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Research article

Balanced and Semi-Distributed Clustering Protocol for Wireless Sensor NetworksSalah A. Aliesawi ^{a,*}, Wesam M. Jasim ^a, Mohanad H. Wasmi ^a^a College of Computer Science and Information Technology, University of Anbar, Ramadi, Iraq,
salah_eng1996@yahoo.com, wmj_r@yahoo.com, mohanad.h1989@gmail.com**Abstract**

In Wireless Sensor Networks (WSNs), energy saving is one of the most essential issues in designing because of the significant restricted power resources of the Sensor Nodes (SNs). Moreover, these nodes are deployed in remote or hostile environments. Clustering techniques gained widespread acceptance due to its characteristic of less energy exhaustion. Intra-cluster communication cost (Intra-cluster term), Inter-cluster communication cost (Inter-cluster term), and Cluster Size (CS) have a great effect on balancing and conserving energy within each cluster in the network. In fact, topology control help in balancing the communication load and preserve the energy of the nodes by reducing both terms and determining the optimal CS. Hence, it would majorly influence improving the lifetime of the network. In order to achieve this, Balanced and Semi-Distributed Clustering Protocol (BSDCP) is proposed, which is suitable for long-scale transmission in WSNs. It uses topology control to manage the convergent sensors within the sensing area and control on CS. Thus, the Intra-cluster term is minimized. Moreover, instead of using Direct Transmission (DT) to send data of Cluster Head (CH) to Base Station (BS), BSDCP uses Multi-Hop (MH) communication between high residual energy Cluster Heads (CHs) and try to reach BS with minimum energy cost. Hence, the Inter-cluster term is reduced. In addition, the Dijkstra algorithm is employed as an effective tool to search for the least cost path efficiently. The simulation results show the significant improvement of our proposal compared to other clustering protocols, and it has a more extended network lifetime and stability period.

Keywords: Wireless Sensor Network, Clustering Protocols, Multi-Hop communication, Network lifetime.

摘要: 在無線傳感器網絡 (WSN) 中, 節能是設計中最重要的問題之一, 因為傳感器節點 (SN) 的功率資源受到嚴重限制。此外, 這些節點部署在遠程或惡意環境中。聚類技術由於其耗能少的特點而獲得了廣泛的認可。群集內通信成本 (群集內術語), 群集間通信成本 (群集間術語) 和群集大小 (CS) 對網絡中每個群集內的能量平衡和節約具有很大影響。事實上, 拓撲控制有助於平衡通信負載並通過減少術語和確定最佳 CS 來保留節點的能量。因此, 它將主要影響改善網絡的壽命。為了實現這一點, 提出了平衡和半分佈式聚類協議 (BSDCP), 它適用於無線傳感器網絡中的長距離傳輸。它使用拓撲控制來管理傳感區域內的會聚傳感器並控制 CS。因此, 群內術語最小化。此外, BSDCP 不使用直接傳輸 (DT) 將簇頭 (CH) 的數據發送到基站 (BS), 而是使用高剩餘能量簇頭 (CH) 之間的多跳 (MH) 通信, 並嘗試到達 BS。最低能源成本。因此, 群集間術語減少了。此外, Dijkstra 算法被用作有效搜索最低成本路徑的有效工具。仿真結果表明

, 與其他集群協議相比, 我們的方案得到了顯著改進, 並且具有更長的網絡生命週期和穩定期。

关键词: 無線傳感器網絡, 群集協議, 多跳通信, 網絡生命週期。

I. INTRODUCTION

Internet of Things (IoT) is a network of intelligence objects interconnected with each other through a communication medium. IoT is expected to perform a vital role in the next years. WSNs as the predecessor of IoT has become a research hotspot [1], [21], [22].

WSNs consist of hundreds to thousands of SNs. Each node has four essential components; the sensing unit, data processing unit, power unit, and the transceiver unit, to perform distributed sensing tasks. It is mainly used in applications where human intervention is not necessary. Actually, energy consumption of SNs in the network is mainly composed of three parts: sensing, data transmission, and data processing. However, data transmission consumes much more energy than other energy events. SNs have limited-energy and are deployed in the remote or dangerous places where recharging is semi-impossible [2, 3]. Energy conservation is considered as the most crucial challenge to ensure the connectivity between network parts and prolong the lifetime of the network [4]. In last years, several techniques for energy conserving have been developed such as; cross-layer design [5], clustering [6], routing protocols [7], etc. The routing techniques are classified into three main types: DT, MH transmission and clustering techniques [8]. In DT, SNs utilized single-hop to transmit their sensed data to BS. Loss of node energy is dramatically proportional with distance. Hence, distant nodes in the large regions will dissipate their energy early as compared to closer nodes from BS and these nodes exposed to energy hole issue. To overcome this issue, MH transmission is utilized, where SNs work cooperatively to relay their data to BS. Unfortunately, close nodes to BS drained their power faster than remote ones because they are used as relays for other distant nodes. In the end, an energy hole occurs in adjacent nodes from BS. Clustering techniques are widely accepted methods to improve energy efficiency and increase the stability period. In clustering, some special nodes which have high residual energy are selected as CHs for gathering information from other nodes before processing it and sending it to BS. On the other hand, low energy nodes act as normal nodes. They sense information and send the data packets to CHs.

Data packets received by CHs from the various nodes are gathered into one packet before transmitting it to BS. Only CHs have the exclusive right to communicate with BS. As a result, the number of forwarded packets is decreased. In this process, the network load is remarkably reduced, so the stability of the network is increased and the network lifetime is prolonged [4, 9]. When the network is splitted into many clusters, the communication cost is divided into two main terms: Intra-cluster term, which includes the energy cost of the non-CH nodes to reach their CH. While Inter-cluster term includes the energy cost of CHs nodes to reach the sink or BS [10].

Often, SNs are randomly deployed in critical environments by a helicopter. Therefore, in many cases, active nodes (ANs) are close enough to each other that they sense the similar data. This increase data redundancy. Thus, Intra-cluster and Inter-cluster terms increase and cause more energy consumption. There are many protocols have been proposed to improve the lifetime of the network. Low-energy adaptive clustering hierarchy (LEACH) is one of the most famous clustering protocols. LEACH and other clustering protocols use a probabilistic model to select CHs. As results for this model, some CHs maybe adjacent to each other which lead to unequal CS. Unequal CS would not maximize the energy efficiency. Thus, some non-CH nodes transmit their data through longer intra-cluster distances. Single-hop inter-cluster communications in most clustering protocols can minimize the energy exhaustion of communication through sending data of CH to BS. However, when the CHs are far away, the transmission distance increases, the single-hop becomes less energy efficient as it consumes more energy for long distances.

In this paper, a hybrid technique is proposed to combine the dijkstra algorithm with MH inter-cluster communications. The proposed technique makes appropriate distance between nodes and prevents them from being close to each other. Thus, ANs are managed regularly over the network and they balance energy consumption between clusters. The proposed protocol is called balanced and semi-distributed clustering protocol, which depends on a semi-distributed manner for choosing CHs. It does not choose CHs in a fully distributed manner, but it excludes the low

energy adjacent nodes and selects high-energy nodes as heads. Further, it reduces intra-cluster communication cost by making some low-energy nodes in sleep mode and distribute CHs uniformly within the sensing field that leads to equal clusters of size. However, the energy dissipated in each cluster is comparably equal, and nodes energy are balanced. The proposed protocol extends the stability period and the lifetime of WSNs by distributing the nodes in equal numbers through clusters. The residual energy is taken of CHs selection, and employing an effective tool to discover the actual shortest path with minimum cost to reach BS. This paper organized as follows: the related works are presented in section II. In section III, LEACH protocol, the radio energy model and the network model are introduced. the BSDCP is illustrated in details in section IV. In section V, the simulation results of BSDCP performance are indicated. Finally, section VI presents the conclusions of this paper.

