cluster to serve as an aggregator or cluster head (CH), considered as an efficient method to increase the lifetime of wireless sensor network (WSN). In this paper, we have proposed an energy efficient CH selection scheme for WSN, to enhance the lifetime and average residual energy of a single WSN cluster. The proposed strategy nominates a group SNs as CHs, based on their channel condition with the base station (BS) and their residual energy. The proposed algorithm is helpful in solving the problem of unbalanced energy consumption in WSNs. Furthermore, the mechanism of using mobile sink during the hand-off stage helps to overcome the delay in data transmission. Moreover, the incorporation of energy harvesting significantly increases the lifetime of WSN. In comparison to a state-of-art technique available in the literature, our scheme shows a 33% increase in lifetime and presents a steady decrease in residual energy for the same rounds of data transmission.

Index Terms—Wireless sensor network (WSN), lifetime, cluster head selection, average residual energy.

I. INTRODUCTION

WIRELESS sensor networks (WSNs) offers a vast range of advantages to many applications by lowering their cost and reducing their overall power consumption [1]. These additive advantages of wireless sensor network (WSN) have increased their use in many fields including advanced agriculture [2], [3] and many other, related to the automatic irrigation system for farmland [4], to improve the yield of crops. The integration of WSN in the internet of things (IoT) can be used to generate an early warning of earthquake [5]. In this context, the WSN provides a wide range of applications and considered as one of key enabling technology for IoT. A WSN is an arrangement of randomly distributed devices, i.e. sensor nodes (SNs), which are interconnected having sensing capabilities to communicate and share data with some special features [6]. These SNs are used for multimedia applications by installing a CMOS device, e.g. camera, on sensor node (SN) [7]. Each SN is equipped with limited resources and thrown in terrain with an unconditional climate having a pre-configured set of tasks,

that it needs to perform. Each of deployed SN in WSN cluster faces a considerable energy issue and needs to manipulate the power consumption to increase their lifetime and make sure that they perform all the allocated tasks.

Diverse solutions are presented in the literature to allow each SN in WSN to utilise their limited resources efficiently. Many energy efficient scheduling techniques are available in the literature [8], to accommodate each SN to perform well under confined power resources. Authors in [9] proposed an idea of multicore energy efficient scheduling with energy harvesting for wireless multimedia sensor network (WMSNs), by utilising lightweight processors (LWP) to manifold multiple tasks practically, without compromising on deadline. In [10] a routing protocol based on spanning tree technique using the hybrid multi-hop partition clustering, is presented to enhance the lifetime of the WSN.

A. Related Work

A plethora of research work has been done by the research community to enhance the energy efficiency of WSN. Deploying each SN in WSN using an effective deployment scheme is considered as one of the critical methodologies to improve the energy efficiency of WSN. In connection, clustering can be utilized while considering the dense deployment of SNs to maintain an acceptable average energy consumption. In [11] a clustering methodology has been introduced that helps the network to recuperate SNs from the futile gateway without considering, re-clustering or close down of the system to increase the overall system efficiency. Furthermore, in [12] the authors propose a constrained coverage (CC) algorithm which introduces two virtual forces to ensure that each cluster node has at least K-Neighbors, but this scheme may result in a low network coverage area and a decrease in lifetime of SNs. Similarly, in [13] the concept of virtual force is utilized for clustering, but the mechanism may lead to an unstable lifetime of WSN.

The selection of a cluster head (CH) in a WSN cluster can be used to prolong the network lifetime and to maximize the communication range. Low-energy adaptive clustering hierarchy (LEACH) [14], is considered as one of the main clustering algorithms to enhance the lifetime of a WSN cluster.

An acceptable amount of research work is available in the literature that exploits the LEACH protocol to increase the energy efficiency of WSN [15]. In [16] a two-step optimized zone based energy efficient protocol (OZEEP) has been proposed, which incorporates the genetic fuzzy systems (GFS) to optimize the clustering and the selection of cluster heads (CHs) in WSN. Authors in [17] suggested a routing protocol based on a novel energy-aware hierarchical cluster (NEAHC) to select CHs by introducing threshold schemes. An energy efficient adaptive selection of CH for wireless sensor networks (WSNs) has been proposed in [18], that uses the dissipated and residual energy levels in the modified version of LEACH protocol to provide a balance energy efficiency.

