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ENERGY EFFICIENT ROUTING ALGORITHMS FOR SCHEDULING DISTRIBUTION OF CLUSTER HEADS IN WIRELESS SENSOR NETWORKS (WSNS)-A REVIEW

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ABSTRACT

The wireless sensor networks (WSNs) operate on resource constrained environment, therefore, changing or recharging the batteries is difficult and unmanageable task. Over the years, several routing algorithms have been studied in WSNs to enhance their lifespan with varying degree of success. The present review compared the energy efficiency of various homogeneous and heterogeneous routing algorithms for scheduling the distribution of cluster heads (CHs) in WSNs. The Low Energy Adaptive Clustering Hierarchy (LEACH), Power Efficient Gathering in Sensor Information Systems (PEGASIS) and Hybrid Energy-Efficient Distributed Clustering (HEED) are intended for homogenous WSNs, while the Stable Election Protocol (SEP), Distributed Energy Efficient Clustering (DEEC), Developed DEEC (DDEEC) and Enhanced DEEC (EDEEC) are important in WSNs which adequately operate within heterogeneous regions. The homogeneous WSNs had nodes with less energy expire sooner, compared with the nodes with high energy. The homogenous clustering-based algorithms are incompetent to delight every node with respect to energy. The HEED protocol has low overhead in terms of processing cycles and message exchanged and does not assume any distribution of the nodes or location awareness. The LEACH has been the most accepted distributed cluster-based routing algorithms in WSNs, which has been highly effective and efficient approach to prolong the network lifetime with increased energy efficiency. The improvement over LEACH is that HEED can evenly distribute the cluster heads in the sensing area by local competition. The Threshold sensitive energy efficient sensor network (TEEN) protocol has not been considered good for applications where the periodic reports are generated because some users may not get any data at all if the thresholds are not reached. The PEGASIS protocol is nearly optimal in terms of energy cost for data gathering applications.

KEYWORDS: Wireless sensor networks, Homogeneous networks, Heterogeneous networks, Networks' lifespan, End-to-end delay.

1. INTRODUCTION

The wireless sensor networks (WSNs) has arisen as persuasive logical stage with extraordinary and story applications. These wireless sensor nodes are deployed over a geographical area in an *ad hoc* manner for event detection and observe data for various ambient conditions (Rawat and Chauhan 2018a). The WSNs has turn out to be an important technological advancement in realizing multifarious applications together with simple phenomena monitoring applications and huge data streaming such as in the field of military operations, environment monitoring and surveillance systems (Muruganathan Siva et al., 2005; Zhang et al., 2008; Priyadarshi et al., 2010; Ramar and Rubasoundar 2015; Priyadarshi et al. 2017). A WSN has been highly complex dispersed system comprising large number of tiny wireless sensor nodes (Akyildiz et al., 2002) and the base station (BS) (Laif et al., 2012; Ramar and Rubasoundar, 2015). Each wireless sensor node consists of sensor, processor, memory, radio frequency transceiver (radio), peripherals, and power supply unit (battery) (Akyildiz et al., 2002; Aslam et al., 2012a, b). In the WSNs, the sensor nodes are connected wirelessly and self-organized to apprehend and perform application-oriented responsibilities (Rawat and Chauhan, 2018a, b). The sensor nodes in each cluster pass on their data to their respective cluster head (CH) and each CH aggregate data and onward them to a central

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BS (Abbasi and Younis, 2007). All cluster member nodes pass on the sensed data to their respective CH, while the CH aggregate data received and forward it to the remote BS (Mhatre et al., 2004; Heinzelman et al., 2000).

The implementation of clustering technique helps in addressing issues related to organization of the network nodes into smaller clusters and to select a CH (Rawat and Chauhan 2018b). In WSN, optimization and load balancing of network resources are considered critical to provide the intelligence for long duration (Priyadarshi et al., 2010). The WSNs which needs to operate on resource constrained environment, therefore, changing or recharging the batteries has been a difficult and unmanageable task. The malfunction of even a single sensor node owing to dropdown of energy level could desperate the entire WSN (Heinzelman et al., 2000). Nonetheless, the problem failure of sensor nodes has gained a worldwide attention and become the researchable issue among the academic researchers for emergent research to enhance the energy efficiency of WSNs using different protocols that focus at node and network level (Zhang et al., 2008; Rawat and Chauhan, 2018a).

Over the years several energy efficient routing protocols have been with variable energy efficiency (Heinzelman et al., 2002; Lindsey and Raghavenda, 2002; Younis and Fahmy, 2004; Smaragdakis and Matta, 2004; Kianzad Vida et al., 2006; Qing et al., 2006; Elbhiri et al., 2010; Saini and Sharma, 2010; Wei et al., 2011; Chang, 2012). In general, the routing protocols in WSNs are categorized as (i) data centric protocols, (ii) location-based protocols, and (iii) hierarchical protocols. The clustering is performed with two different type of networks viz. homogenous and heterogeneous WSNs. The WSNs comprised of nodes of same energy level are called homogenous WSNs. The Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman et al., 2002), Power Efficient Gathering in Sensor Information Systems (PEGASIS) (Lindsey and Raghavenda, 2002) and Hybrid Energy-Efficient Distributed Clustering (HEED) (Younis and Fahmy, 2004) are the type of cluster based protocols which are intended for homogenous WSNs and such algorithms inadequately perform within heterogeneous regions. The homogeneous WSNs had nodes with less energy expire sooner, compared with the nodes with high energy. Because homogenous clustering-based algorithms are incompetent to delight every node with respect to energy. The clustering the sensor nodes significantly improves systems' overall scalability and energy efficiency (Kannan and Raja, 2015).

In heterogeneous WSNs, the sensor nodes are deployed with different initial energy levels. In fact, heterogeneity in WSNs arise because of re-energizing of WSNs to enlarge the network lifetime (Smaragdakis and Matta, 2004; Khan et al., 2012, Kashaf et al., 2012). Among the heterogeneous protocols, Stable Election Protocol (SEP) (Smaragdakis and Matta, 2004), Distributed Energy Efficient Clustering (DEEC) (Qing et al., 2006), Developed DEEC (DDEEC) (Elbhiri et al., 2010), Enhanced DEEC (EDEEC) (Saini and Sharma, 2010) are important in WSNs. Younis and Fahmy (2004) reported that hybrid energy efficient distributed (HEED) clustering protocol has been an extension of basic LEACH protocol. The HEED protocol encompasses two parameters for the selection of CHs. The basic parameter for CHs' selection has been the residual energy (E_o) and the secondary parameter has been the degree of the sensor node. Younis and Fahmy (2004) reported that the degree of a node and the number of nodes in its range, help in distributing the load among CHs for load balancing. The HEED protocol has low overhead in terms of processing cycles and message exchanged and does not assume any distribution of the nodes or location awareness. Kannan and Raja (2015) proposed distributed cluster head scheduling (DCHS) algorithm to achieve the network longevity in WSNs. The DCHS protocol has the advantage that the network is divided into primary and secondary tiers based on received signal strength indication of sensor nodes from the BS. The DCHS has 2 tier WSNs' architecture and provides guidance to elect the CH nodes and gateway nodes for both primary and secondary tiers. Smaragdakis and Matta (2004) applied SEP protocol, which is an extension of LEACH protocol and is based on heterogeneity. In SEP, a node becomes CH based on weighted election probability, which uses a function of the remaining energy of the nodes to ensure uniform usage of node energy. The underlying network of the SEP considers two levels of heterogeneity, consisting two types of nodes viz. (i) normal nodes, and (ii) the advanced nodes. The energy of the advanced node is higher than the normal nodes and their number is less than that of the normal nodes due to the increased cost factor.

2. LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH) PROTOCOL

The LEACH has been the most accepted distributed cluster-based routing algorithms in WSNs, which has been highly effective and efficient approach to prolong the network lifetime with increased energy efficiency (Heinzelman et al., 2000, Heinzelman et al., 2002). In LEACH, each sensor node applies a stochastic algorithm at each round to decide whether it would become a CH in the round or not (Heinzelman et al., 2002). The nodes which have been the CHs, cannot become CHs again for *'P'* rounds, where '*P'* is the desired percentage of CHs. Therefore, each node has a '*1/P'* probability of becoming a CH in each round. In LEACH protocol, the CHs are elected without considering the residual energy (E_O) or the other properties of the sensor nodes. Nonetheless, the random CHs' selection mechanism does not provide assurance even distribution of clusters over the network (Arboleda and Nasser, 2006). The LEACH works on rounds where each round is composed of two phases viz. set-up phase and the steady state phase. In LEACH, the CHs may not be dispersed uniformly throughout the entire region because of their random selection. Another disadvantage of LEACH has been that the number of CH nodes is not fixed due to stochastic selection (Singh et al., 2017).

These weaknesses were addressed modified LEACH protocols viz. Low energy adaptive clustering hierarchy-Centralized (LEACH-C) and fixed LEACH (Heinzelman et al., 2002). According to Heinzelman et al., (2002) the limitation was addressed by dispersing CHs over the entire network for better performance. The BS in LEACH-C protocol organizes the nodes and controls the network in such a way that within each round of LEACH-C, a node needs to send its residual energy (E_o) and location information to the BS. On the basis of information received at BS, the BS can uniformly distribute the CHs throughout the topology and adjusts the size of each cluster. The BS also adjusts the probability (P) of selecting the CHs based on the nodes' E_o because the BS has several energy intensive tasks like cluster formation and CHs selection. However, in fixed-LEACH protocol, the number of CHs is fixed, and the sensor nodes elect their nearest node as CH where the number of supported nodes is different for each CH. It often leads to the uneven dissipation of E_o among the nodes.

The LEACH-C protocol uses centralized algorithm for the selection CH and the same steady state phase as in LEACH protocol (Heinzelman et al., 2002). In the set-up phase, the BS gathers the position and energy level of the sensor nodes. The nodes with higher energy as compared to those with average energy of all sensor nodes would be elected as CH. This approach only considers the energy level of sensor nodes while selecting the CH, but there has been a greater probability of elected CH is far away from BS which consumes more energy when they are communicating between BS and CH. Unlike basic LEACH protocol, where nodes self-configure themselves into clusters, LEACH-C uses the BS for cluster formation. To start with each node ends its information viz. location and energy level to the BS, which uses this information and employ a Simulated Annealing (SA) approach to find a predetermined number of CHs and configure the network into clusters.

3. HYBRID ENERGY-EFFICIENT DISTRIBUTED CLUSTERING (HEED) PROTOCOL

Younis and Sonia (2004) proposed Hybrid Energy-Efficient Distributed clustering (HEED) protocol which periodically chooses the CHs based on their E_o. The improvement over LEACH is that HEED can evenly distribute the cluster heads in the sensing area by local competition (Elhabyan and Yagoub, 2015). The HEED algorithm supports for sensing a two-level hierarchy, and lack for multi-level hierarchies. Chand et al., (2014) reported that heterogeneous HEED protocol for WSNs considers 3 parameters viz. (i) residual energy, (ii) node density, and (iii) the distance. The HEED protocol applies fuzzy logic to determine the CHs (Chand et al., 2014). In HEED protocol, data may be lost if CHs are not able to communicate with each other. Further enhanced version of HEED protocol which has been an energy efficient protocol and employs fuzzy logic for heterogeneous WSNs and has been an extension of HEED (Chand et al., 2014). In HEED protocol, cluster formation is achieved with an iterative approach. CHs selection in this protocol is primarily based on the E_0 of each node. To increase energy efficiency and prolonged network lifetime, a secondary clustering parameter considers intra-cluster '*communication cost*' was introduced which can be a function of neighbor proximity or cluster density. The main objectives of HEED were to distribute energy consumption to prolong network lifetime, minimize energy during the CH selection phase, and reduce the control over head of the network.

4. THRESHOLD SENSITIVE ENERGY EFFICIENT SENSOR NETWORK (TEEN) PROTOCOL

Manjeshwar and Agarwal (2001) proposed TEEN protocol based on hierarchical clustering. In TEEN protocol, a CH broadcasts 2 thresholds to the nodes viz. (i) hard threshold, and (ii) the soft thresholds for sensed attributes. The hard threshold has the minimum possible value of an attribute to trigger a sensor node to switch on its transmitter and transmit to the CH. Therefore, the hard threshold permits the nodes to transmit only when the sensed attribute has been in the range of interest. It helps reducing the number of transmissions considerably. However, the soft threshold further reduces the number of transmissions if there is a little or no change in the value of the sensed attribute. The TEEN protocol has not been considered good for applications where the periodic

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reports are generated because some users may not get any data at all if the thresholds are not reached. This protocol was extended with the development of resultant protocol known as 'Adaptive Threshold Sensitive Energy Efficient Sensor Network' (APTEEN) protocol (Manjeshwar and Agarwal, 2002). The APTEEN protocol has been meant for capturing periodic data collections and time critical events and it permits the users to set threshold values and a count time interval. The major limitation of the APTEEN protocol has been the high overhead and complexity of forming the clusters.

5. POWER EFFICIENT GATHERING IN SENSOR INFORMATION SYSTEM (PAGASIS) PROTOCOL

The PAGASIS protocol is nearly optimal in terms of energy cost for data gathering applications. The basic idea in PEGASIS has been the formation of a chain among the sensor nodes so that each node receives from and transmits to a closest neighbor node (Singh et al., 2017). The gathered data moves from node to node, gets fused, and, eventually, a designated node transmits it to the base station (BS). The nodes take turns in transmitting to the BS so that the average energy spent by each node per round is reduced (Singh et al., 2017).