II. RELATED WORKS

In recent years, many clustering protocols are developed. LEACH [11] is the first clustering protocol proposed by Heinzelman et al. It uses a distributed clustering approach for CHs selection process. The role of CHs is rotated between nodes per Group of Rounds (GOR). CHs in LEACH protocol use DT to forward data to BS. Thus, far CHs from BS consumes more energy cost and dies early.

LEACH is improved by Fan and Song. They proposed a new protocol energy-LEACH (E-LEACH) [12]. The major interest is given to the residual energy of SNs especially during CHs selection process to achieve more balance in energy consumption. The information about the residual energy of other nodes must share with all nodes. In this protocol, CHs are not uniformly distributed. As result, CHs could be located at the edges of the cluster.

Deng and Qi proposed a technique for restricting the number of CHs that can send their data directly to BS. This method named three-layered LEACH (TL-LEACH) [13], which rely on the ideas found in both LEACH and PEGASIS protocols. The CHs nodes of the set-up phase in LEACH are elected to be CHs of the second CH level, which have the ability to communicate directly with BS. But in a large scale network, CHs will dissipate their energy in short time.

In [14], energy efficient MH LEACH (EEM-LEACH) is discussed. It uses MH technique from SNs to BS with minimum distance. If nodes are close enough to BS, they can send their information directly to BS. While far once will use MH model between clusters. Moreover, CHs are selected based on both the residual energy and average energy consumption of SNs. Subsequently, only SNs that have higher residual energy and least power dissipation become CHs and are able to relay data. It uses a distributed approach for choosing CHs. So, there is no need for global information exchange. EEM-LEACH does not take into accounts least energy cost through data transmission but takes the minimum distance to transmit its data to BS.

In [15], Lee and Kao suggested a semi-distributed clustering approach called hybrid hierarchical clustering approach (HHCA) that is based on a three-layer hierarchal structure. In fact, it is extended work of TL-LEACH protocol. HHCA uses both centralized and distributed manner in CHs selection process. It is a top-down approach. Firstly, it selects the heads of the upper level (grid heads) in a centralized manner. On the other side, it uses a distributed manner in CHs selection at a lower level. Thus, the number of sensors that can communicate directly with BS is restricted. Therefore, the topology control is employed to prolong the lifetime of the network and balance the energy pregnancy of SNs as much as possible.

Abd Elwahab et al. proposed four layer LEACH (FL-LEACH) protocol with location-based topology control (LTC) in [16]. It uses LTC to manage the convergent ANs through the sensing range. Furthermore, four layers are employed. This helps in restricting the number of CHs which can send their data directly to BS, LTC is dependent on the inter-distances between ANs to prevent them from getting closer to each other less than a predetermined distance. As results both intra-cluster and inter-cluster communications techniques are reduced, the communication load is balanced, and the network lifetime is prolonged. One of drawback of this protocol, it is not applicable to large-scale network or in long distance transmission case.

Emad and Lon in [17] proposed a new version of MHT-LEACH protocol called improved MH technique (IMHT-LEACH), which route data to BS through multi-levels. IMHT-LEACH uses more than two levels for distributing CHs in the network. Moreover, it classifies CHs based on the distance from BS in order to distribute the energy

load through all parts of the network and increase the lifetime. Hence, this technique is more suitable for large networks. IMHT-LEACH is considered MH inter-cluster to transmit data to BS, it do not take into account the energy cost of CHs during the optimal path detection process.

Mohanad et al., in [18] propose a new routing protocol named distributed semi-clustering protocol (DSCP) to improve the lifetime of the large-scale WSNs. It aims to reduce the Inter-cluster term by considering the energy cost between CHs and find an optimal path among them to reach BS. It suffer from some drawbacks. One of these drawbacks is the some nodes close to each other. Thus, the cluster sizes is not equal.

III. BACKGROUND AND ASSUMPTIONS

A. LEACH Protocol

LEACH [11] is one of the most prominent clustering mechanisms that achieve energy saving in the sensor network. In LEACH, SNs organize itself as CHs and non-CHs (normal nodes) through a certain period called round. Each round is divided into two phases: the setup phase and the steady state phase. The round begins with a setup phase as shown in figure 1.

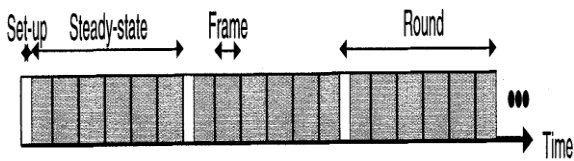


Figure 1. LEACH Protocol Process [19].

This phase is concerned with CHs selection and cluster formation based on the probabilistic model and the received signal strength. Each sensor node makes an independent decision to be a CH or not, by using a fully distributed algorithm; without any centralized control. A random number between 0 and 1, is allocated for every node. If the number is less than a threshold value $T(i)$ as referred in equation (1), the node becomes CH in the current round and broadcasts its decision. The role of CH is rotated among the nodes in every GOR to distribute energy cost evenly. Non-CH nodes choose closer CHs to access them using minimum communication energy. Hence, all SNs can determine their related cluster.

$$T(i) = \begin{cases} \frac{p}{1 - p(r \bmod 1/p)} & , \text{if } i \in G \\ 0 & , \text{otherwise} \end{cases} \quad (1)$$

where p is the desired percentage of SNs to be selected as CHs from the sensor population, r represents the current round number, if a node $i \in G$, this means that node has not been selected as a CH in the recent rounds ($1/p$). This guarantees the rotation role of CH periodically among all SNs. The setup phase is followed by a steady-state phase; this phase is concerned with data transmission between nodes. The communication between Member Nodes (MNs) and their CH is determined using Time Division Multiple Access (TDMA). Non-CHs nodes communicate directly with their their CH and then to BS as shown in figure 2.

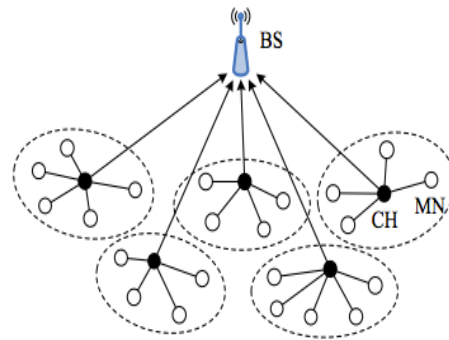


Figure 2. Basic Structure of LEACH [20].

LEACH can aggregate and fuse data locally in each cluster to reduce the transmission cost to reach BS. Although LEACH acts in an effective manner, it suffers from significant drawbacks. One of these drawbacks is CHs are not uniformly distributed. As result, CHs could be located at the edges of the cluster or could be close enough to each other. Another drawback is the transmission of CHs to BS using single-hop. Hence, it is not applicable to large-scale networks.

