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Research paper

Performance investigation of proposed adaptive heterogeneity in WSN

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Abstract

Recently Wireless Sensor Networks (WSNs) have become the optimal solution for handling many tasks. However, there are many tasks due to their critical situations need continues and a comprehensive monitoring of the environment. Accordingly, judicious designs of such networks are necessary. In this work, an adaptive scheme for enhancing the network performance in terms of load balancing during the heterogeneous WSN life time is proposed. The proposed scheme is based on dynamically modifying the probability of Cluster Heads (CHs) election in order to balance the load during the latest rounds when the network began to lose its power and thus weakening its reliability. The network performance is investigated based on the proposed scheme materialized by many scenarios. And it has shown that, adaptively electing CHs related to the network energy will enable the network to recover its reliability and enhancing the performance in terms of throughput and living nodes.

Keywords: *Cluster Head; Heterogeneous WSN; Load Balancing; WSN Throughput; WSN Life Time.*

1. Introduction

Recently WSN have been attracted many researchers' efforts due to the significant and reliable role these networks play in many applications such as; military surveillance, patient monitoring, environmental monitoring, traffic transportation, and vibration monitoring [1].

WSN consists of tiny, low power, small storage capacity and limited processing ability sensors, where they are usually randomly employed at the region of interest. How to manage and configured WSN is still a big challenge and the area of exploring new schemes to enhance the networks performance is still widely opened.

However, each application or task that employs WSN has its own specifications and Quality of Services (QoS) requirements. Accordingly, the researcher contributions were considering different aspects of WSNs. Some applications' objective is only monitoring the environment of continuous and homogeneous events, where the network life time is the significant concerns even with low nodes density. Designing or enhancing routing protocol, proposing new energy conservation schemes are the main topics in these applications to prolong the network life time despite other aspects.

Other applications need to collect data from environment with nonhomogeneous events for a finite interval. In such applications, supporting QoS in terms of low delay and/or high throughput has the priority among other metrics. The next section introduces some of these researches' contributions.

The researcher in [1], proposed a modified protocol to enhance the performance of heterogeneous WSN in terms of Life Time by dynamically selects CHs in a four levels of node energy depends on residual energy levels of nodes and average energy level of the network.

An adaptive data collection scheme was proposed in [2], where multiple sensing tasks are required. In this work sensors compete together when they sensing and transmitting the same data class, while sensors which are sensing different classes sharing the same channel in a priority manner according to the QoS levels required.

A dynamic routing is optimized for each sensor node in WSN in [3]. The proposed algorithm is based on residual energy estimation for dynamically select an optimal channel to extend the lifespan and reduce the information loss.

In [4], the researcher represents the advantages of proposed adaptive system that forming and selecting the best cluster heads at each round in order to manage the energy consumption. The proposed scheme was being simulated for an ad hoc networking system, which composed from mobile sensors that communicate via radio frequencies. The best cluster was formed based on offloading the CHs computational tasks by forming the cluster with sensors that sense the most similar data.

The researcher in [5] introduces an efficient scheme for enhancing the network QoS in terms of throughput by energy conservation. The proposed scheme based on both inter- and intra-cluster routing and cluster heads rotation in a multi-layers scenario. A threshold of dropped packets and load balancing between nodes are the metrics that were based for implementing and evaluating the proposed scheme.

A fuzzy logic algorithm was based in [6-7] in order to select the most eligible nodes as CHs. The selection of eligibility in [6] is a tradeoff between throughput and the energy consumption. The author considers that increasing the number of CHs not necessarily increase the throughput, since large number of packets may leads to collision and hence loss of data and energy. While in [7], the selection of appropriate nodes as CHs is a tradeoff between the location of these nodes relative to the sink nodes from one side, and the nodes members from the other side. Where the CH's location effects directly the number of cluster connection and hence energy.

In [8], a new hybrid algorithm which is derived from two nature inspired optimization algorithm is proposed to optimize the selection of CHs. The simulation results show an enhancement in terms of end to end delay, number of packets drop and alive nodes compared to origin CHs selection protocol. The cost function was materialized by multi-objective function and solved by soft computing.

