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A Mobile BS and Multi-Hop LEACH-C Extension for WSNs

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Abstract

It is critical for wireless sensor networks (WSNs) to have an uninterrupted power source. Increasing the lifetime of WSNs will require employing an energy preservation mechanism. In many WSN applications, sensors are used to detect events and collect environmental data, which are then delivered to a sink node or a base station node (BS) through a communication link. Sensors consume energy during wireless data communication, which is higher than the computational energy. This paper proposes an enhanced LEACH-C protocol that manages the network energy consumption and prolongs sensors lifetime. The proposed protocol is named Leach-C Multihop and Mobile (LEACH-CM). The proposed LEACH-CM protocol distributes the energy consumption between the network nodes and enables more data to be transmitted over a WSN. The proposed LEACH-CM protocol is simulated in the NS2 simulation, which is supported by the μ-AMPS project and is developed by MIT researchers. The simulation result shows that the proposed LEACH-CM protocol can decrease the energy consumption, and increase the amount of transmitted data compared to the LEACH-C protocol. Furthermore, the LEACH-CM protocol outperforms the LEACH-C protocol when comparing the dead time of the first node, which is a good indication of network stability.

Keywords: Wireless sensor networks; Network lifetime; LEACH-C; K-means; Clustering; Mobility.

1. Introduction

Wireless Sensor Networks (WSNs) have many real-life applications. They are used to monitor environmental conditions, such as temperature and vibration, and detect events, such as forest fires and earthquake. WSNs consist of several sensor nodes that are equipped with data processing unit, communication unit, and a battery with limited-energy [1, 2].

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The sensors nodes collect environmental data and send them to a sink node or a base station (BS). The sensor nodes are the main component of a WSN. They can be deployed either manually or dropped randomly on the desired areas that are difficult to access, Sensors can have automatic configuration. In most cases, hazardous working environments can make it impossible to replace or recharge the depleted batteries of the sensor nodes [3]. Therefore, it is important to employ an effective energy saving protocol to extend the battery life-time of individual nodes, and consequently extend the life-time of the WSN. There have been many research projects that are focused on developing techniques to extend the lifetime of WSNs [4, 5, 6]. The network lifetime is a function of the amount of remaining energy in the sensor nodes. Data routing and transmission between nodes dissipates the most energy [7]. Routing protocols in WSNs can be classified based on several criteria. For example, the routing protocols can be proactive or reactive. Proactive routing protocols construct and maintain routes, regardless of whether there is a traffic flow or not. Meanwhile, reactive routing protocols construct and maintain routes only if there are data that need to be transmitted to other nodes. The routing protocols can also be classified based on the architecture of the WSN. The sensor nodes can be homogenous or heterogeneous and the routing protocols can be classified as flat or hierarchical topology [8]. The flat routing topology protocols assume that all nodes have the same energy, and find routes to the sink node with different hop counts. On the other hand, hierarchical (or cluster) routing protocols group sensor nodes into clusters and the data from a single cluster are aggregated and transmitted to the BS. Hierarchical routing protocols have better scalability and can manage more efficient communication [9].The choice of a routing protocol should consider its efficiency in consuming the energy of nodes. There are many energy efficient routing techniques [10, 11, 12], In Power-Efficient Gathering in Sensor Information Systems (PEGASIS) protocol [13], the nodes are divided into chains either by sensor nodes using a greedy algorithm or by the BS. Each node sends and receives the data to and from the nearest neighbor node, and the chain leader combines all the data in order to transmit them to the BS. In Threshold sensitive Energy Efficient sensor Network protocol (TEEN) [14], data are sent to the BS based on changes in the sensed environment. The TEEN protocol is data-driven and it is used in time-critical application. The energy consumed in data transmission is more than the energy consumed in data sensing. Therefore, the TEEN protocol preserves energy because the sensor continuously senses the medium, while the data are transmitted only when an event occurs. Routing protocols depend on different factors such as the change in locations of sink nodes or base station (BS). The clustering method [15], which is one of the significant methods used in WSN, consists of two phases. In the first phase, the clusters and the cluster Heads are identified according to the value of energy of each node and based on some other parameters. In the second phase, the data are transmitted to a sink node or the BS. This paper proposes an energy saving routing protocol based on the clustering technique. The proposed protocol is named Leach-C Multihop and Mobile (LEACH-CM).The main features in the proposed LEACH-CM protocol are that it sends the sensed data to a neighboring node, instead of sending it directly to the CHs, and the communication between CHs and BS is optimized by introducing mobility to the BS. The objectives of the proposed LEACH-CM protocol are as follows: (1) maximize the lifetime of the network which is done by balancing the energy dissipation to all sensor nodes; (2) maximizing the amount of received data by the BS, and (3) extending the network stability by enhancing the dead time of the first node. Using the dead time of the first node to measure stability was used in [16].