B. Radio Model

Each sensing node can perform multiple tasks such as; sensing, processing, transmitting and receiving data. Every one of the above tasks exhausts a specific part of node energy [3]. The first order radio energy model in [19], is used to estimate the energy consumption of the node and the total network lifetime. This model is depicted in figure 3.

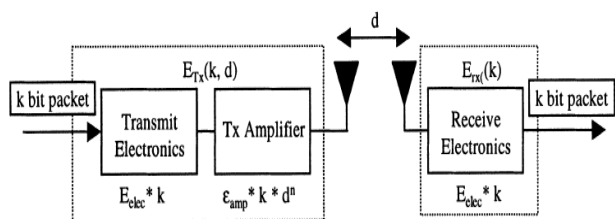


Figure 3. Radio Energy Dissipation Model.

The radio model takes into account the free space and multipath fading models when a node wants to transmit data (k -bit) to a destination through distance d . If the transmission distance d is less than or equal to a threshold value d_0 , the transmission energy in free space model (d^2 power loss) is used. Otherwise, the transmission energy in multipath fading model (d^4 power loss) is employed. The amount of energy consumption by transmitter E_{TX} for sending k -bit data through a distance d is given in equation (2). E_{TX} consists of two terms; the component cost term which interested with operation the electrical circuits, and another term is the amplification cost which works on amplifying the transmitted signal to make it capacity to overcome noise in its path.

$$E_{TX}(k, d) = \underbrace{K * E_{TX_elec}}_{\text{Component Cost}} + \underbrace{K * \epsilon_{amp} * d^n}_{\text{Amplification Cost}} \quad (2)$$

$$= \begin{cases} K * E_{TX_elec} + K * \epsilon_{fs} * d^2 & , \text{if } d \leq d_0 \\ K * E_{TX_elec} + K * \epsilon_{mp} * d^4 & , \text{if } d > d_0 \end{cases}$$

If the receiving node executes processing tasks on the data, it will consume an additional amount of energy equals $K * E_{DA}$, thus the total power that is required by the destination node is given by

$$E_{RX}(k) = \underbrace{K * E_{RX_elec}}_{\text{Component Cost}} + \underbrace{K * E_{DA}}_{\text{Aggregation Cost}} \quad (3)$$

where E_{TX_elec} and E_{RX_elec} are the required energy to operate the electronic circuit per *bit* in both transmitter and receiver. The amplifier parameters ϵ_{fs} and ϵ_{mp} are the amplification energy per bit over a distance d^2 for free space model and d^4 for multipath fading model, respectively. The threshold value d_0 denoted as:

$$d_0 = \sqrt{\epsilon_{fs} / \epsilon_{mp}} \quad (4)$$

If a node works as an intermediate node to relay data from source to destination, its radio expands:

$$E_{Relay}(k, d) = E_{RX}(k) + E_{TX}(k, d) \quad (5)$$

$$= \begin{cases} 2 * K * E_{elec} + K * E_{DA} + K * \epsilon_{fs} * d^2 & , \text{if } d \leq d_0 \\ 2 * K * E_{elec} + K * E_{DA} + K * \epsilon_{mp} * d^4 & , \text{if } d > d_0 \end{cases}$$

E_{elec} means either E_{TX_elec} or E_{RX_elec} . The description of these parameters are given in table 1.

Table 1 Parameters Description

Operation	Description	Dissipated Energy
K	Packet length	4000 bits
E_{TX_elec} / E_{RX}	Energy spent to operate the electronic circuit	50 nJ/bit
E_{DA}	Energy spent in data aggregation	5 nJ/bit/signal
E_{TX-amp}	Energy of transmission amplifier	ϵ_{fs} or ϵ_{mp}
d_0	Threshold distance	$\sqrt{\epsilon_{fs} / \epsilon_{mp}}$
ϵ_{fs}	Free space model (<i>fs</i>) is used, if $d \leq d_0$	10 pJ / bit/m ²
ϵ_{mp}	Multipath model (<i>mp</i>) is used, if $d > d_0$	0.0013 pJ / bit/n

C. Network Model

The work is based on some practical assumptions as follows:

- SNs are deployed randomly inside the $M \times M$ square field (target area).
- BS and all SNs are stationary after deployment.
- BS can be placed on the border of the sensing field or located far away from it.
- All nodes assumed to be homogenous, and each one has a unique ID.
- SNs use power control to set the amount of send power according to the threshold distance.

IV. BALANCED AND SEMI-DISTRIBUTED CLUSTERING PROTOCOL

The proposed BSDCP aims to decrease both Intra-cluster and Inter-cluster terms by controlling on the convergent nodes and finding an effective path between CHs and BS; this helps to save the energy consumption and prolong the network lifetime.

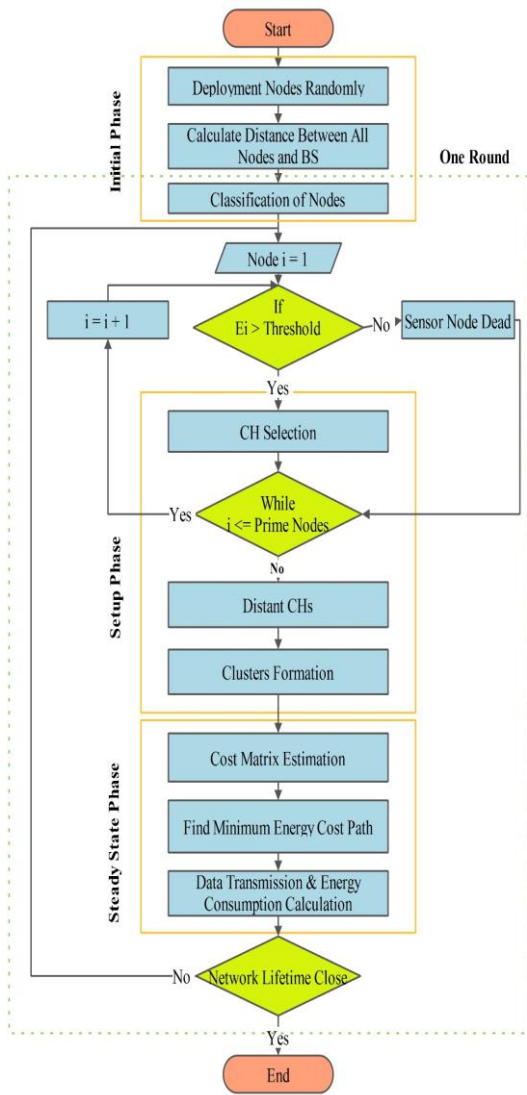


Figure 4. Flowchart of Proposed BSDCP

The BSDCP controls the neighboring nodes of each other, hence permitting some SNs going to sleep mode; it is considered the convergent ANs a waste of power because their sensing information are very similar. Moreover, CS is considered one of the most significant cluster characteristics owing to its pivotal role in saving energy and balancing load. It is attainable to achieve the least amount of data communication power inside the cluster. Furthermore, MH technique in BSDCP relays on using a hybrid method for finding the optimal path before the transmission process. Then, each CH sends its data to the nearest CHs until reaching to BS. This achieves least energy cost. Also, finding the least cost between CHs affect significantly on enhancing hotspot problem and stability period because this prevents the far CHs from DT and avoid CHs that be close to BS from overload. Hence, the energy required for sending data over the long distances is minimized. BSDCP

operation mainly divided into three phases: the initial phase, the set-up phase, and the steady-state phase. It's flowchart is illustrated in figure 4 and explained in details in the next subsection.