6. ENERGY EFFICIENT CLUSTERING PROTOCOL (EECP) PROTOCOL

The single-hop energy-efficient clustering protocol (S-EECP) and multi-hop energy-efficient clustering protocol (M-EECP) were proposed by Kumar (2014). In S-EECP, the CHs were selected by a weighted probability (p) based on the ratio between E_0 of each node and average energy of the network. In a single-hop communication, data packets are directly transmitted to the BS without any relay nodes. The nodes located far away from the BS had the higher energy consumption because of long range transmission and these nodes may die out first. However, this problem was solved in M-EECP by using multi-hop communication to the BS. The M-EECP uses a greedy approach to solve the single source shortest problem to find the shortest path from each cluster head to the BS. A stable and energy efficient clustering (SEEC) protocol was extended it to multi-level SEEC by Farouk et al., (2014). The SEEC depends on network structure which is divided into clusters, and each cluster has a powerful advanced node and some normal nodes deployed randomly in this cluster. However, in the multi-level architectures, more powerful supper nodes were assigned to cover distant sensing areas. Each type of nodes has its role in the sensing, aggregation or transmission to the base station.

7. PERFORMANCE EVALUATION OF WSN ALGORITHMS

The stability of the cluster in LEACH protocol is greatly reduced because LEACH protocol particularly on the irregular networks causes a decrease in aggregate data efficiency (Lee et al., 2015). Therefore, the basic LEACH protocol was integrated with HEED and LEACH protocol was proposed. Aslam et al., (2016) compared two energy efficient route planning routing protocols for three levels of heterogeneous WSNs, viz. Central Energy Efficiency Clustering (CEEC) with Two-hop Heterogeneity awareness (THCEEC) and Advanced Equalization (ACEEC). The comprehensive simulation results revealed that CEEC, ACEEC, and THCEEC central cluster deployments has resulted in improved reliability and energy efficiency performance, providing better network lifetime and successful data transmission than LEEC, SEP, ESEP and DEEC's traditional distributed routing protocols (Aslam et al., 2016). The ACEEC outperforms CEEC by providing more network stability time. The analytical assessment revealed that THCEEC outperforms CEEC and ACEEC protocols (Vançin and Erdem, 2018). Elbhiri et al., (2010) reported that the DDEEC protocol has been optimized by the public WSNs, and it has been more likely that advanced nodes will be chosen as CH in the first broadcast rounds. When the E_0 is reduced, these sensor nodes had the same probability of CHs' election as normal sensor nodes. However, Saini and Sharma (2010) reported that EDEEC protocol employing a clustering method with a three-level heterogeneous structure provided a significntly high amount of energy level called '*super sensor nodes*'.

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Table 1. Comparative evaluation of four protocols viz. Developed Distributed Energy Efficient Clustering (DEEC), Enhanced Distributed Energy Efficient Clustering Protocol (EDEEC), Enhanced Developed Distributed Energy Efficient Clustering Protocol (EDDEEC) and the proposed protocol i.e. artificial bee colony optimization (ABCO) algorithm and energy harvesting WSN (EH-WSN) clustering method for first dying rounds of the nodes and dead rounds of all nodes in wireless sensor networks (WSNs) (Source: Vançin and Erdem, 2018).

Protocols	First dying rounds of the nodes	Dead rounds of all nodes
DEEC	1512	2813
EDEEC	2179	2654
EDDEEC	2557	4258
Proposed (ABCO+EH-WSN)	2761	4536

Javaid et al., (2013) introduced a Enhanced Developed Distributed Energy Efficient Clustering Protocol (EDDEEC) routing protocol in which the CHs' selection probability was dependent on the E_0 quantity of the sensor nodes with the average energy of the WSN. Vançin and Erdem (2018) compared Developed Distributed Energy Efficient Clustering (DEEC), Enhanced Distributed Energy Efficient Clustering Protocol (EDEEC), Enhanced Developed Distributed Energy Efficient Clustering Protocol (EDDEEC), and the proposed algorithm viz. artificial bee colony optimization (ABCO) algorithm and energy harvesting WSN (EH-WSN) clustering method. Their results revealed that the first node died in 1512, 2179, 2557, and 2761th rounds, respectively, and all nodes died in 2813, 3654, 4258, and 4536th rounds, respectively (Table 1). In the 2500th round, DEEC, EDEEC, EDDEEC, and the proposed algorithm were 800, 750, 640, and 550 milli seconds (mS), respectively. These observations underpin that proposed algorithm delivers data packets with minimum latency and relay after calculating the optimal possible distance for the next hop. Nonetheless, the CHs were placed at optimal distance to BS (Vançin and Erdem, 2018).

Qureshi et al., (2013) proposed Balanced Energy Efficient Network Integrated Super Heterogeneous (BEENISH) protocol which assumes that WSN contains four energy levels of nodes viz. normal nodes, advance nodes, super nodes and the ultra-super nodes. However, DEEC has only two types of nodes viz. normal nodes and the advance nodes. In BEENISH, the CHs were elected based on E_0 level of nodes. The proposed protocol BEENISH implements the same concept as for DEEC protocol in terms of selecting CH which is based on E_0 level of the nodes with respect to average energy of network.

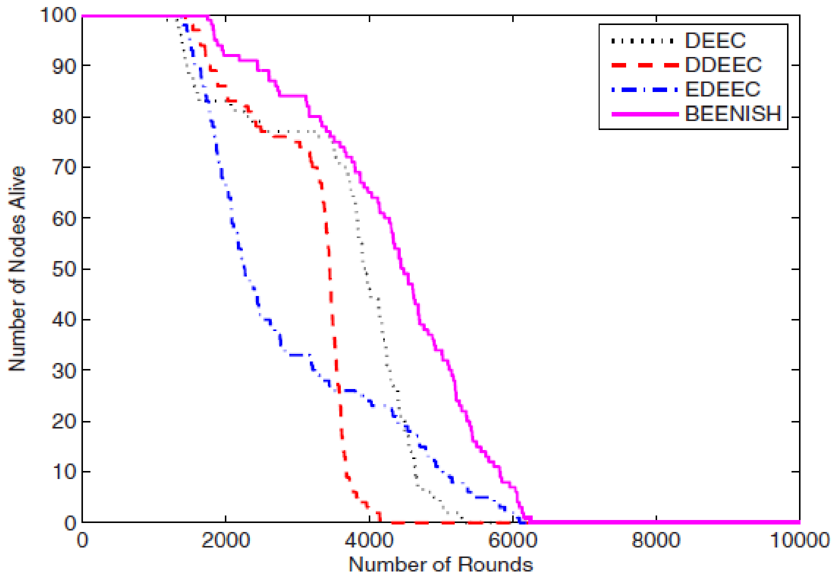

Figure 1a. Relationship between number of alive nodes vs. number of rounds for four wireless sensor networks (WSNs) algorithms viz. Distributed Energy Efficient Clustering (DEEC), Developed DEEC (DDEEC) and Enhanced DEEC (EDEEC) and Balanced Energy Efficient Network Integrated Super Heterogeneous (BEENISH) Protocols (Source: Qureshi et al., 2013).