1.1. Structure of the paper

The rest of the paper is organized as follows. Section 2 discusses previous literature related to the addressed problem. Section 3 discusses the LEACH-C protocol phases. Section 4 discusses the proposed protocol. Section 5 provides simulation analysis and results .Section 6 provides some final conclusions and directions for future work.

1.2. Related Work

The application of routing protocols into WSNs results in the appearance of several weak points. For example, in the flooding technique [17], each node broadcasts the received data and controls packets sent to the rest of the nodes. The flooding process repeats until the data reach the destination node. This technique suffers from an implosion problem [18], where it can expedite the energy dissipation and shorten the network lifetime. This is because it does not take into consideration the limited energy of the sensors. Moreover, this technique suffers from what is called overlapping of the sensed data problem [19], where duplicate packets can be circulated in the network. Moreover, packets with the same data can also be sent from different nodes due to nodes sensing the same region and sending the same data at the same time. The gossiping technique [20, 21], overcomes the flooding technique problems. In the gossiping technique, when a node receives a packet, it randomly selects one of its neighboring nodes to send the packet to it. This process is repeated until a packet reaches its destination. In the gossiping technique, a sensor would receive only one copy of a packet being sent, and therefore it alleviates the implosion problem. However the gossiping technique suffers from a significant delay when transmitting a packet through a WSN, and this delay becomes longer when the number of nodes is increased. The LEACH protocol [22], was the first hierarchical routing protocol for WSN to increase the WSN lifetime. The LEACH protocol runs in many rounds, where each round works in two phases; the cluster setup phase and the steady-state phase. In the setup phase of a round, each node decides whether to be a cluster head or a non-cluster head for that round, the CH node announces its role to all sensor nodes by sending broadcast message to inform all nodes of the CH nodes ID. Sensor nodes join one of the clusters based on the signal strength. A node joins the cluster of the CH with the highest received signal strength, which means that this CH is the closest one to the sensor node. This result in preservation of the energy required to send the sensed data to the CH. At the end of this phase, the CH node assigns time slot for each node member using TDMA technology to guarantee that no collision will occurs between data messages. In the steady-state phase, a CH node aggregates the data received from the sensor nodes in its cluster then transmits the data to the BS using the CSMA technique, which is used to make sure that only one CH node send its data at a time .

2. LEACH-C protocol

There have been different techniques developed to transmit the data from cluster nodes to their CHs, and the BS. Most hierarchical protocols are derived from the LEACH protocol, and the LEACH-C (LEACH-Centralized) protocol is one of them [23].

In the LEACH-C setup phase, a centralized clustering algorithm is applied. Each node should be aware of its location, which might be obtained by a GPS receiver or other localization techniques. The location information and the energy level of nodes should be sent to the base station at each round. The base station finds the nodes with the higher energy level than the average node energy to be eligible to be a CH. A cluster is formed using the simulated annealing (SA) algorithm [24], where the optimal cluster is found and the cluster nodes are assigned to the closest CH to preserve the network energy. Following that, the BS will broadcast a message with the CH nodes ID (to inform all nodes of its role for this round), and the TDMA slot determined for each node for data transmission. This process will be repeated in each round, and the CH role is distributed among the other nodes to balance the energy loss to all network nodes. In the LEACH-C steady state phase, the same tasks are performed as those performed in the steady state phase of the LEACH protocol. The CH sends aggregated data received from cluster nodes to the BS [25]. Figure 1 shows an example of a network topology used by the LEACH-C protocol. The LEACH-C protocol solves the non-uniform distribution of CH problem in the LEACH protocol, which neglects the factor of the remaining energy of CH by choosing them randomly. However, LEACH-C has a disadvantage when sending data in 1-hop [26] from cluster nodes to CH.