A. Initial Phase

SNs are deployed randomly inside the target area $M \times M$ square field as a first step. Adjacent nodes sense similar information. This of course cause squandering in energy. Therefore, we will classify the nodes using certain SD for keeping ANs away from each other with suitable distances to cover the target area. The adjacent ANs swap a control packet with each other. The sensor node that receives a strong signal from its neighbor and this node has less energy, it will be marked as a spare node, while its neighbor will be a prime node. This role is rotated between them to distributed energy evenly. For simplicity, the distance has replaced with the signal as shown in figure 5.

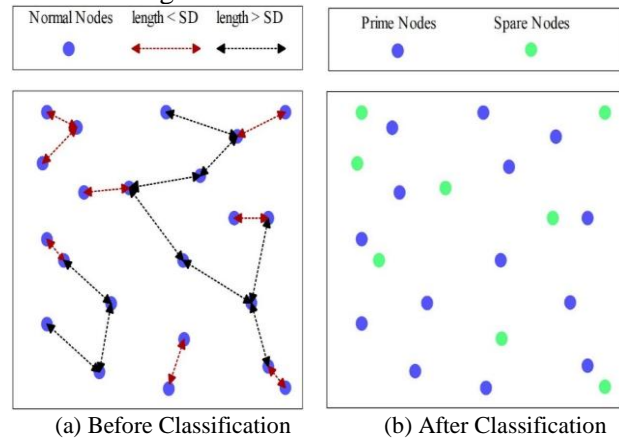


Figure 5. Distant Nodes Classification

SD is a complete application dependent factor, which is highly related to the network aim. At the end of the filtration process, it will get uniformly distributed nodes.

B. Set-up Phase

During this phase, CHs are selected, and many clusters are going to be established with equal size. It is divided into three sub-phases; CHs selection, distant CHs and cluster formation

1) CHs Selection

In this stage, each prime node can make its independent decision to be CH or not, in a semi-distributed manner. The prime node takes its decision based on a probabilistic model similar to that is used in LEACH. Meantime, the spare nodes turn to sleep mode to maintain its energy

2) Distant CHs

Convergence CHs from each other lead to varying numbers of nodes that belong to each

cluster as shown in figure 6-a. This produces an unbalance energy load within clusters.

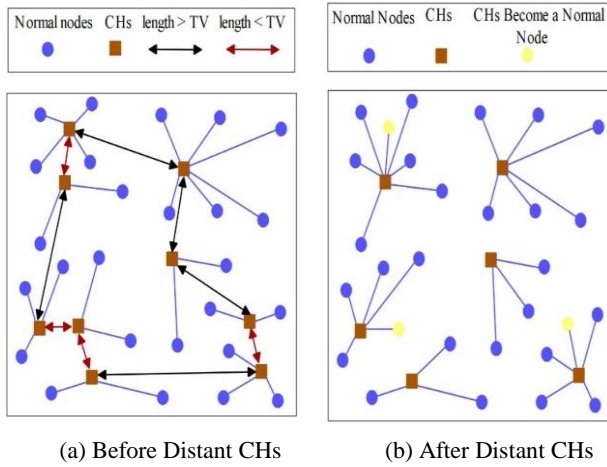


Figure 6. Distant CHs Process

After CHs selection in a random process, each CH broadcasts its decision with other CHs. If the distance between CH i and CH j is less than a Threshold Value (TV), CH that has higher energy is considered as a confirmed CH. Otherwise, it will be a normal node. Therefore, clusters have a relatively equal number of nodes as shown in figure 6-b. Further, CHs are distributed evenly in all over the network. Hence, the energy of CHs consumed in each round is comparably equal and the network is balanced. CHs selection that makes them away from each other is illustrated in the algorithm (1)

Algorithm 1. CHs Selection & Distant CHs

Input: Prime nodes, d, E, TV .

Output: Distant CHs.

Process:

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1: for node  $i = 1$  : Prime nodes number
2:  $i$  chooses  $RN$  between  $(0, 1)$ 
3: if  $RN \leq (p / (1 - p * (r \bmod \frac{1}{p})))$ 
4:  $i = CH$ 
5:  $CHs = CHs + 1$ 
6: end if
7: end for
8: for CH  $i = 1$  :  $CHs - 1$ 
9: for CH  $j = i + 1$  :  $CHs$ 
10: if  $(d_{ij} < TV)$ 
11: if  $(E_i \geq E_j)$ 
12: CH $_i$  become a normal node
13: else
14: CH $_j$  become a normal node

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15: end if
16: end if
17: end for
18: end for

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3) Clusters Formation

By the end of CHs selection and distant CHs processes, cluster formation begins. CH-nodes broadcasts advertisement message to neighbors' nodes. Based on the Received Signal Strength Indication (RSSI) of the advertisement message, the non-CH nodes determine their nearest CH. Then, each node sends a Join-REQ message that contains its ID to its CH. Each CH creates nodes schedule list according to the received Join-REQ messages and broadcasts this list to its cluster members. This list is used for telling the nodes related with the cluster, so they can transmit their data to the CH regularly to reduce the consumed energy

C. Steady-State Phase

As soon as CHs selection and clusters formation sub-phases are completed, the steady state phase starts, as shown in the final part of the flowchart in figure 4. The transmission of data through the long distances between CHs consume the most of nodes energy. Therefore, finding the optimal path between clusters is one of the solutions that would help in achieving energy efficiency and balancing the consumed energy of BSDCP. Nodes in BSDCP are filtered in previous two phases (initial and setup phases). Hence, only higher energy nodes will work as CHs and be relays for data.

Steady-state phase is portioned into three sub-phases. It begins to find an economical way to transmit the aggregated data to BS. Each CH has to paid energy cost for sending and receiving data. These costs have to be considered before estimating the optimal path using the Dijkstra algorithm. First of all, all costs between CHs and BS is estimated. Then, the Dijkstra algorithm starts to determine the least energy consumed path among CHs. We consider the energy cost as weights for edges between CHs instead of depending on the distance as weights between them. Hence, the Dijkstra algorithm assigns initial cost and try to improve them gradually until reach to BS with the best route which achieves the least cost. Accordingly, each CH routes packets via the best path found. The energy of CHs of the path is updated in each round until the network dies. At the start of each

round, the old path is deleted, and a new operation is repeated.

V. PERFORMANCE EVALUATION

The performance of BSDCP with clustering protocols are estimated. Several performance metrics are used for evaluating the performance of the clustering protocols such as:

- Network lifetime: The time duration from the start of the network operation until the last sensor node dead.
- First Dead Node (FDN): Denotes the elapsed time duration in which the first node died (stability period).
- Half Dead Node (HDN): Refers to the elapsed time duration in which half of the nodes (50%) are dead.
- Last Dead Node (LDN): Indicates the elapsed time duration in which last node (100%) dies.
- Un-Stability period: Duration of elapsed time after FND until LND in the network.
- Residual energy: The remaining energy of all SNs over the network operation time.
- Throughput: Indicates the number of packets received at BS over the network operation.
- Scalability: The network maintains its performance when the number of nodes is increased

A. Simulation Environments and Parameters

Matlab 2016a is used as a simulation platform to evaluate the performance of BSDCP. The network model consists of a number of homogeneous nodes in different sizes of networks. Hence, the nodes have the same initial energy. The interest is on large-scale networks and long-distance transmission cases, thus two scenarios of BS location are considered during simulation and each scenario has two models of network size. The first scenario, BS located at the border. While the second scenario, BS located far away from the sensor area. All simulation parameters are mentioned below in table 2.