A dynamic cluster head selection method (DCHSM) for WSN has been introduced in [19], that dynamically selects a CH based on their residual energy and dynamically changes the CH after the death of the previous CH. In [20] the authors use the approach of hesitant fuzzy for CH selection by analysing their distance from the centre of the cluster and their range from the base station (BS) location. Similarly, in [21] the concept of nominating a CH based on their position on a WSN cluster is combined with their energy consumption while assuming a uniform distribution of SNs. In connection, the authors in [22] connect the location-based approach with balanced energy consumption to select a CH. Furthermore, the concept of spare CH is introduced in [23], while considering a hybrid key management mechanism.

B. Our Contributions

In this paper, we have proposed an energy efficient CH selection scheme to optimize the overall lifetime and average energy consumption of a WSN cluster. The proposed technique significantly increases the lifetime of WSN and provides a solution to the problem of unbalanced energy consumption in the WSNs. The main highlighted contributions of the paper are as follows:

- An energy efficient scheme has been proposed that equips the BS with a group of CHs, selected from a WSN cluster.
- The idea of the mobile sink has been utilized to decrease the delay and to efficiently cater to the low power state of the CH during the hand-off stage.
- To prolong the network survival time, each CH changes its state to sleep mode and perform energy harvesting after reaching the hand-off threshold level.
- We are incorporating the use of harvesting energy to enhance the reusability of each CH node, enduring the sleep mode.

The remaining part of the paper is organized as follows: Section 2 explained the system model and the proposed scheme in detail. Section 3 shows a comparison of the proposed methodology with a technique available in literature through some simulations. Finally, we conclude the paper in Section 4. Moreover, in Table I, symbols used throughout the article has been listed to provide ease to the readers.

TABLE I
SYMBOLS USED THROUGHOUT THE PAPER

Symbol	Meaning
δ	Hand-off threshold
β	Residual energy threshold
α	Channel gain threshold
γ	SNR threshold
g_n	Gain of user n
P_n	Received power of user n
d	BS location from WSN Cluster
τ	path loss exponent
Pt_n	Transmit power
Rs_n	Residual energy of user n

II. SYSTEM MODEL AND PROPOSED SCHEME

A. System Model

We have assumed a single cluster of WSN, pictorially expressed in Fig. 1. The cluster of a WSN consists of N number of SNs that are generated randomly and deployed uniformly. A BS is located at a distance d from the WSN cluster. A Rayleigh fading channel has been assumed between each transmitter and receiver pair. The following equation can be used to calculate the path-loss between each transmitter and receiver in dB:

$$PL = FSPL + 10\tau \log_{10}(s) + X_{\zeta}, \quad (1)$$

where, s is the distance between the receiver and the transmitter, τ is the path-loss exponent, X_{ζ} incorporates the large scale signal variation, and FSPL is the free space path loss. The FSPL can be calculated using the following equation

$$FSPL = 20 \log_{10} \left(\frac{4\pi f}{c} \right), \quad (2)$$

where, f is the carrier frequency and c is the speed of light. Thus, the received power P_n of SN n at the receiver end is calculated using the following equation:

$$P_n = PL * Pt_n * g_n^{-\tau}, \quad (3)$$

where, Pt_n is the transmit power of SN n and g_n is the channel gain of the same SN. A series of SNs are selected by the BS, to nominate them as a CH. The selected SNs is then dynamically assigned to a numerical rank value. The SN with the highest rank is selected as the CH. Moreover, if the R_n of the selected CH node drop below the hand-off threshold δ , a hand-off procedure is initiated by cooperating with a nearby mobile sink, this cooperation reduces the delay in the data transmission between the SNs and the BS. The SN, which handover its duty as a CH, changes its state from active to sleep and starts harvesting energy to be renominated as CH. In this experimental setup, we have assumed that the SNs changing their state, have a redundant node, which is considered while SNs deployment. We have defined one round