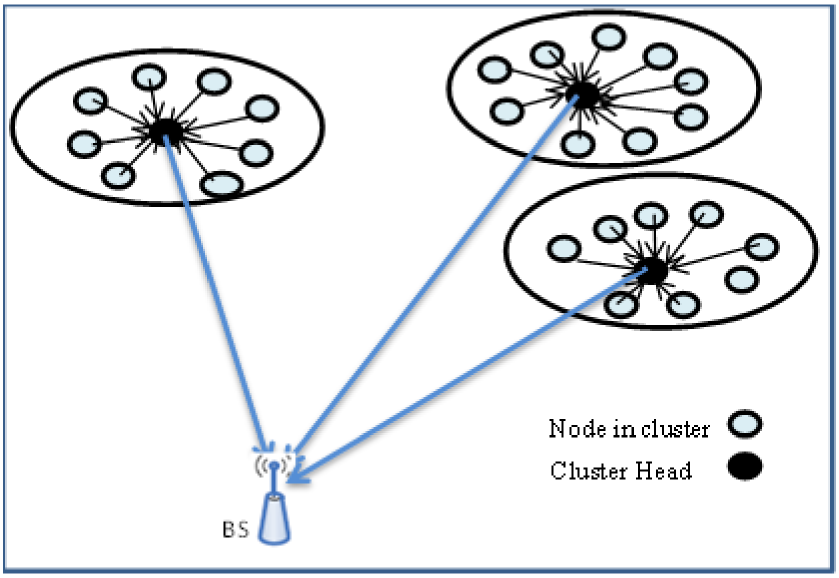

Figure 1: LEACH-C Architecture

3. Leach-C Multihop and Mobile (LEACH-CM)

The proposed LEACH-CM protocol addresses the issue of data transmission from the cluster nodes to their CHs, and from the cluster heads to the BS. The data transmission issue has a significant impact on the overall energy dissipation.

3.1. Setup phase

The objective of this phase is to create the clusters and find the CHS of the cluster. The k-means algorithm [27] is used for cluster formation. Nodes are divided into K clusters, where the number of clusters is determined in advance. The BS receives information about the sensor nodes, which includes their locations and residual energy. The average of the network residual energy can be calculated as follows: E total = $\frac{\sum_{i=1}^{n} e_i}{n}$ where n is the total number of nodes, and e is the residual node energy. When the residual energy of a sensor node is higher than the average of the network energy, this sensor node will be eligible to be a cluster head for this round. In the start of a simulation run, it is assumed that each node starts with equal energy =2j, which means that all nodes will be eligible to be CHs for the first round. Therefore, k nodes are selected randomly. The center point of each cluster is calculated by C= $\frac{\sum_{i=1}^{n} X_i}{n}$ where Xi is the coordinates of sensor node i. Each node measures the distance to the center points using the Euclidean distance function, and then it is assigned to the cluster that contains the nearest center point. The process is repeated until the same points are assigned to the same clusters in consecutive rounds. Starting from the second round, the eligibility of rounds to be CH is determined based on the residual of the nodes energy. It is found from the simulation results that the cluster formed faster. A poor cluster constructions in a round should not negatively affect the network performance [23]. Since the energy dissipated by a CH node is higher than that of the non-cluster nodes, it is important to assign different nodes as cluster heads in different rounds. As a consequence, the energy dissipation will be balanced throughout the nodes.