Table 2 Simulation Parameters

Parameters	First Scenario (BS at Border)		Second Scenario (Far Away BS)	
	WSN-1	WSN-2	WSN-1	WSN-2
Sensing field dimensions	200x200 <i>m</i> ²	400x400 <i>m</i> ²	200x200 <i>m</i> ²	400x40 0 <i>m</i> ²
Number of	100	200	100	200

nodes				
BS location	(100, 0)	(200, 0)	(100,-100)	(200,-200)
Active nodes threshold	5 m			
CHs threshold value	15 m			
E_0	0.5 J			
p	0.1			
E_{TX_elec} / E	50 nJ/bit			
E_{DA}	5 nJ/bit			
ϵ_{fs}	10 pJ/bit/m ²			
ϵ_{mp}	0.0013 pJ/bit/m ⁴			
Data packet size (K)	4000 bits			
Number of rounds	1500			

Where E_0 is initial energy, p is the desired percentage of SNs to be selected as CHs from the sensor population, E_{TX_elec}/E_{RX_elec} , E_{DA} , ϵ_{fs} , ϵ_{mp} , k are previously explained in a table 1

B. Simulation Results

• First scenario (BS at border)

In this scenario, two WSNs models are implemented to evaluate the performance of BSDCP with other protocols. In order to achieve fair comparison in each model, all SNs are published randomly, and these SNs have the same position for all protocols. Furthermore, BS in first and second models located at a border of the network.

1) Network lifetime

The network lifetime refers to the number of SNs that have not yet consumed of their energies versus rounds. The network lifetime for LEACH, E-LEACH, TL-LEACH, FL-LEACH, DSCP, and BSDCP run in two models (WSN-1, WSN-2) at which BS at the border. As shown in figure 7, there is an improvement in network lifespan of BSDCP in each of the two considered models as compared to other protocols. In both models, LEACH and E-LEACH have roughly the same lifetime of alive nodes because they have the same work principle, except E-LEACH depends on the residual energy of nodes during CHs selection. Hence, the stability of E-LEACH is relatively more than LEACH by 3.28% in WSN-1 and 40% in WSN-2. TL-LEACH uses two levels of CHs, and only CHs in the 2nd level can communicate directly with BS.

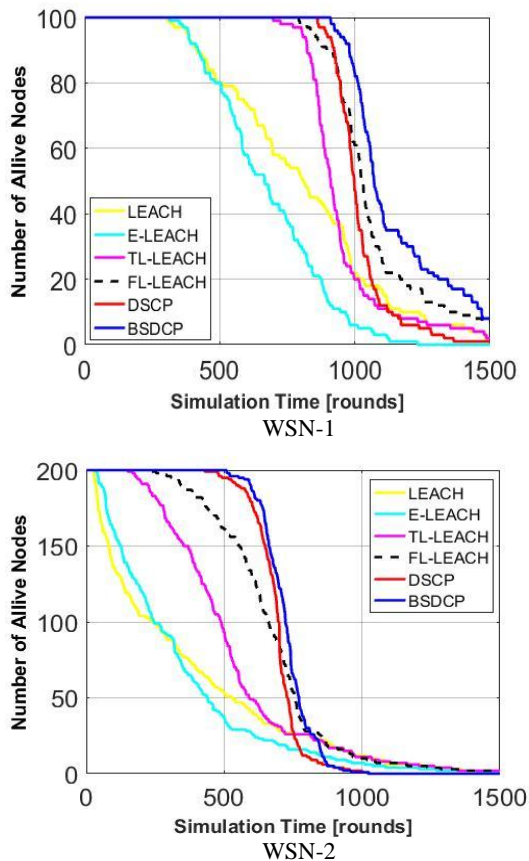


Figure 7. Network Lifetime when BS at Border.

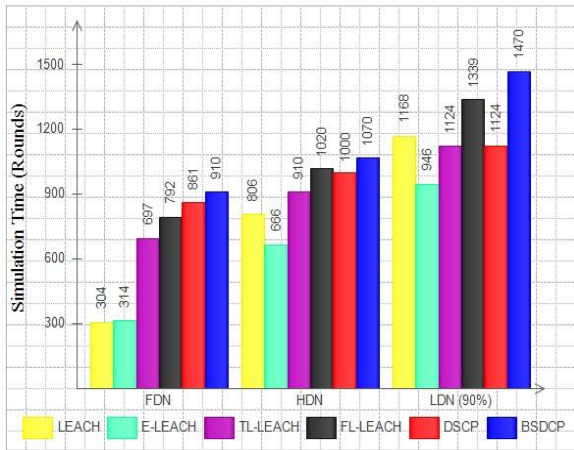
Therefore, the transmission distance to reach BS by the CHs of the 1st level is divided and energy cost is minimized. Hence, TL-LEACH performs better than both LEACH and E-LEACH by 12.9%, and 36.6% in WSN-1, and by 104.6%, and 100.4% in WSN-2 respectively. FL-LEACH uses LTC with three levels of CHs, and only CHs in the 3rd level can communicate directly with BS. Thus, it performs better than the previous three protocols by 26.5%, 53.1%, and 12% in WSN-1, and by 177.3%, 171.6%, and 35.5% in WSN-2 respectively. DSCP achieves the best number of rounds in terms FDN compared with mentioned above protocols because it depends on finding the least cost path to reach BS. In general, FL-LEACH in WSN-1 is finest of DSCP in terms HDN and LDN by 2% and 19%, due to DSCP is more suitable for large scale-networks as shown in WSN-2 where it excelled on FL-LEACH by 5.3% regarding HDN.

BSDCP fulfill a higher number of rounds compared with all the above protocols. It is not only depended on finding the least cost path to reach BS but also distant the close SNs and distributed the member nodes to CHs in a fair way. Moreover, it considers the energy cost of

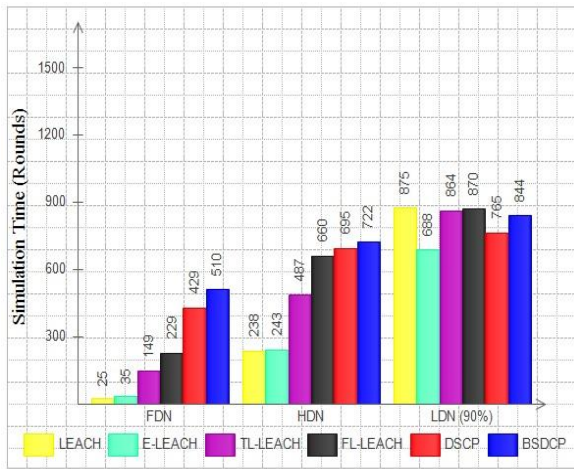
the CHs. This of course, will balance the Inter-cluster term energy cost between CHs. Hence, the transmission distance and communication cost are decreased.

The network lifetime is evaluated in three ways as shown in figure 8. One way used is to measure the round when FDN (stability period) and another way used is to measure the round when HDN and last way used is to measure the round when LDN. In WSN-1 model, BSDCP enhances FDN compared with LEACH, E-LEACH, TL-LEACH, FL-LEACH, and DSCP by 199.3%, 189.8%, 30.5%, 14.8%, and 5.6% respectively, while HDN is improved by 32.7%, 60.6%, 17.5%, 4.9%, and 7% respectively, and also it increases LDN by 25.8%, 55.3%, 30.7%, 9.7%, and 30.7% respectively.