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The simulation results revealed that BEENISH outperforms with longer stability, lifetime and more effective messages as compared with DEEC, Developed Distributed Energy Efficient Clustering (DDEEC) and Enhanced DEEC (EDEEC). In BEENISH protocol, the ultra-super nodes were largely elected as CH than the super, advance and normal nodes, which help in equal distribution of energy consumed by all nodes. They (Qureshi et al., 2013) reported that BEENISH was energy efficient clustering protocol for heterogeneous WSNs, with the election of CH based on E_0 and average energy of the network. Therefore, the nodes with high energy have more chances to get selected as CH, as compare to the low energy nodes. The BEENISH protocol has proved to be the most efficient protocols as compared to DEED, DDEEC and EDEEC for all types of WSNs in terms of stability period, network lifetime and throughput (Figure 1a, b).

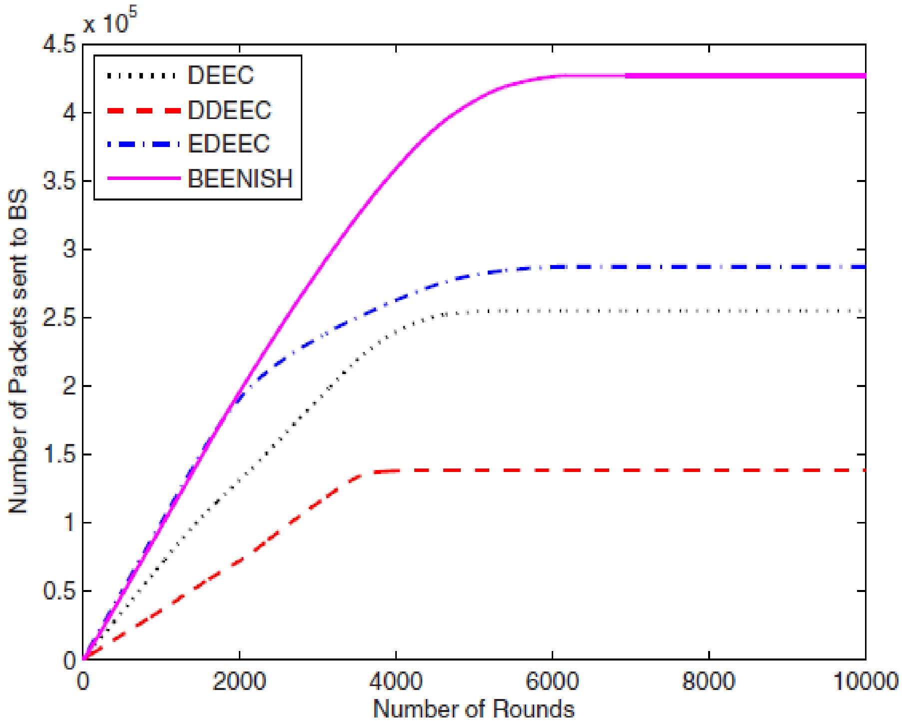

Figure 1b. Relationship between number of rounds vs. number of packets sent to the base station (BS) for four wireless sensor networks (WSNs) algorithms viz. Distributed Energy Efficient Clustering (DEEC), Developed DEEC (DDEEC) and Enhanced DEEC (EDEEC) and Balanced Energy Efficient Network Integrated Super Heterogeneous (BEENISH) Protocols (Source: Qureshi et al., 2013).

Singh et al., (2017) compared the network lifetime by implementing DEEC protocol for our network model. The DEEC implementation for the existing 1-level, 2-level, and 3-level heterogeneous network models are denoted as DEEC-1, DEEC-2, and DEEC-3, respectively, and for our proposed 3-level heterogeneous network model, the DEEC implementations are denoted as hetDEEC-1, hetDEEC-2, and hetDEEC-3, respectively (Figure 2). The number of alive nodes with respect to the number of rounds for the DEEC-1, hetDEEC-1, DEEC-2, hetDEEC-2, DEEC-3, and hetDEEC-3. They have reported that hetDEEC-3 provides longer lifetime. For all levels of heterogeneity, we carried out simulations for large number of input parameters, i.e., by taking different energy levels of the nodes and various values of fraction parameters. The values of the average network lifetime 1558, 2391, 3960, and 4404 by using total network energy as 50 J, 70 J, 100 J, and 100 J, for the DEEC- 1/hetDEEC-1, DEEC-2/hetDEEC-2, DEEC-3 and hetDEEC-3, respectively.

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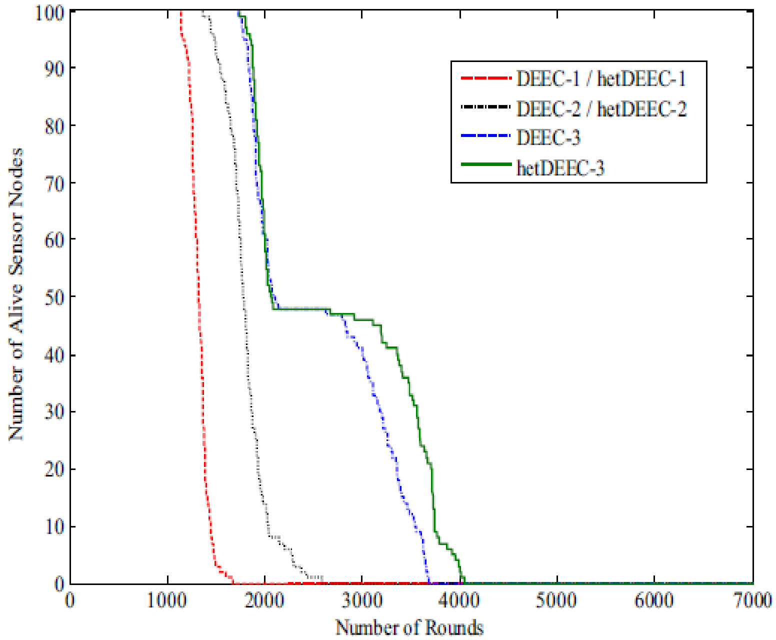

Figure 2. Relationship between number of alive nodes vs. number of rounds for four wireless sensor networks (WSNs) algorithms viz. DEEC-1/hetDEEC-1, DEEC-2/hetDEEC-2, DEEC-3 and het DEEC-3, when number of advanced nodes m=0.48, m_0=0.44, α=1.82, β=2.42 and θ=0.52 (Source: Singh et al., 2017).

The network lifetime in DEEC-2/hetDEEC-2, DEEC-3, and hetDEEC-3 increases by 53.5%, 154.2%, and 182. 7% for increasing ~40%, ~100%, and ~100% in the network energies, respectively, with respect to the original DEEC, i.e., the DEEC-1/hetDEEC-1. Thus, nodes in the DEEC-1/hetDEEC-1 protocol die much faster and in the hetDEEC-2 the nodes die slowly as compared to the hetDEEC-1 due to the advanced nodes. In DEEC-3 and hetDEEC-3, the nodes die further slowly due to advanced and super nodes. However, the nodes in the hetDEEC-3 die slower than that of the DEEC-3 because it elects the cluster heads in an effective manner which helps in prolonging the network lifetime (Figure 2).