3.2. Steady state phase

Clusters can apply two types of transmission. One type is applied for data transmission between the CH and the cluster members (i.e. for inter-cluster traffic).While the other type is applied for data transmissions between the BS and the CHs (i.e. for outer-cluster traffic). In the proposed protocol, the inter-cluster traffic is handled by a neighboring node to CH. After the clusters are formed and the CHs are selected, the data become ready to be sent from the sensor nodes to the CHs. In the proposed LEACH-CM protocol, instead of sending the data directly from the sensor nodes to the CH, the following is done. The farthest node from the CH in the cluster is found, where this node is defined as the series master (SM). A neighboring node to the SM is found. The TDMA schedule is assigned for each node, starting from the SM followed by the neighbor nodes. This means that the SM will be the first node which will send its data to the neighbor node and so on until the data reach the CH. By sending this way, the total travel distance between the clusters nodes to the CH is minimized, which directly affects the total network life time. A sensor node will send the data directly to the CH only if the CH is the next neighbor of the node. The CH will aggregate the received data from the cluster sensor nodes and send it to the BS. Since the CH should forward large amount of received data from sensor nodes plus its own sensed data, then the CH energy will drain faster. Therefore, in order to preserve the CH energy, the CH nodes will be replaced by another node in the next round. Once a CH aggregates cluster data, it sends the data to the BS. The cluster head position is different in each round, and so the proposed protocol makes the BS mobile to minimize the distance between the BS and current CHs. The BS has full information about the locations of the CHs, and so it will calculate the new relative position between itself and the CHs (center point between the CHs) using the following formula

$X_{(BS)} = \sum \frac{X(CH)}{k}$, $Y_{(BS)} = \sum \frac{y(CH)}{k}$, where x (CH) is the X coordinates of CH nodes, y (CH) is the Y coordinates of CH nodes and K is the number of CHs determined by the K-means algorithm. The aforementioned calculation is based on decreasing the overall transmission power of the outer-cluster traffic by decreasing the distance between the CHs and the BS to preserve the CH energy. Figure 2 shows an example of a WSN that consists of 3 clusters, with 3 cluster heads. The inter-cluster traffic can be viewed as a chain inside its cluster. The BS calculates the best new position it should move to it in order to receive the outer-cluster traffic with the lowest overall energy consumption.

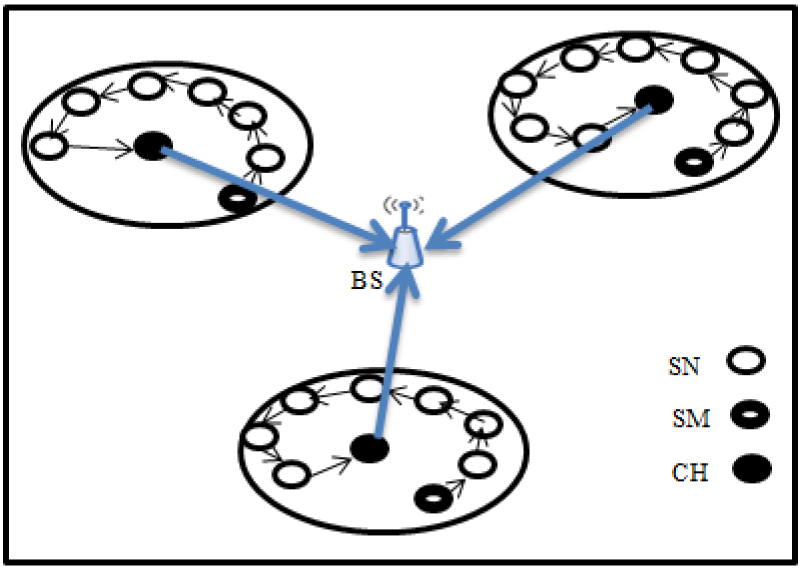

Figure 2: Sensor nodes network instance

4. Simulation Results and Analysis

The NS2 simulator is used to evaluate the proposed LEACH-CM protocol and compare its performance to the LEACH-C protocol. NS2 [28] network simulator is installed on Linux Ubuntu 10.04 virtual platform, The µ-AMPS (Micro-Adaptive Multi-domain Power-aware Sensors) project developed by MIT researchers is used to simulate the LEACH-C protocol. The following files are modified for this work (genscen,bsagent,ns-bsapp,ns-leach-c, leach_test) to implement the K-means algorithm, construct the node series to send the inter-cluster, and achieve mobility for the BS to send outer-cluster traffic. The simulation parameters are set as in Table 1.