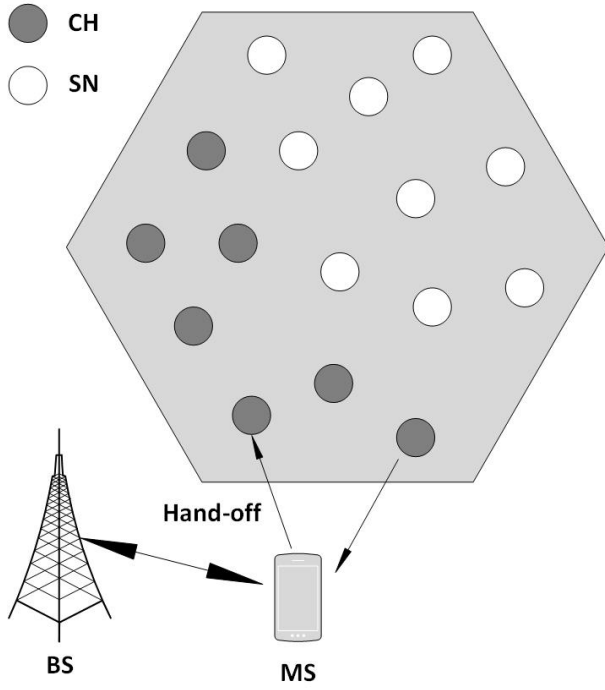


Fig. 1. An illustration of a WSN cluster having SNs with selected CHs and the hand-off procedure using a nearby mobile sink.

as the time taken by the packet to be successfully received by the BS, transmitted from the CH. In connection, the time taken to perform a hand-off is also considered as one round. Furthermore, we assume that for each round the overall energy consumption is the same. The energy consumption in each round E_{rnd} can be calculated using the following equation:

$$E_{rnd} = t(N * PL + N * \theta * D_{S-C} + \theta * D_{C-B}), \quad (4)$$

where, t is the total taken by each round, D_{S-C} is the distance between the SNs and the current CH, D_{C-B} is the distance between the current CH and the BS and θ is the total re-transmission losses. Therefore the lifetime of WSN is calculated using the following equation:

$$L_r = \frac{E_t}{E_{rnd}}, \quad (5)$$

where, E_t is the total initial energy of the network and L_r is the total number of successful rounds during the life cycle of WSN.

B. Proposed Scheme

An energy efficient approach to select a CH for a WSN is presented in this paper. The proposed approach exploits the use of energy harvesting to increase the overall lifetime of a WSN. A Rayleigh fading channel has been considered between each CH and the BS. A group of SNs are nominated by the BS to be considered as CHs, if they satisfy the channel gain threshold α and residual energy threshold β , respectively. A list of nominated CHs by the BS are further categorized based on their channel gain g_n and residual energy R_n and

are tagged with a unique identification i.e. $rank = 1, \dots, r_n$, in a descending order. The residual energy at the BS for each CH is calculated using their P_n , i.e. we have assumed that P_n and R_{s_n} have a good correlation. Algorithm 1 provides an insight into the proposed scheme. The proposed algorithm analysis the pilot signal received by each SN and use N , g_n , P_n , and R_{s_n} as its main input. Moreover, the algorithm works in the following four stages:

- In stage 1, the algorithm compares the received power P_n of each SN with the SNR threshold γ . The SNs, that satisfies the first condition is further analysed using their channel gain and residual energy values. Again the SNs that satisfies the second condition, are nominated as CHs.
- In stage 2 of the algorithm, the nominated CHs are tagged using a unique identification, i.e. rank and are labelled in descending order, based on their residual energy and channel gain.
- The selection of a CH for WSN is made at stage 3. The nominated SNs with the highest rank is selected as a CH.
- If the residual energy of the selected CH drops below the hand-off threshold δ , a hand-off process is initiated by the BS using the cooperation of nearby mobile sink. For the experiment, we have assumed that a mobile sink is always available during the hand-off stage.