When the network becomes extensive as in WSN-2 model, stability of LEACH, E-LEACH, TL-LEACH, and FL-LEACH fade quickly, but our proposal maintains on its performance for a longer period. Therefore, large values will appear during a comparison BSDCP with others, especially in FDN. our protocol increase the network lifetime in terms FDN by 1940%, 1357%, 242.2%, 122.7%, and 18.8% compared with LEACH, E-LEACH, TL-LEACH, FL-LEACH, and DSCP respectively. With reference to HDN as the lifetime evaluation metric, the lifetime enhances by 203.3%, 197%, 48.2%, 9.3%, and 3.8% respectively. In terms LDN, BSDCP enhances only on DSCP and E-LEACH by 22.6% and 10.3% respectively. Although the time of the LDN of LEACH, TL-LEACH, and FL-LEACH is longer than that of BSDCP, it means that the energy consumption of these protocols is not so well balanced. Thus many SNs have more residual energy to live longer.



WSN-1



WSN-2

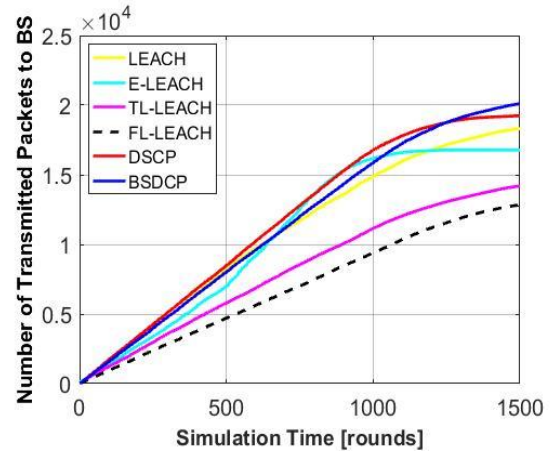
Figure 8. FDN, HDN, and LDN when BS at Border

2) Throughput

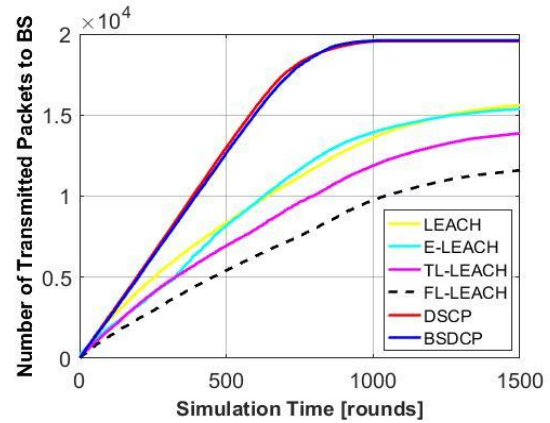
The number of transmitted packets to BS over the rounds for both models is shown in figure 9. In FL-LEACH, few numbers of CHs (only of 3rd level) have the exclusive right to send data packets to BS; and in TL-LEACH, only of 2nd level can communicate with BS and send data packets to it. Hence, the number of the received packet is strictly related to their numbers.

While in LEACH and E-LEACH, all CHs can send data to BS, but faraway CHs will die early. However, they sent packets higher than TL-LEACH and FL-LEACH; and lower than DSCP and BSDCP for both models. On the other hand, in DSCP and BSDCP, all near CHs to BS can relay data. Thus, the throughput is higher than that of LEACH, E-LEACH, TL-LEACH, and FL-LEACH. Although of network lifetime of BSDCP is better than DSCP, but the throughput of both them is relatively equal, due to that BSDCP put some nodes in sleep mode. As result, semi-clustering protocols (DSCP, BSDCP) have

better performance, since BS receives much more packets from CHs during the network lifetime.



WSN-1



WSN-2

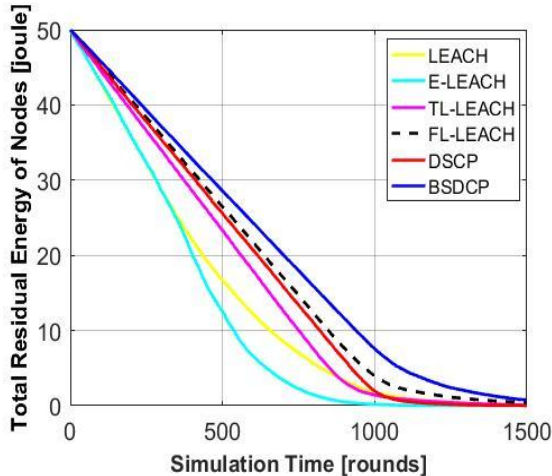
Figure 9. Total number of received packets when BS at border

3) Residual energy

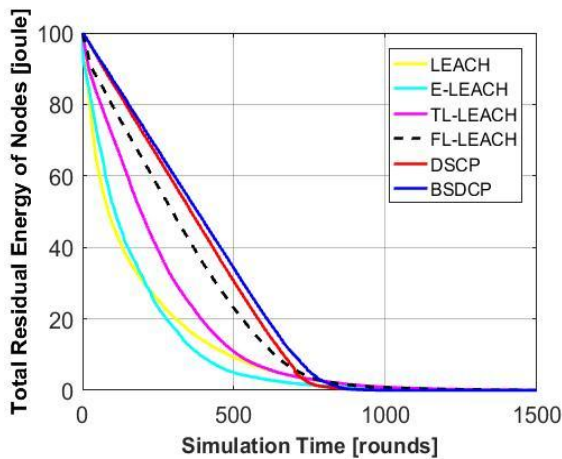
Figure 10 shows the residual energy of SNs over the rounds for both models. In LEACH and E-LEACH, all CHs have the ability to communicate directly with BS and use single inter-cluster to send data to BS. Hence, CHs require more power to transmit their data to BS; especially in large-scale networks. This makes the slope of LEACH and E-LEACH curve is significantly below for both models.

TL-LEACH and FL-LEACH depend on multi-levels to send their data from CHs to BS instead of using DT to do so. Therefore, the slope of TL-LEACH and FL-LEACH curves is higher than LEACH and E-LEACH. DSCP divided the cost communication among CHs and always looked for the least-cost path. Hence, its curve is higher than LEACH, E-LEACH, and TL-LEACH. FL-LEACH uses sleep mode. Therefore, FL-LEACH has more residual energy from DSCP when compared with it, especial in the small-scale networks (WSN-1). Additionally to MH

and least-cost path, BSDCP tries to choose nodes that have high energy to be CHs and makes low energy nodes in sleep mode. Thus, its slope of residual energy curve is higher than all above protocols for WSN-1 and WSN-2 models.



WSN-1



WSN-2

Figure 10. Total residual energy per round when BS at border

4) Scalability

The deployed SNs are depending on the application type, and these nodes varied from a few numbers to a few thousand. Thus, the proposed protocol must be scalable and work efficiently with a huge number of sensors. The effect of scalability on the BSDCP is analyzed. The focus is on large-scale networks. Thus, only WSN-2 model are considered. The simulation result is displayed in figure 11. It can see that varying the diffused nodes number does not effect on the network lifetime and this is desirable.