Figure 3 show an instance of total energy consumption and number of packets transmitted to the base station with respect to the number of rounds for 1-level, 2-level, and 3-level of heterogeneity, respectively. This measure refers to the instantaneous amount of energy exhausted in the network per round, i.e., the energy difference from the beginning of the round till its end. Here, the total initial energies are 50 J, 70 J, and 100 J, for type-1, type-2, and type-3 nodes, respectively. The hetDEEC-3 performs better than all the levels of the DEEC. The number of packets transferred to the base station using the DEEC-1, DEEC-2, DEEC-3, and hetDEEC-3, are, respectively, 1.2 x10^4, 2.1x 10^4, 3.3 x 10^4, and 3.8 x 10^4, with respect to the number of rounds (Figure 4).

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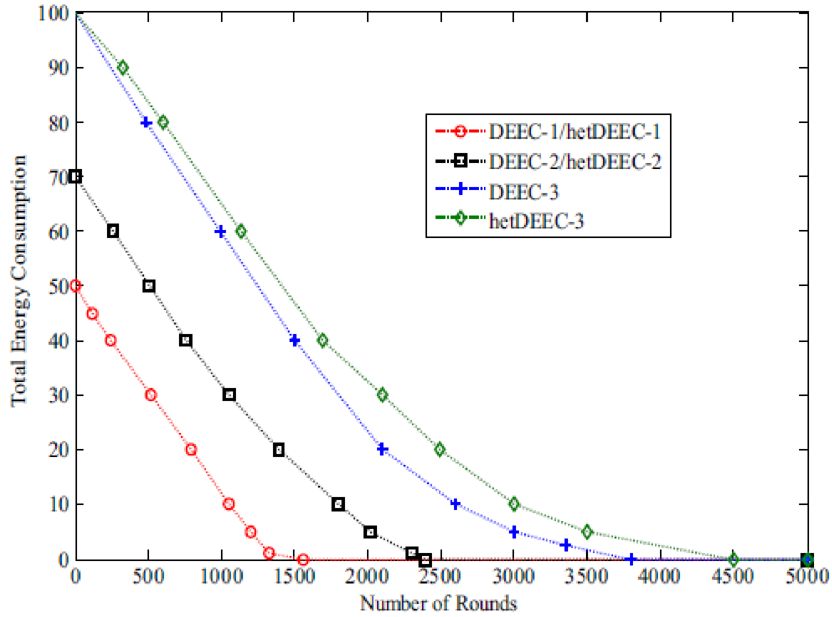

Figure 3. Relationship between number of alive nodes vs. number of rounds for four wireless sensor networks (WSNs) algorithms viz. DEEC-1/hetDEEC-1, DEEC-2/hetDEEC-2, DEEC-3 and het DEEC-3, when number of advanced nodes m=0.48, m_0=0.44, α=1.82, β=2.42 and θ=0.52 (Source: Singh et al., 2017).

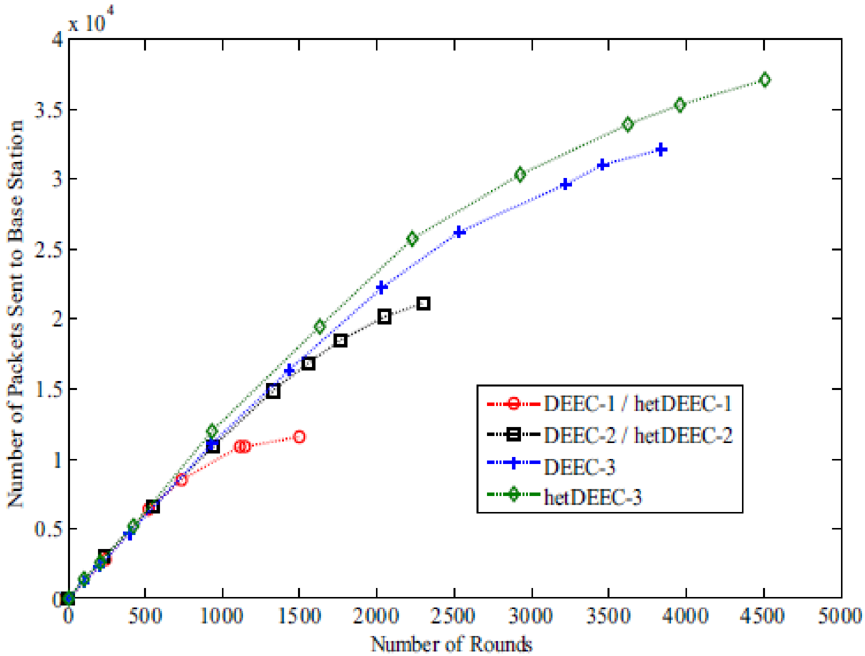

Figure 4. Relationship between number of rounds vs. number of data packets sent to the base station (BS) by for four wireless sensor networks (WSNs) algorithms viz. DEEC-1/hetDEEC-1, DEEC-2/hetDEEC-2, DEEC-3 and het DEEC-3, when number of advanced nodes m=0.48, m_0=0.44, α=1.82, β=2.42 and θ=0.52 (Source: Singh et al., 2017).

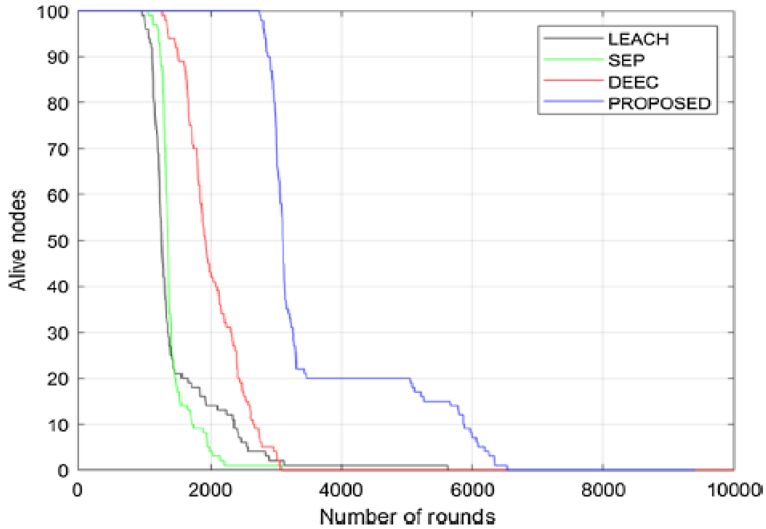

Figure 5. Relationship between number of rounds vs. number of alive nodes to the base station (BS) for four wireless sensor networks (WSNs) algorithms viz. Low Energy Adaptive Clustering Hierarchy (LEACH), Distributed Energy Efficient Clustering (DEEC), Stable Election Protocol (SEP) and the proposed Protocols.