After the hand-off stage, the SN changes its state to sleep mode and starts to harvest energy using the installed harvesting circuit. Furthermore, the algorithm runs in a recursive manner till the battery drainage of each SN or the unavailability of a SN to perform as CH for WSN. This recursive nature of the algorithm running at the BS helps to re-analyse the SNs performing energy harvesting.

C. Complexity Analysis of Proposed Algorithm

In this section, we have calculated the computational complexity of our proposed, CH selection algorithm, using Algorithm 1. For the input, the number of sensors N has no complexity because of its independent nature. The remaining inputs g_n , P_n , and R_{s_n} respectively has a complexity of $\mathcal{O}(N)$, therefore the total complexity of input becomes $\mathcal{O}(N)$. To make the complexity analysis simpler, we have calculated the complexity of each step separately, as shown in Algorithm 1. Starting from step 1, we have a for-loop that performs its operation between line 3 and 9 of the algorithm and has a complexity of $\mathcal{O}(N)$. Inside this for-loop, we have a different set of operations having a maximum complexity of $\mathcal{O}(2)$. The output at this stage has a complexity of $\mathcal{O}(N)$. Using this detailed step by step analysis, the overall complexity of step 1 is $\mathcal{O}(N)$. Secondly, for step 2 we have two nested for-loops having a complexity of $\mathcal{O}(N)$ and $\mathcal{O}(N - 1)$ respectively. Inside these, for loops, the maximum complexity is $\mathcal{O}(2)$. Therefore the overall complexity of step 2 is $\mathcal{O}(N^2)$. Thirdly, for step 3, again we have a for-loop having a similar complexity of $\mathcal{O}(N)$, because of its dependency on N with inside operations having a maximum complexity of $\mathcal{O}(1)$. The complexity at this stage is $\mathcal{O}(N)$. For the last step of the algorithm, we have a for-loop having an inside operation

that reconsiders the step 3, which makes the complexity of this step as $\mathcal{O}(N^2)$. Our proposed algorithm has a complexity of 2^{nd} order polynomial, i.e. $\mathcal{O}(N^2)$, which can be explained further using the following equation:

$$\mathcal{O}(N^2) = \mathcal{O}(N) + \mathcal{O}(N^2) + \mathcal{O}(N) + \mathcal{O}(N^2). \quad (6)$$

Algorithm 1 CH selection and hand-off mechanism using mobile sink

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1: INPUT ( $N, g_n, P_n, R_{s_n}$ )
2: Step 1: Selection of CHs
3: for  $b = 1, \dots, N$  do
4:   if  $P_n(b) > \beta$  then
5:     if  $g_n(b) > \alpha$  &&  $R_{s_n}(b) > \delta$  then
6:       push  $N(a)$  user in new array  $Z[a]$ 
7:     end if
8:   end if
9: end for
10: OUTPUT List of selected CHs  $Y[\cdot]$ .
11: Set  $Rank = 0$ 
12: Step 2: Rank assignment
13: for  $c = 1, \dots, length(Z)$  do
14:   for  $d = c + 1, \dots, length(Z)$  do
15:     if  $g_n(c) > g_n(d)$  &&  $R_{s_n}(c) > R_{s_n}(d)$  then
16:       Assign  $Z[c] = Rank + 1$ 
17:     end if
18:   end for
19: end for
20: Step 3: Selection of 1st CH
21: for  $e = 1, \dots, length(Z)$  do
22:   if  $Z[e] == HighestRank$  then
23:     select  $Z[e]$  as CH
24:   else if  $Z[e] == (HighestRank - 1)$  then
25:     select  $Z[e]$  as CH
26:   end if
27: end for
28: Step 4: Changing of CHs using mobile sink
29: for  $e = 1, \dots, length(Z)$  do
30:   if  $R_{s_n}(e) < \delta$  then
31:     Perform hand-off using mobile sink
32:     Repeat step 3
33:   end if
34: end for