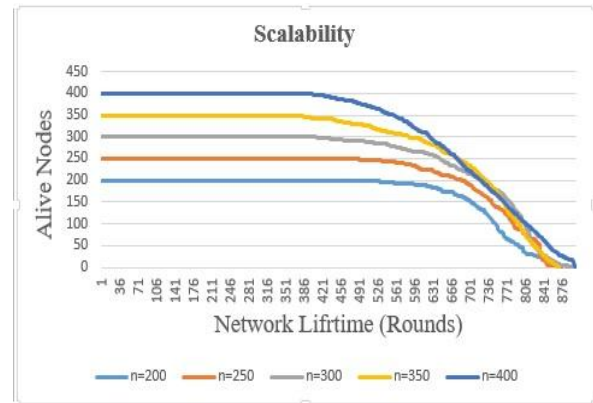


Figure 11. Scalability effect on the network lifetime when BS at border (WSN-2)

• Second Scenario (Far away BS)

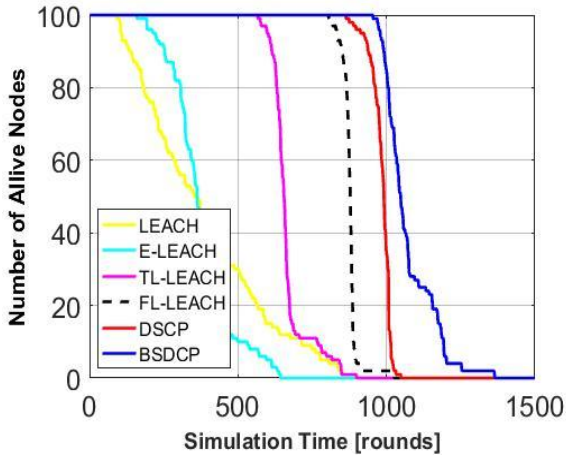
When sink or BS moved away from the sensing field, the impact of BSDCP in improving the network lifetime and stability period is greatly enhanced. In this scenario, two WSNs models are used to evaluate the performance of BSDCP with other protocols. BS in both models located far away from the sensing field.

1) Network lifetime

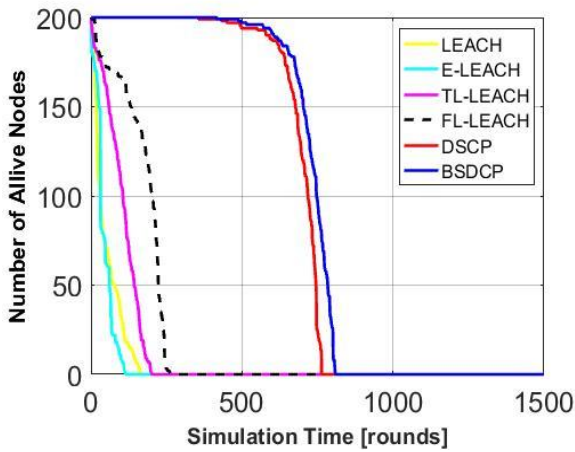
The network lifetime, stability, and instability period for protocols under comparison for first and second models are illustrated in figure 12. Figure 13 illustrates FDN, HDN, and LDN for LEACH, E-LEACH, TL-LEACH, FL-LEACH, DSCP, and BSDCP that are calculated for two models.

In both models, the curve of LEACH, E-LEACH, TL-LEACH, and FL-LEACH quickly descends especially in the second models, because BS moved away from the sensing field and distance become long. Hence, comparison of our proposal with these protocols will be great. It is obvious that BSDCP achieved the highest number of FDN, HDN, and LDN in comparison with others. In regarding FDN, BSDCP is more efficient than LEACH, E-LEACH, TL-LEACH, FL-LEACH, and DSCP by 984%, 500%, 68.5%, 18.5%, and 10.5%, respectively. LEACH protocol performance is the worst one regarding FDN because the faraway CHs consumed much more energy in sending its data directly to BS, hence they die early. Either concerning HDN, BSDCP also outperforms by 198.3%, 189%, 60%, 19.2%, and 5.6% respectively, due to BSDCP is away between the adjacent nodes, these nodes keep their energy for a longer period. Either when taking LDN as evaluating matrix, the

proposed protocol enhances by 66%, 139%,55.7%, 34.3%, and 17.6% respectively, in the case of WSN-1 model.



WSN-1

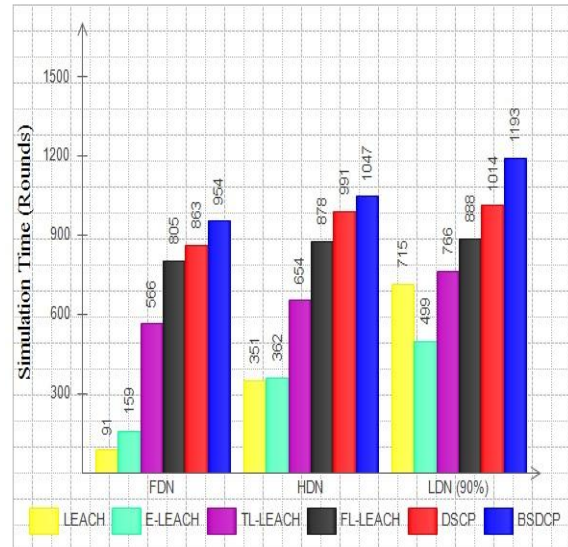


WSN-2

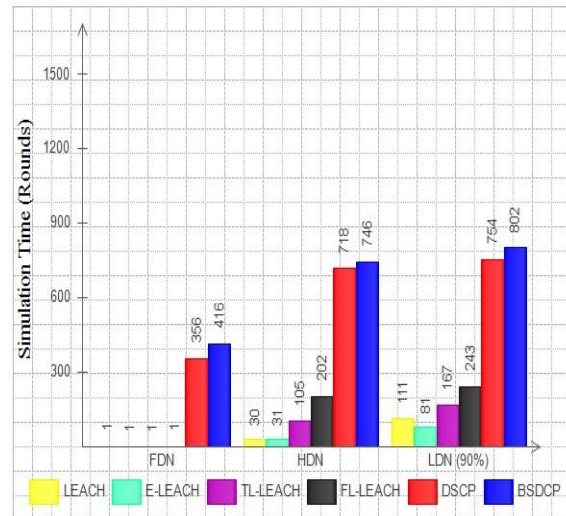
Figure 12. Network lifetime when BS far away

Either in WSN-2 model, the impact of BSDCP in improving the stability period and prolonging network lifetime appears in a clearer manner. This is illustrated during comparison of scenario 1 with scenario 2, respectively. We conclude from this result, DSCP and BSDCP are maintaining their performance when the network is large-scale and BS far away, this is the main target of our research. While LEACH, E-LEACH, TL-LEACH, and FL-LEACH are fading in a short time. Hence, no need to mention all the percentage improvement between our proposal and other contributors. We will only compare between BSDCP and DSCP, where BSDCP is more efficient than DSCP by 16.8% regarding FDN. Either in terms of HDN, BSDCP also outperforms on DSCP by 3.8%, and by 6.3% concerning LDN. It implies, the protocol is more efficient than others in large-scale networks or when BS moved away from CHs, where the

impact of employing MH communication and distant CHs in long-distance transmission appears on the lifetime and stability of the network. Hence, BSDCP achieves lower energy consumption and becomes more stable.