In this work, the role of proposed adaptive scheme is simulated and investigated. This scheme is implemented in heterogeneous WSN to modify the probability of CHs election in order to enhance the network performance by balancing the load between nodes through successive rounds. The proposed scheme can be implemented in many applications where specific phenomena need a comprehensive observation, in addition to continuously sensed and reported such as disaster cases.

The rest of this paper organized as follows; section two will present the main theoretical aspect related to WSN. The system model will be introduced in section three. The simulation results will be illustrated in section four with their analyses and discussions. Finally, the main conclusion is introduced in section five.

2. WSN theoretical background

The hierarchical routing protocols were proven to be the best solution for balancing the load between the nodes in order to extend the network life time [9]. By implementing those protocols, the network is divided into clusters and each cluster is constructed from a set of member nodes and one CH. CHs take the responsibility of gathering the data from the clusters member nodes, processing and re-transmitting these data to the Base Station (BS) [10]. Low Energy Adaptive Clustering Hierarchy (LEACH) was the first hierarchal protocol that was implemented in a homogenous network, where all nodes have the same battery initial energy (Eo). LEACH prolongs the network life time energy by randomly rotating the function of CH between nodes through many rounds, and hence evenly distributes the energy between the nodes [11]. The CH election decision is determined by comparing a random number r (between 0 and 1) to a threshold value T(n) as in equation (1) [11]:

$$T(n)=\begin{cases}\dfrac{P}{1-P(r\bmod(\frac{1}{P}))} & if n\in G\\ 0 & otherwise\end{cases} \quad (1)$$

Where P is the probability of CHs election, n is the node number and G is the total nodes. In reality not all nodes experience the same energy consumption. Accordingly, a new Stable Election Protocol (SEP protocol) was introduced for heterogeneous network [9]. SEP implements heterogeneity by proposing two groups of sensor nodes, advance with m% density and extra α% energy more than of the rest normal nodes. By applying SEP, CHs are elected based on weighted election probabilities according to the remaining energy in each node. The probability for normal and advance node to be a CH are $Pnrm$ and $Padv$ respectively which are given by [12] as below:

$$P_{nrm}=\frac{P}{1+\alpha.m} \quad (2)$$

$$P_{adv}=\frac{P}{1+\alpha.m}(1+\alpha) \quad (3)$$

Later, SEP is extended to SEP-E [13] in order to introduce more robust performance in terms of network life time. SEP-E introduces three levels of heterogeneity by deploying intermediate nodes with b% density and µ% extra energy and it acts as intermediate level between advance nodes and normal nodes. The CH election probability is modified to be convenient with the three types of nodes to be as given by [13]:

$$P_{nrm}=\frac{P}{1+\alpha.m+\mu.b} \quad (4)$$

$$Padv=\frac{P}{1+\alpha.m+\mu.b}(1+\alpha) \quad (5)$$

$$P\text{int}=\frac{P}{1+\alpha.m+\mu.b}(1+\mu) \quad (6)$$

3. Problem statement and proposed adaptive scheme

The probability of electing CHs for different type of nodes in a multilevel heterogeneity network is based on the predetermined probability and the density of each level's nodes as abovementioned in equations (2)-(4). Accordingly ($1/Pnrm$), ($1/P\text{int}$) and ($1/Padv$) will determine the number of rounds that a normal node, intermediate and advance nodes can be re-elected as CH respectively. The number of rounds for re-selecting each type of nodes is identified as epoch. Hence, each nodes type will has different epoch. As the network passing its stability period (the number of rounds till first node dies), its performance began to degrade as its nodes began to loss energy and die. As a result, the number of elected CHs and the throughput per round will be decreased. At the latest rounds, there may exist rounds with very limited or even non CHs, we called it "poor and empty rounds". This is due to the death of nodes with high election probability and the long epoch for the rest live nodes. Accordingly, the network will either loss its energy faster at poor rounds, because less number of CHs means large cluster size and hence more energy consumption for the members nodes. Or, the system will suffer from scars sensed information at empty rounds, since each sensor sends its sensed information only to its CH.