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III. PERFORMANCE EVALUATION

In this section, we demonstrate the improvement achieved regarding the energy efficiency of WSN using some simulation performed in MATLAB. We use two performance indicator parameters, i.e. lifetime and the average residual energy of WSN, respectively, to show the significance of our proposed scheme. Furthermore, we compare our proposed technique with a state-of-art dynamic CH selection mechanism available in the literature.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
δ	2.5 Joule
β	-120 dBm
γ	-120 dBm
Pt_n	8 dBm
N	50 to 500
$round$	200 seconds
d	2 meters
τ	3.5
$Powerbank$	10 Joule

A. Simulation Parameters

In the experimental setup a total number of $N = 50$ SNs are deployed in a WSN cluster. The total coverage area of a WSN cluster is set as $300 m^2$. The maximum transmit power Pt_n for each SN is set as 8 dBm, and it varies between 1 dBm and 8dBm in discrete levels, depending upon their residual energy. The value of path loss exponent τ is set as 3.5. We assumed that at the deployment stage, each SN is equipped with a power bank of 10 Joules and it decreases by 0.5 Joule with packet transmission. The SNR threshold γ is set as -120 dBm and the channel gain threshold α correlates with γ . The hand-off threshold δ strictly depends upon the remaining power in the power bank of each SN and is set as 2.5 Joule. The SNs is equipped with a single antenna for wireless transmission, and an energy harvesting circuit is installed on it. The selected CHs that are in sleep mode and to be renominated for the selection of CH, can perform energy harvesting, while remaining SNs are restricted. The BS is located at distance $d = 2$ meters from the WSN cluster as shown in Fig. 1. We have also assumed that each SN transmits its packet to the BS, by using its allocated time slot, while the CH can aggregate up to 5 SNs packets before transmitting it to the BS. The value of a single round is set at 200 seconds. We have assumed that the SNs performing energy harvesting can charge up their battery by 0.25 Joules in a single round. Moreover, the numerical values considered during the simulation process is summarized in Table II.

B. Simulation Results

In this section, we have compared our proposed technique with [19], using some key parameters, i.e. lifetime and average residual energy of WSN. Firstly, in Fig. 2 we have plotted the lifetime of WSN against the varying number of SNs in a WSN cluster. For this experimental setup we have varied the value of N from $N = 50$ to $N = 300$. From the simulation results, it is quite evident that our proposed scheme outperforms and increases the overall lifetime of a WSN by 33% in comparison to [19]. The increment in the lifetime of a WSN by using our proposed approach can be explained from the fact that, our approach uses a group of CHs rather than sticking to a single CH. Moreover, the scheme in [19] looks for a new CH after

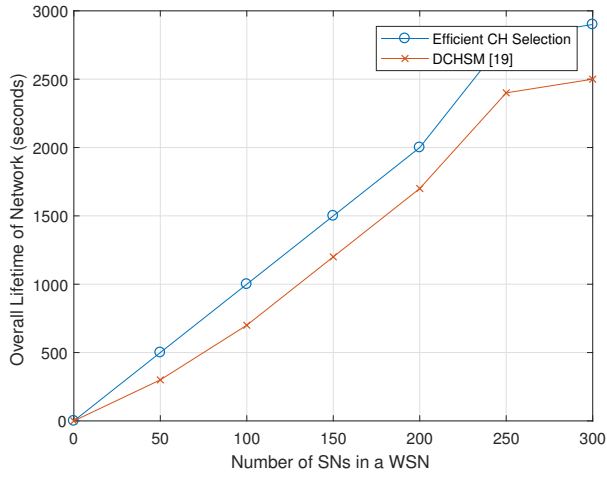


Fig. 2. A comparison of overall lifetime with varying number of SNs in a WSN cluster.