Table 1: Test network parameter

Number of Node	100,200
Node state	Homogeneous
Network Size	100 m x 100 m
Base station	Mobile
No. of CH nodes	3,5,7,10
Initial energy per node	2 joule

The nodes are distributed randomly over a network area of size 100 meter by 100 meter as shown in Figure. 3, which is within the communication range of each other. The mobile base station in initially located at

(50m,50m). The nodes have the capability to send their information (location and energy level) to the BS. The simulation is run with 200 sensor nodes and different number of CHs (3, 5, 7, and 10).

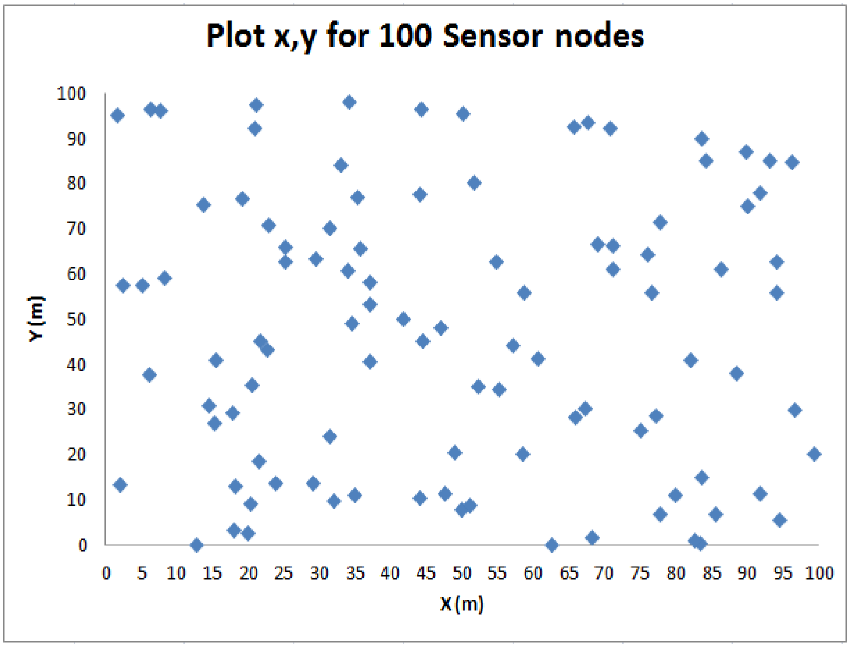

Figure 3: Distribution of 100 sensor nodes

The LECH-CM protocol uses the K-means algorithm for cluster formation, instead of the simulated annealing algorithm, which is used with the LEACH-C protocol. This is done to exploit the advantage of a faster cluster formation. Moreover, K-means is simple and easy to implement.

In the proposed approach, the inter-cluster traffic flow starts from the Series Master (SM) node, to the series of neighbor nodes, and then to the CH, as previously explained.

The proposed LEACH-CM protocol can balance the overall energy consumption of the transmission energy through cooperation between nodes. This energy balance has a direct impact on the network lifetime since the nodes lifetime are closer to each other. Unlike the LEACH-C protocol, in which the data are sent to a CH using one hope communication, the BS moves to optimize its relative position to the CHs as shown in Figure .4. Therefore, the energy consumed during the reception of the outer-cluster traffic is decreased.

The results shown in Figs 5 and 6 indicate that the proposed OCM LEACH-C protocol has a good impact on the overall network lifetime and the total number of transmitted data. Fig. 5 shows a comparison between the network lifetime of the proposed OCM LEACH-C and the LEACH-C protocol. The network lifetime is measured here by the number of rounds. The OCM LEACH-C protocol outperforms the LEACH-C protocol in the number of rounds as the energy loss is balanced between all nodes, which results from the way the data are transmitted between the sensor nodes and the CHs and the mobility of the BS. This keeps many sensor nodes a live for a long time.