To solve this problem, an adaptive scheme is proposed in this work, so that the probability of reelecting CHs will be dynamically changed during the network life time and hence the heterogeneity percentage. The re-election probability was modified to be proportional with the percentage of living nodes during the network life time as shown below:

$$P_{adv}^{\ r+n}=\beta P_{adv}^{\ r} \quad (7)$$

$$\beta\propto\Delta m^{r+n}+\Delta\mu^{r+n} \quad (8)$$

$$P_{\text{int}}^{\ r+m}=\gamma P_{\text{int}}^{\ r} \quad (9)$$

$$\gamma\propto\Delta m^{r+m}+\Delta\mu^{r+m} \quad (10)$$

Where, $P_{adv}^{\ r+n}$ and $P_{\text{int}}^{\ r+m}$ represent the new election probability for advance node after passing n rounds and intermediate nodes after passing m rounds respectively. β and γ represent the modification factors for advance and intermediate nodes respectively, and these factors proportional with the variation of advance and intermediate nodes density at n and m rounds.

The proposed adaptive scheme enables the network to reduce the election probability as the nodes density decrease and hence reduce the number of rounds per epoch, which results in increasing the average number of CHs per rounds and hence average throughput. To investigate the contribution of the proposed scheme, simulation was performed for different scenarios as will be discussed through next section.

4. Simulation results and discussion

The proposed scheme was simulated using Matlab version R2016b for 100x100 m^2 network area. 100 nodes were considered with 10% advance nodes and 20% intermediate nodes. The extra energy equals to (1) and (0.5) for advance and intermediate nodes respectively. The network parameters are assumed as in table 1. Many scenarios were suggested and simulated as below:

1) Modifying the probability is performed according the death of all nodes' type, then probability of each type CHs' election is modified according to the percentage of death of this type. The network was tested when the election probability is modified once at the 75% and 50% of the network living nodes. The results of these scenarios are addressed as "Ma1 and Ma2" respectively.
2) Modifying the probability according to the death of each node's type once during the network life time, thus the modification of each type is done independently of the others. The results of these scenarios are addressed as "Mb1" and "Mb2" for 75%, 50% of the nodes density respectively.
3) The network was tested when the election probability is modified twice; at 75% and then at 50% of the network life represented by the nodes density. The results of these scenarios are addressed as "Mc".

Table 2 represents the behavior of the network during the execution of the proposed scheme, where 1st and 2nd columns represent the modified percentage of advance and intermediate nodes respectively in addition to corresponding rounds. The new election probabilities are illustrated in 4th – 6th columns for normal, intermediate and advance nodes respectively. The simulation results in terms of average throughput, CHs distribution and probability of living nodes at each period of the network life time are investigated and compared to original SEP-E protocol (referred to it as scenario "O") as will be introduced through next sections.

4.1. Performance in terms of average throughput per round

Throughput is referred to the number of bits per second received through the network lifetime. Throughput (Thr) can be determined by the summation of packets (Nprec) that can be collected by the CHs per n rounds as in equation below [14]:

$$Thr = \sum_{r=1}^{n} \frac{Nprec * P_{bit}}{T} \qquad (11)$$

Where(P_{bit})represents the number of bits per packet. In this work, the throughput is assessed and compared according to (Nprec) only, since the number of bits per packet and the round time is fixed for all nodes.

Fig. 1 depicts the average cluster throughput per round for all the above mentioned scenarios and table 3 illustrates the results. The results are represented using box plots. Box plot is a statistical method used to determine the distributional characteristics of a group of data by depicting the minimum, maximum and median values beside the 1st and 3/4th quartile. The spacing between the quartile indicates the spreading degree of data [15]. The following points can be noticed from table (3):