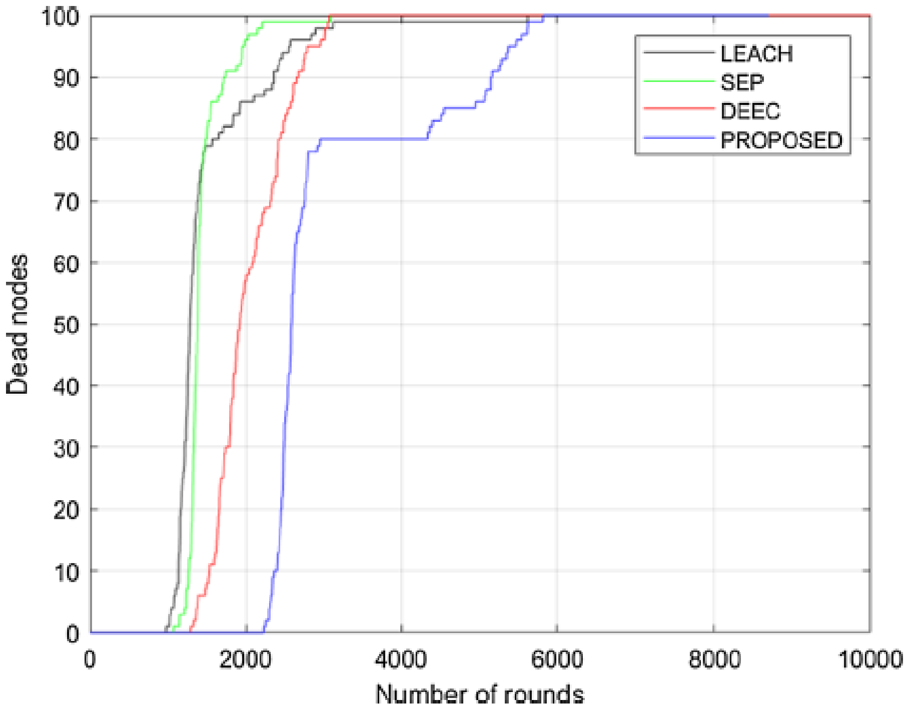

Figure 6. Relationship between number of rounds vs. number of dead nodes to the base station (BS) for four wireless sensor networks (WSNs) algorithms viz. Low Energy Adaptive Clustering Hierarchy (LEACH), Distributed Energy Efficient Clustering (DEEC), Stable Election Protocol (SEP) and the proposed Protocols

Comparison of the LEACH, DEEC, SEP and the proposed convention has a three-level heterogeneous bunching methodology to upgrade the WSNs energy productivity. The three-levels of heterogeneity split the sensors into 3 diverse groups using their energies. The proposed protocol selects the most capable nodes as CH by utilizing the threshold and energy factors. Figure 5 illustrates the survival of the nodes in different rounds for different

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protocols. The WSN survived for 3073, 3134, 3475, 5743 rounds in LEACH, SEP, DEEC, and proposed protocols, respectively. However, Figure 6 illustrates the dead nodes in different rounds to show the stability of the network. The stability region was maintained for 1037, 1278, 1820, and 2746 rounds in LEACH, SEP, DEEC, and proposed protocols, respectively. Vançin and Erdem (2018) applied energy efficient three-level heterogeneous clustering method protocol i.e. DEEC in comparison to the advanced threshold balanced sampled DEEC (TBSDEEC), Enhanced Distributed Energy Efficient Clustering Protocol (EDEEC), and Enhanced Developed Distributed Energy Efficient Clustering Protocol (EDDEEC) protocols. It included living nodes on the network, network efficiency, energy consumption, number of packets received by the BS, and average latency.

Kannan and Raja (2015) reported that the number of rounds for LEACH, HEED, LEACH-C and DCHS protocols for first node dead were 142, 241, 379, and 554, respectively. The DCHS algorithm took a greater number of rounds for first node dead when compared with the other schemes (Figure 7). They (Kannan and Raja, 2015) have reported that the number of rounds LEACH, HEED, LEACHC and DCHS take for half of the nodes alive were 320, 590, 850, and 901, respectively. The DCHS algorithm has significantly enhanced the energy efficiency by ~ 7.5–12% as compared to LEACH-C protocol, when the number of rounds ranges from 500 to 700, whereas the LEACH-C protocol shows an energy efficiency of ~17.5% and 39.7% as compared to HEED and LEACH protocols, respectively. Their results revealed that DCHS protocol could achieve 7.5–39.7% overall reduction in consumed energy when compared with the existing hierarchical protocols.

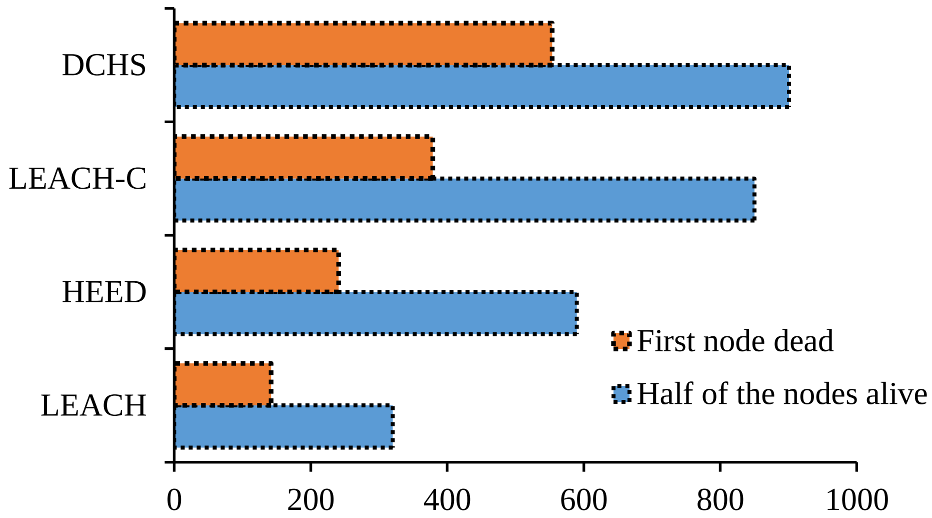
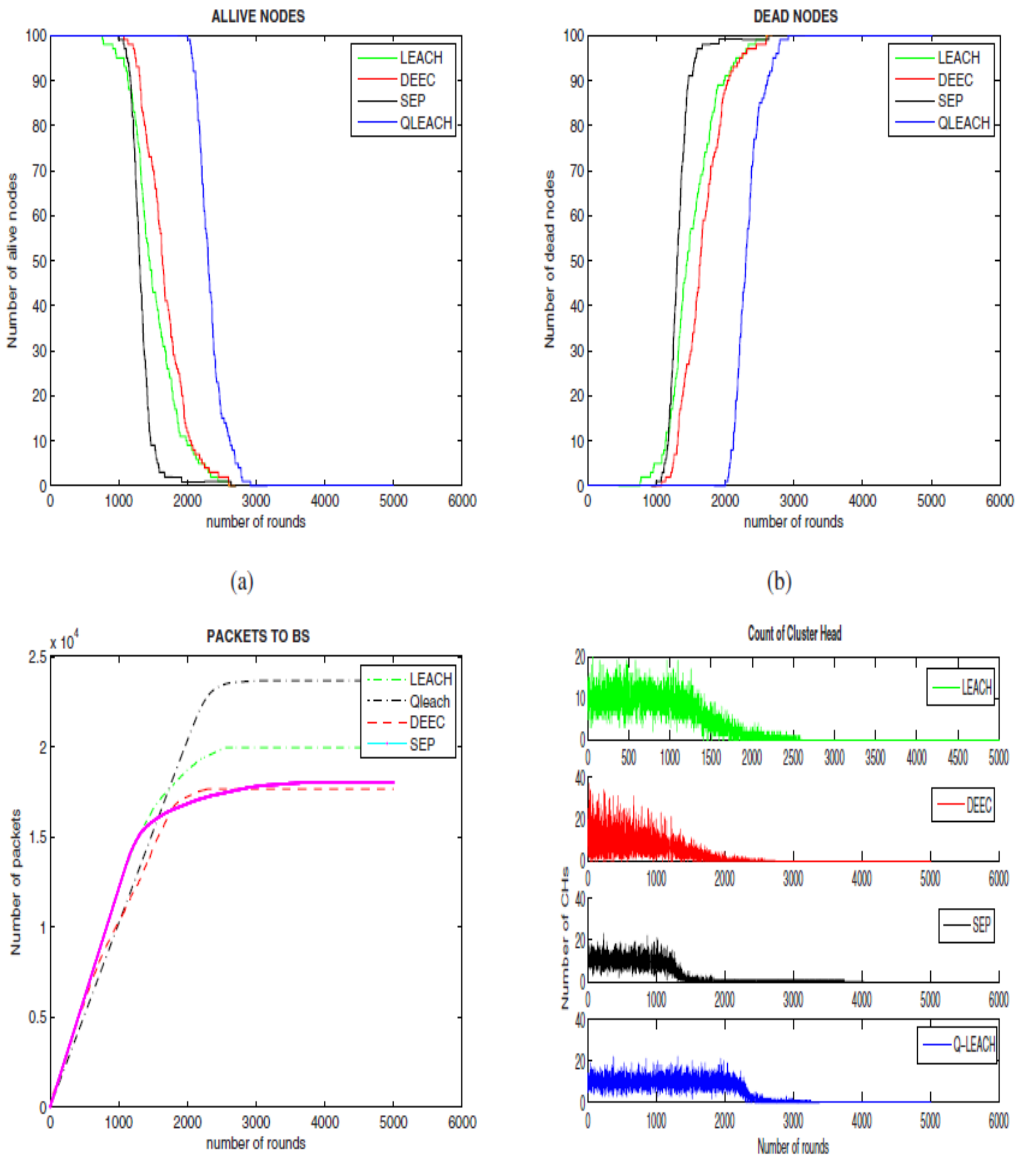