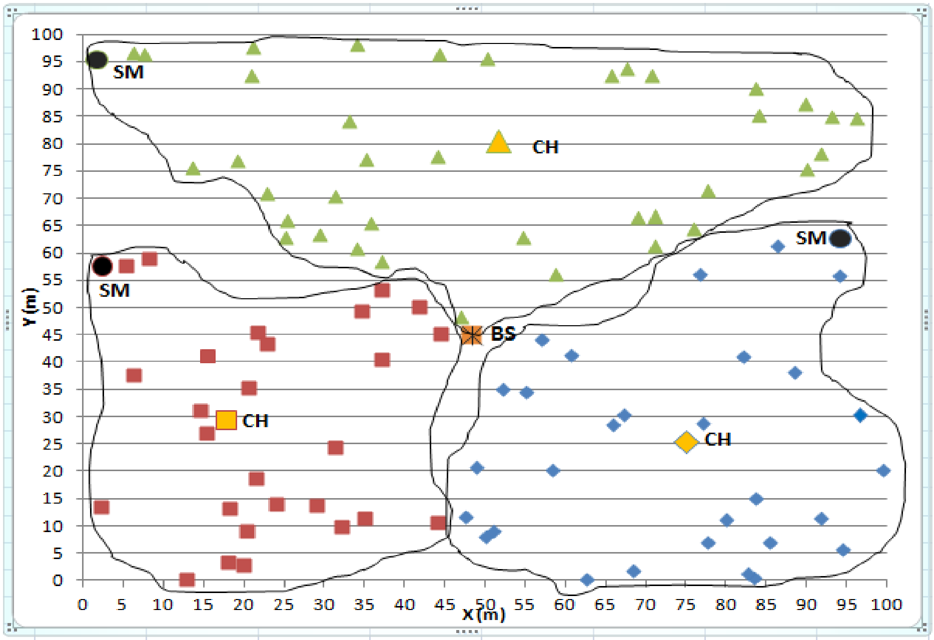

Figure 4: Sample of 3 Clusters with CH, SM and mobile BS Coordinates

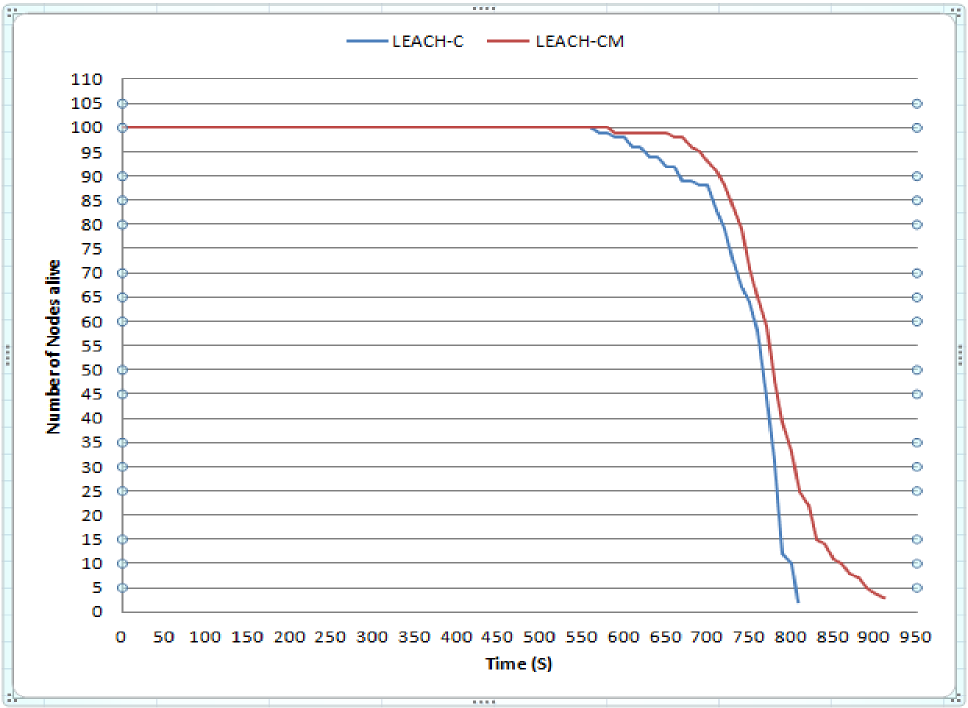

Figure 5: Network lifetime

From the simulation results, the network lifetime is increased in the proposed LEACH-CM protocol, and thus the amount of the transmitted data is increased. This is shown in Fig.6. The total transmitted data are increased with a small value in the proposed LEACH-CM protocol until the alive nodes of the LEACH-C protocol start to die. More nodes die faster when applying the LEACH-C compared to the proposed LEACH-CM protocol. Consequently, the LEACH-C protocol experiences network failure (all nodes dead) faster. It should be noticed that the increase in the transmitted data in the proposed LEACH-CM causes an increase in the visibility of the monitored area.

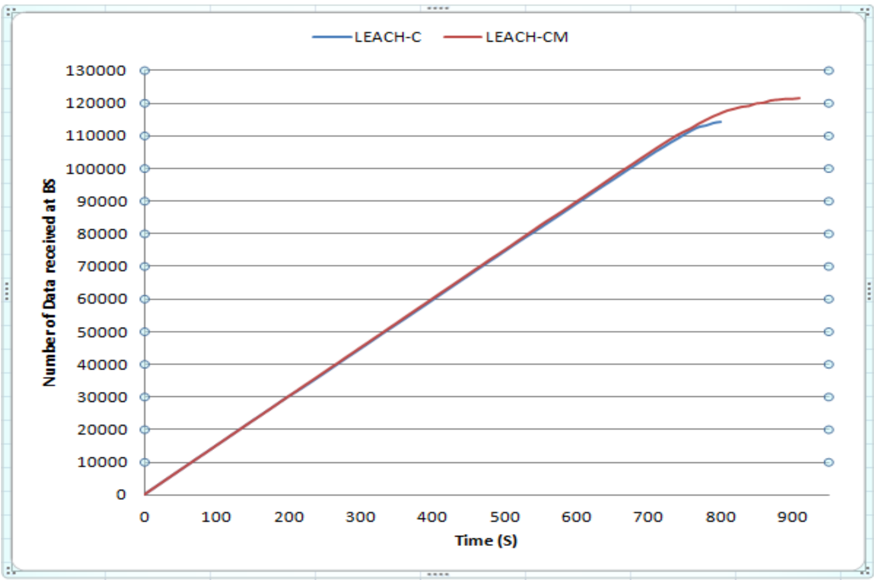

Figure 6: The amount of received data by BS