1) The maximum (minimum throughput is achieved by scenario "Ma" when the probability is modified at 50% of the nodes density and no empty rounds are noticed in both "Ma1" and "Ma2" scenarios. This due to the reduction of heterogeneity materialized by the death of advance nodes and the reduction of intermediate nodes (as was noticed through the simulation steps), which in turns increase the probability of normal nodes to be CHs.
2) Scenarios "Ma1" then "C" gain the highest median values, which reflect an increasing in the average throughput per rounds.
3) Scenario "Ma1" achieves the shortest boxplot (Q3-Q1) which indicates that the proposed scheme in this scenario success in redistribute the throughput more uniformly during the network life time.
4) The value (Q3-Med) represents the average throughput at the early rounds of the network life time, where the throughput is usually high. At the other side, the value (Med-Q1) represents the average throughput at the late rounds of the network life time, where the throughput is usually low. From this point of view, Scenario "C" scheme has the almost the most normally distribution among other scenarios.

Table 1: Some of Parameters of Network Model [6]

parameter	value
Packet size	12000 bits
Probability of mode to become cluster head	0.1
Transmit/Receive Energy	Eele= 50nJ/bit
Data Aggregation Energy	EDA=5nJ/bit
Transmitter Amplification d <= Threshold distance	Efs = 10pJ/bit/m^2
Transmitter Amplification d> Threshold distance	Emp= 0.0013pJ/bit/m^4
Initial Energy	Eo =0.3 J

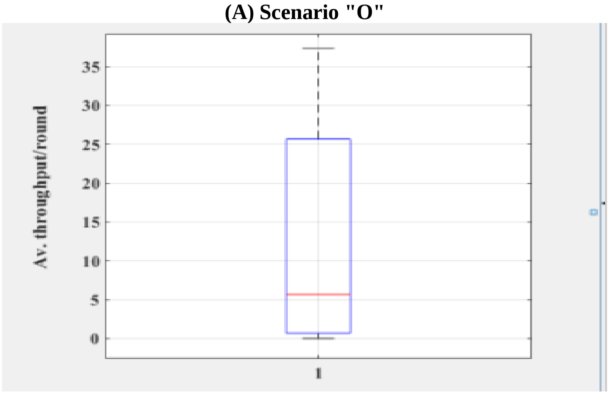
Table 2: Adaptive Scheme Parameters

scenario	m%/r	b%/r	P_{nrm}	P_{int}	P_{adv}
"O"			0.0833	0.125	0.1667
"Ma1"	0/150	0.03/150	0.0985	0.1478	0.1970
"Ma2"	0/116	0.08/116	0.0962	0.1442	0.1923
"Mb1"	0.07/44		0.0855	0.1282	0.1709
		0.15/107	0.0885	0.1327	0.177
"Mb2"	0.05/50		0.087	0.1304	0.1739
		0.1/118	0.09	0.1364	0.1818
"C"	0.07/44		0.0855	0.128	0.1709
	0.05/63		0.0885	0.1327	0.177
		0.15/100	0.09	0.1357	0.181
		0.07/123	0.0939	0.1408	0.1878

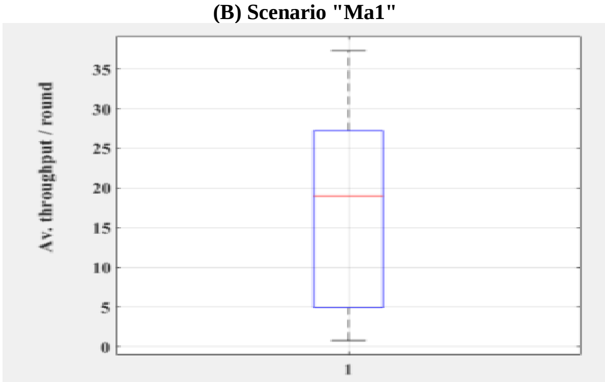
Table 3: Simulation Results in Terms of Throughput

scenario	"O"	"Ma1	"Ma2	"Mb1	"Mb2	"C"
Max.	37.3	37.3	37.3	38.3	37.3	42.1
Min.	0	0.788	0.38	0	0	0
3rd Q	25.66	27.5	26.5	26.3	28.2	29.8
1st Q	0.667	4.9	0.58	0.44	1.5	1.12
Median	5.66	19	9.62	4.9	11.8	13.2
3rdQ- 1stQ	25	23	26	25.86	26.6	29
3rdQ- Median	20	9	17	21.4	16.4	16.6
Median- 1stQ	5	14	9	4.46	10.2	12.4