Figure 7. Number of rounds before first node dead and half of the nodes were alive when number of sensor nodes = 50 for Low Energy Adaptive Clustering Hierarchy (LEACH), LEACH-Centralized (LEACH-C), HEED (Hybrid Energy-Efficient Distributed clustering) and distributed cluster head scheduling (DCHS) algorithms used in wireless sensor networks (Source: Redrawn from Kannan and Raja, 2015).

Manzoor et al., (2013) compared Low Energy Adaptive Clustering Hierarchy (LEACH), Distributed Energy-Efficient Clustering (DEEC), Stable Electron Protocol (SEP) and Quadrature-LEACH (Q-LEACH) protocols for wireless sensor networks (WSNs). They have reported that network life span was enhanced significantly with Q-LEACH when compared with other clustering approaches (viz. LEACH, SEP, and DEEC). The Q-LEACH algorithm enhanced the network life span by keeping alive almost up to 2900 rounds. It was ascribed to increased stability period first node dies around 2000 rounds whereas, in schemes like LEACH, DEEC and SEP this value is much lower (Figure 8a,b). Their results revealed that the selection of CHs follow some patterns and throughput increases quiet remarkably respectively (Figure 8c,d) with the distribution of sensor nodes in different quadrants which has helped in uniform distribution of nodes to make clustering technique more effective and efficient.



(c) (d)

Figure 8. Relationship between number of rounds vs. number of alive nodes (a), number of dead nodes (b), number of packets sent to the base station (BS) (c) and number of cluster heads (CHs) for Low Energy Adaptive Clustering Hierarchy (LEACH), Distributed Energy-Efficient Clustering (DEEC), Stable Electron Protocol (SEP) and Quadrature-LEACH (Q-LEACH) protocols for wireless sensor networks (WSNs) (Source: Manzoor et al., 2013).

Elhabyan and Yagoub (2015) reported that the number of aggregated packets received at the BS for each protocol (Table 2) while Figure 9 presents the latency distribution for those packets. Although TPSO-CR has higher throughput than the other protocols, it has higher packet latency. For example, Fig. 9 reveals that, for the competent protocols, over 90% of the received packets have a maximum latency of 1 ms. For TPSO-CR, only 16% of the packets have a maximum latency of 1 ms. The reason that TPSO-CR is experiencing higher latency is because the Medium Access Control (MAC) layer of each relay node buffers each packet before transmitting it to the next relay node.

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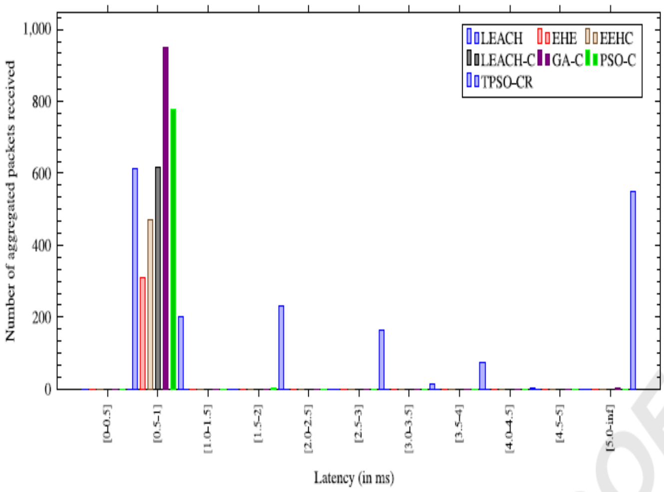

Figure 9. Application level latency (in ms) for different protocols used for energy efficiency enhancement and in routing algorithms in wireless sensor networks (WSNs) (Source: Elhabyan and Yagoub 2015).

Table 2. The number of data packets received at base station (BS) using different protocols viz. The Low Energy Adaptive Clustering Hierarchy (LEACH), LEACH-Central (LEACH-C), energy efficient heterogeneous clustered (EEHC), energy efficient heterogeneous clustered LEACH (EHE-LEACH), GA-C, particle swarm optimization-Centralized (PSO-C), and newly proposed centralized two tier PSO protocol (TPSO-CR) in wireless sensor networks (WSNs) (Source: Elhabyan and Yagoub 2015).