WSN-1



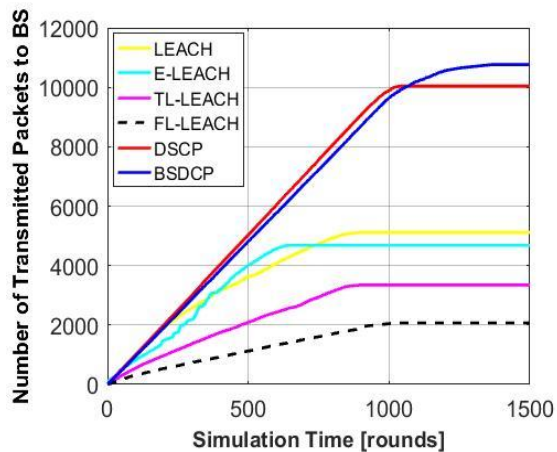
WSN-2

Figure 13. FDN, HDN, and LDN when BS far away

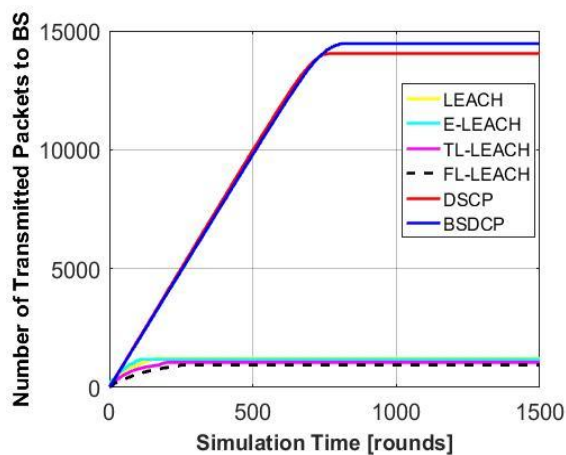
2) Throughput

Two models of throughput are illustrated in figure 14. This figure presents the efficiency of BSDCP that achieves the highest throughput of received packets against its counterparts (LEACH, E-LEACH, TL-LEACH, FL-LEACH, and DSCP) for both models, due to the lifetime of BSDCP is larger than others and ensures that CHs are uniformly distributed in large-scale, and they can gather data from all MNs in the field. Thus, a larger number of SNs still able to send their packets to BS duly. The prominent reasons

for increasing throughput are efficient transmission manner in inter-cluster communication, a spacing of convergent nodes, and efficient CHs selection then distribute them.



WSN-1



WSN-2

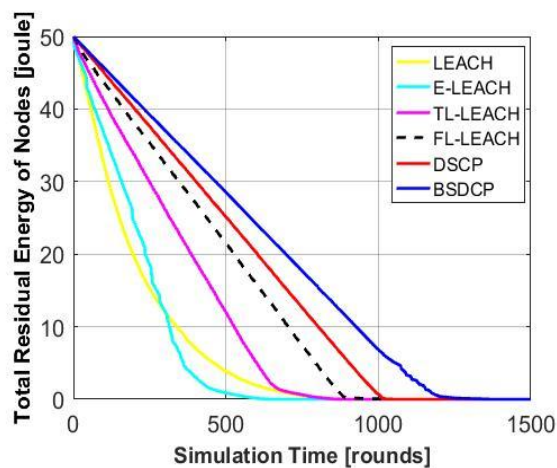
Figure 14. Total number of received packets when BS far away

3) Residual energy

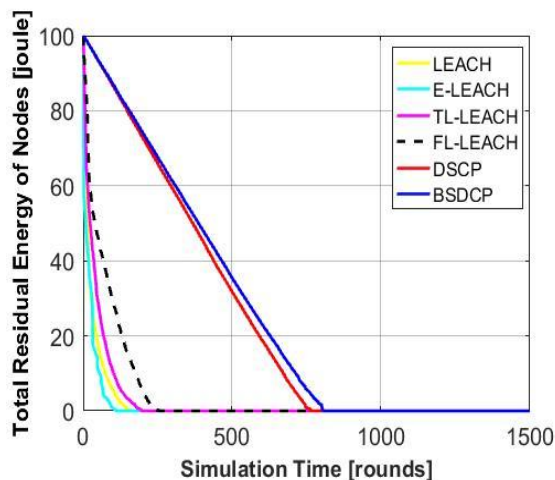
Figure 15 shows the total residual energy of the network in BSDCP and other protocols with respect to a number of rounds in both models. It is desirable to balance energy consumption over the long-distance transmission case. This is achieved by MH inter-cluster, and all CHs have an equal number of nodes to avoid surplus CH load. These factors are achieved in BSDCP, and this proposal ensures energy dissipation balancing.

It is observed that remaining energy of LEACH, E-LEACH, TL-LEACH, and FL-LEACH are gradually decreasing at an almost close rate with each other when sensing field is not very large as in the case of WSN-1. DSCP and BSDCP have higher residual energy curves

respectively. But when the network area grows and the transmission distance increases, the energy curves of LEACH, E-LEACH, TL-LEACH, and FL-LEACH are fallen apart very quickly. While DSCP and BSDCP maintaining on higher residual energy curves respectively. This appears when compare WSN-1 model with WSN-2 model.



WSN-1



WSN-2

Figure 15. Total residual energy per round when BS far away

4) Scalability

The scalability is also evaluated in faraway BS. The number of alive nodes is compared in WSN-2 model by changing the number of SNs. The results are shown in figure 16. However, in our case, we have only considered a number of alive nodes. It can be seen that changing the number of nodes does not effect the number of alive nodes

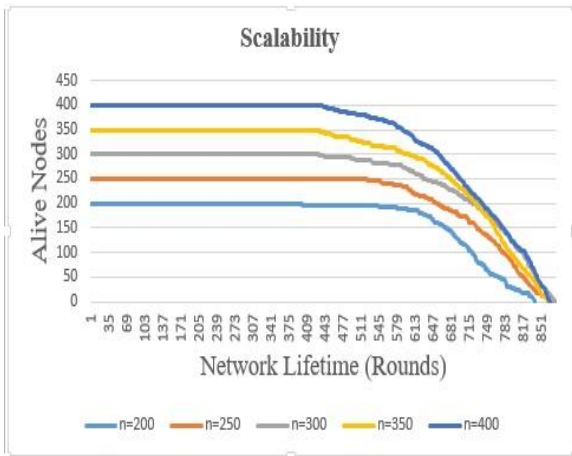


Figure 16. Scalability effect on the network lifetime when BS far away (WSN-2)

VI. CONCLUSION

Efficient energy upgrading is a major challenge in WSNs. Intra-cluster and Inter-cluster terms as well CS have a direct impact on enhancing the gain of energy and extending network lifetime. In this paper, we proposed a BSDCP for large-scale WSNs. In BSDCP, nodes are filtrated based residual energy and predetermined distance. Definitive CHs are elected based on a random process on ANs, their distance from each other, their residual energy. Moreover, the proposed protocol uses an effective tool to find minimum energy cost path. The considered parameters are used to make all clusters, even in size, less intra-cluster and inter-cluster communication costs. Therefore, energy consumption is balanced over the sensing area, and provide energy efficient intra-cluster and inter-cluster transmission. BSDCP can be used for applications that require scalability and very long network lifetime. The results display that BSDCP performance is more efficient than its comparatives. It has best network lifetime, throughput, and residual energy. In future works, K-means algorithm can be used to achieve the optimal number of CHs and get a uniform cluster distribution.

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