(A) Scenario "O"



(B) Scenario "Ma1"



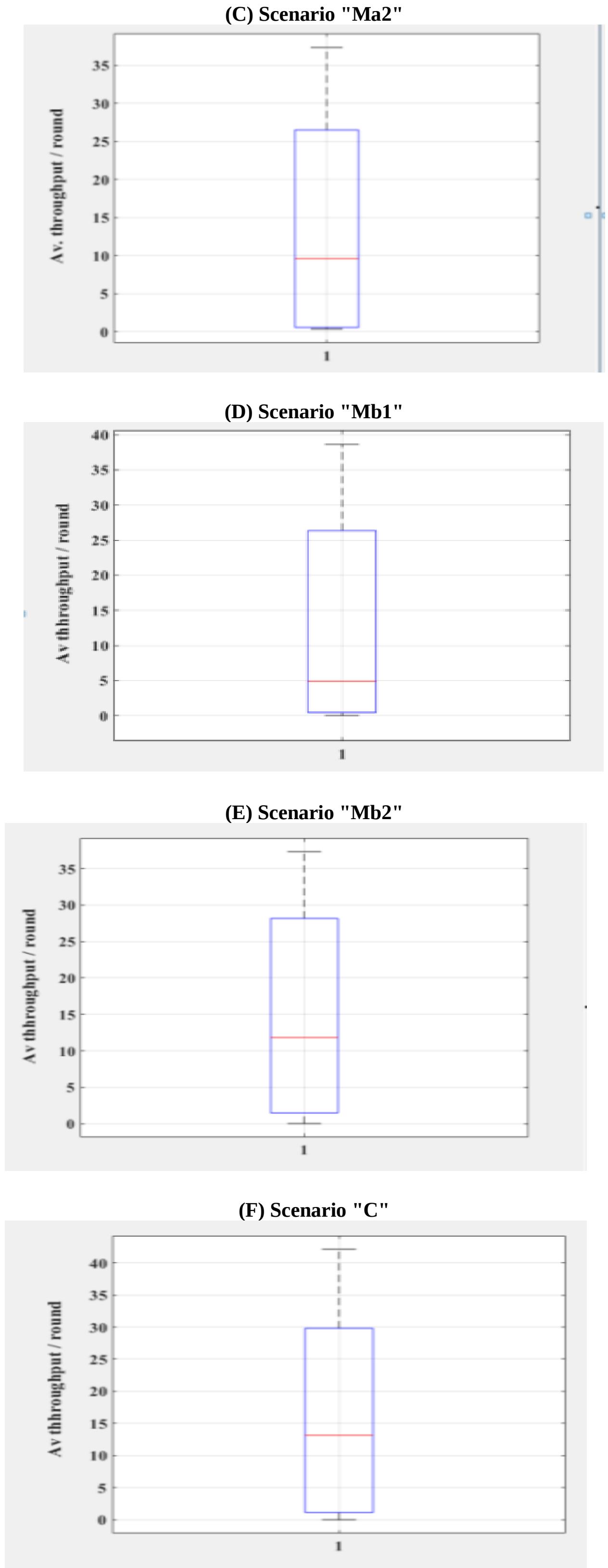


Fig. 1: Average Throughput per Rounds.

4.2. Performance in terms of number of CHs

Fig. 2 depicts the average CHs per round distribution and the results are illustrated in table 4. It can be noticed that:

1) The results show that the system implemented scenario "Ma1" scheme, gains the most uniformly load balancing between CHs per rounds with mean value equals to 4.4 CHs/round.
2) Comparing the number of CHs /round for the cases within same scenario, it obviously shown that the scaling the modification effects the results. As an example, the number of CHs /round in scenario "C" is larger than others when the modification is implemented twice, and in scenario "Mb2" is larger than in scenario "Mb1".
3) Scenario "C" achieves the maximum summation of CHs during network life time and hence the maximum total packets received by BS.
4) Although the network life time of scenario "O" is long than the network life time of scenario "Ma1", but total packets received by BS in scenario "Ma1" is higher than the total packets received by BS scenario "O". That's because network with scenario "O" include poor and empty rounds, which are eliminated in scenario "Ma1".