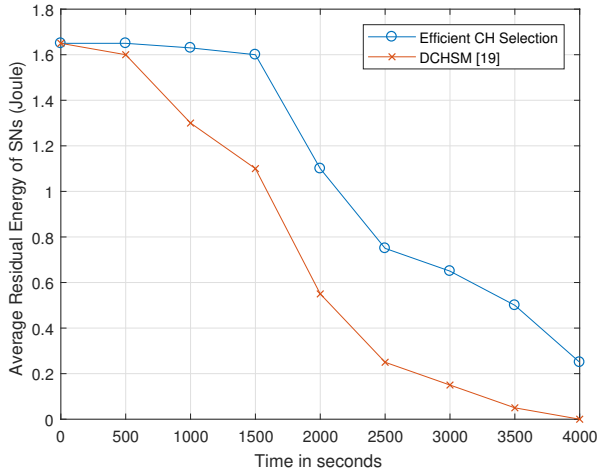


Fig. 3. A comparison of overall average residual energy of a WSN cluster with varying number of rounds during T time duration.

the death of the first CH and does not propose any method to reuse that CH. Finally, the concept of using a mobile sink makes the hand-off stage more efficient without the loss of extra energy and reduces the delay.

In Fig. 3, we have shown a trend of residual energy with some successful rounds. Our proposed scheme shows a significant improvement, by stabilizing the residual energy even with an increased number of rounds. In comparison to a state-of-art methodology [19], our proposed scheme enhanced the overall average residual energy by the orders of 1.5 in magnitude. The stability in the average residual energy can be explained by the utilization of energy harvesting by the CHs. Furthermore, the decreased performance of [19] is because it drains all the energy of the current CH. Moreover, in [19], the mechanism of redundant SNs can be considered as an efficient method but on the expense of increased cost.

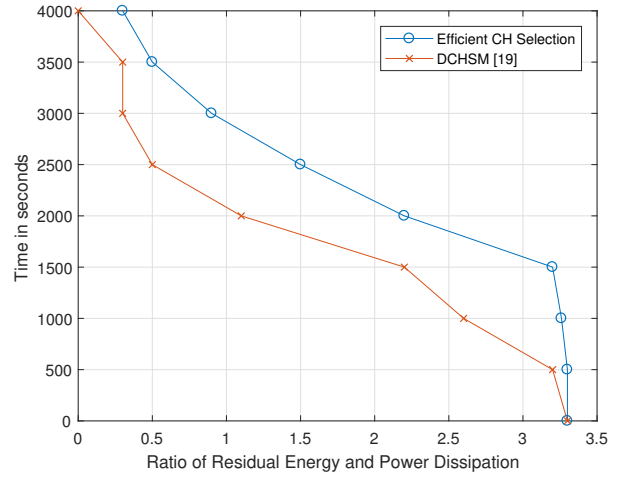


Fig. 4. A comparison of ratio of average residual energy and power dissipation per round with the total number of rounds taken during T time duration.

To further show the improvement in overall performance of a WSN by using our proposed scheme, we have plotted the variation in the ratio of average residual energy and power dissipated per round, with the total number of successful rounds during the T time duration. This variation can be seen in Fig. 4. For each successful round, the average residual energy of a WSN is divided by the total power dissipated by the WSN during packet transmission. In comparison to [19], our algorithm shows an increase in improvement by order of approximately 2.5 in magnitude. The improvement is by the utilization of energy harvesting performed by the SNs, competing to renominated as CHs. Moreover, the trend is to some extent similar in both the schemes. The incorporation of the energy harvesting circuit in our scheme also increases the cost, but in return, it increases the overall average residual energy and lifetime of a WSN.

IV. CONCLUSION

In this paper, an energy efficient mechanism for the selection of CHs of WSNs is presented. The experimental results are carried out by considering the average residual energy and the lifetime of a WSN. The comparison has been made with a state-of-art technique available in the literature, to validate the performance of our proposed algorithm. The proposed scheme improves the inequality of average energy consumption and reduces the delay effect in the transmission by using a mobile sink during the hand-off stage, which prolongs the WSN lifetime. Furthermore, our proposed scheme enables the reuse of a CH node by utilizing the energy harvesting technique. Finally, the proposed scheme shows an improvement in the lifetime of a WSN by a factor of 33% and the average residual energy has been increased by 1.5 orders of magnitude while comparing with the DCHSM method. In future, we are aiming to enhance the re-usability of CHs by employing some machine learning techniques.

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