Protocol	Number of data packets sent to the base station (BS)
LEACH	613.5
LEACH-C	472.5
EEHC	618.5
EHE-LEACH	309.5
GA-C	778.5
PSO-C	952.5
TPSO-CR	1237.2

Hady et al., (2013) applied LEACH-CS protocol for WSNs and reported that LEACH-CS extends the lifetime of WSNs by proposing a mechanism that performs an intelligent choice of functioning nodes depending on the data sensed at the time being. The Intelligent Sleeping Mechanism (ISM) algorithm was applied for selecting nodes modes of functionality. As compared with LEACH-C, LEACH-CS succeeds in extending the lifetime of the network by ~35% through network scaling and minimizing the end-to-end delay of data sending by an average ~50% less than LEACH-C. Figure 10 illustrates the number of rounds the network is alive before no nodes are alive in the network. The LEACH-CS protocol increased the lifetime by ~20% (range from 50 to 500 nodes), and it increases until it reaches its peak at the 1000 nodes network by a factor of ~45% increase in lifetime. Figure 11 showed that the first node to die is affected by the modification done in LEACH-CS and that it died after more rounds than LEACH-C. Figure 12 illustrates that LEACH-CS decreases the delay by ~50% as the sleeping mode may target the large numbered clusters in any round, and thus, the overall mean delay will show a reasonable decrease.

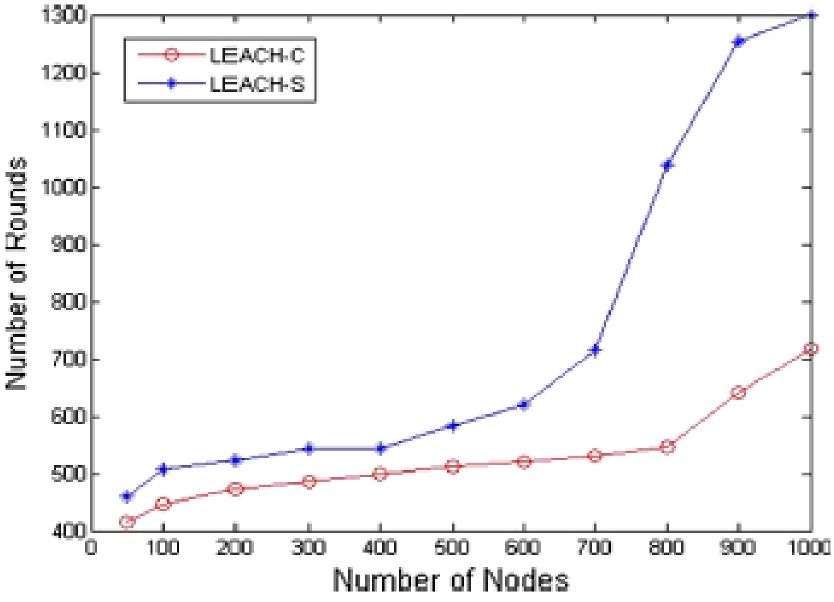

Figure 10. Relationship between number of rounds vs. number of nodes before the network is dead for Central Low Energy Adaptive Clustering Hierarchy (LEACH-C) and Low-Energy Adaptive Clustering Hierarchy Centralized Sleeping Protocol (LEACH-CS) for wireless sensor networks (WSNs) (Source: Hady et al., 2013).

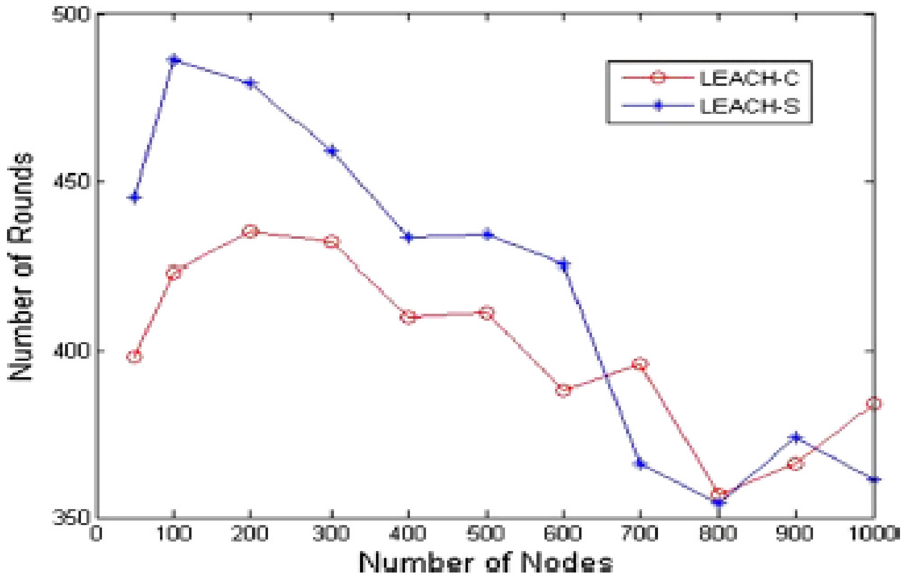

Figure 11. Relationship between number of rounds vs. number before the first node is dead for Central Low Energy Adaptive Clustering Hierarchy (LEACH-C) and Low-Energy Adaptive Clustering Hierarchy Centralized Sleeping Protocol (LEACH-CS) for wireless sensor networks (WSNs) (Source: Hady et al., 2013).

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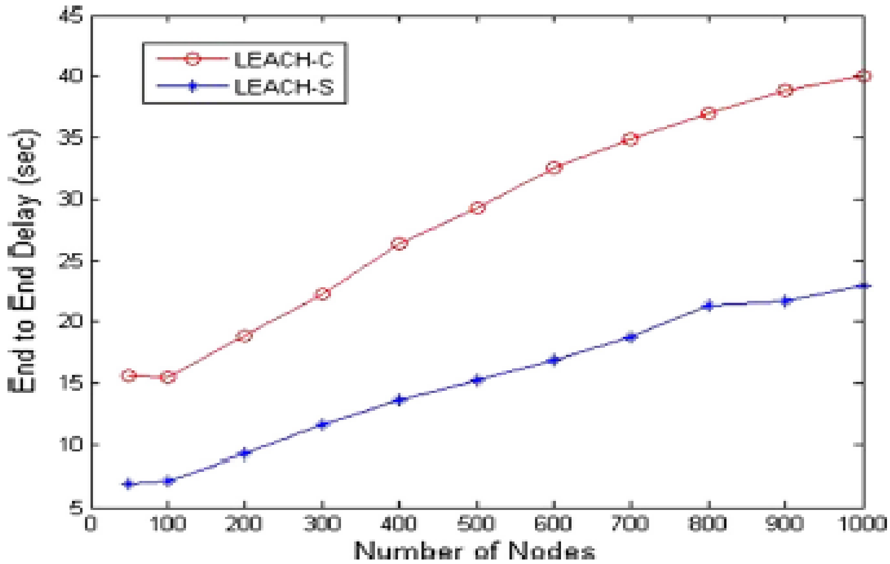

Figure 12. Relationship between number of rounds vs. end-to-end delay for Central Low Energy Adaptive Clustering Hierarchy (LEACH-C) and Low-Energy Adaptive Clustering Hierarchy Centralized Sleeping Protocol (LEACH-CS) for wireless sensor networks (WSNs) (Source: Hady et al., 2013)

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