4.3. Performance in terms of lives nodes

The cumulative density function (CDF) is used in Fig. 3 to represents the probability of living nodes per rounds for each possible value of them. The following points can be observed:

1) Scenario "Ma1" achieves the maximum (mean living nodes). Also, this scenario has almost the most uniform distribution of live nodes per rounds, where 50% of the network nodes lives for 50% of the network half time.
2) After 70% of the network life time, "Ma1" is considered as the best case scenario, where it conserves 13% of the living nodes. At the contrary, "Mb1" and "O" are considered as the worst case scenarios, where about 98% of the nodes are dead after 70% of the network life time.

Table 4: Simulation Results in Terms of CHs

scenario	Life Time (rounds)	Total CHs	Packets to BS
"O"	383	1426	985894
"Ma1"	297	1464	984083
"Ma2"	367	1464	984552
"Mb1"	398	1456	990373
"Mb2"	340	1461	985887
"C"	353	1540	980731

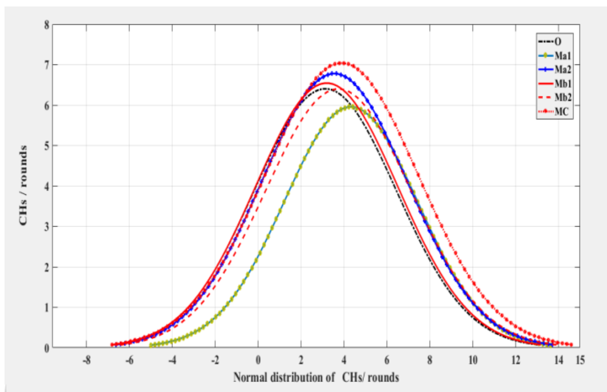


Fig. 2: Distribution of CHs per Rounds.

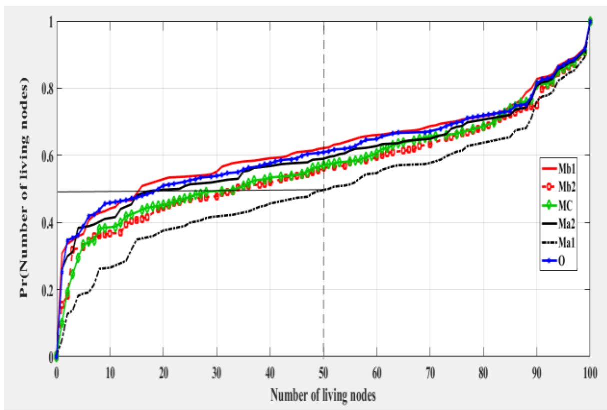


Fig. 3: Probability of Living Nodes.

5. Conclusion and future work

This work investigates the performance of heterogeneous WSN when an adaptive scheme is proposed for dynamically modify the election of CHs according to the network energy. This scheme is implemented via multi-scenarios to verify the judicious rule that governs the adaptation procedure. From the above mentioned simulation results, it can be noticed that each scenario has its own pros and cons. Scenario "Ma1" seems to distribute the load more uniformly and enable the network to recover its reliability especially at the latest rounds. Hence, this scenario is more suitable for application where poor or empty rounds are not desirable despite the consideration of long network life. At the other side, scenario "C" achieves the higher throughput in terms of packets received by BS. Increasing the throughput means more living nodes for most of the rounds, and then it degrades sharply at the end of network life. Hence, this scheme is useful for application with high throughput demand. Accordingly, the applications' requirement is the only thing to dominate the best scenario and must be considered carefully in order to make sensible decision.
Many other factors and scenarios can be later investigated; BS location, deployed area, energy consumption….etc. which will be considered in our next research.

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