In order to check the proposed LEACH-CM protocol validity under different network configurations, different metrics of network performance are explored using different cluster heads configurations. The simulation environment parameters are selected to be 200 nodes per network, and the cluster heads nodes are 3, 5, 7, or 10 nodes in each round.

Figure 7 shows the behavior of the proposed LEACH-CM protocol and the LEACH-C protocol. The total numbers of rounds are increased when the number of CHs is decreased. The proposed LEACH-CM protocol can increase the number of rounds to an almost fixed number of rounds, regardless of the CHs parameter. As mentioned above, an increase in the total number of rounds indicates an increase in the overall network lifetime.

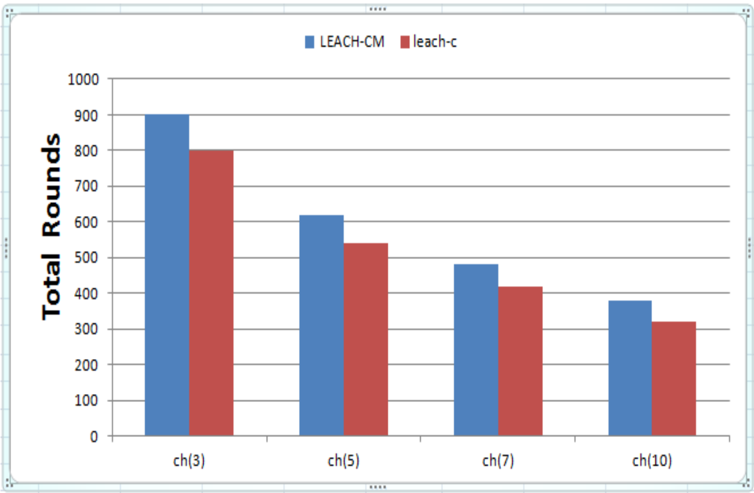

Figure 7: Total rounds with different number of CHs

Under different network topologies, the proposed protocol can consume almost the same energy level. The energy balance concept, which is introduced in the proposed LEACH-CM protocol, shows an encouraging behavior for different number of CH nodes. The number of CHs affects only the total number of rounds as shown in Figure. 7

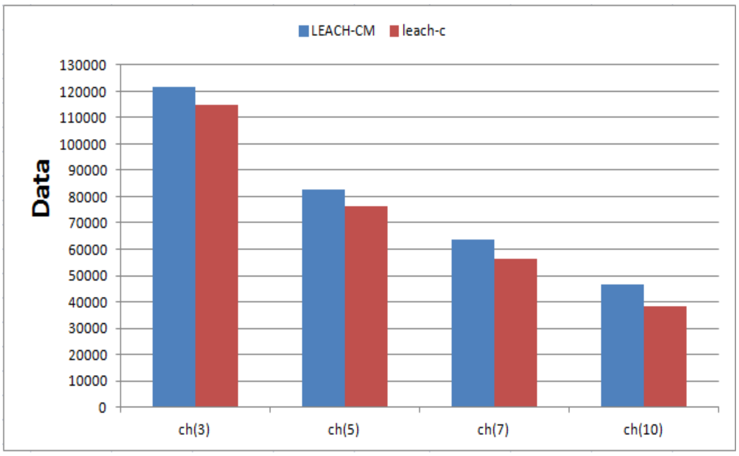

Figure 8: Total transmitted data with different number of CHs

Figure.8 shows the total amount of transmitted data versus different number of CHs. For different number of CHs, the proposed LEACH-CM protocol can transmit data more than the LEACH-C protocol.

Figures7 and 8 shows that increasing the number of CHs have a negative effect on the total number of rounds, as well as on the total transmitted data. This is because the outer-traffic dissipates a large amount of the CHs energy. Increasing the number of the CHs nodes accelerates the death rate of nodes, which leads to decreasing the network lifetime. The consistency of the behavior of the proposed approach is checked under different number of nodes in the network, and the effect on the important network metric behavior is investigated as shown in Table 2 and 3. The result shows that the proposed approach has the same behavior when the number of nodes is increased to 200 nodes as shown in Table 3.

Table 2: Total rounds and total received data with 100 nodes and (3,5,7 and 10 CHs)

No. of CH	No. CH(3)		No. CH(5)		No. CH(7)		No. CH(10)	
Approach	LEACH-CM	LEACH-C	LEACH-CM	LEACH-C	LEACH-CM	LEACH-C	LEACH-CM	LEACH-C
Total Rounds	860	800	620	540	500	420	400	320
Total Data	120502	116338	82685	77353	63412	56652	46942	38679

It is noticed that different network topologies has no effect on the performance. Moreover, the number of rounds and the total amount of transmitted data are always better than that of the LEACH-C protocol. The proposed

LEACH-CM protocol preserves the network stability for a longer time than the LEACH-C protocol as the first node died later than the LEACH-C, which is shown in Fig.5 and Table 4.

Table 3: Total rounds and total received data with 200 nodes and (3, 5,7 and 10 CHs)

No. of CH	No. CH(3)		No. CH(5)		No. CH(7)		No. CH(10)	
Approach	LEACH-CM	LEACH-C	LEACH-CM	LEACH-C	LEACH-CM	LEACH-C	LEACH-CM	LEACH-C
Total Rounds	1620	1600	1080	1000	820	760	580	560
Total Data	241878	235433	164702	158398	124665	119023	90672	85928

Table 4: First dead node for 100 sensors with different number of CHs

Protocol Name	FND at CH (3)	FND at CH (5)	FND at CH (7)	FND at CH (10)
LEACH-C	570	370	260	200
LEACH-CM	590	410	350	280

Table 4 shows, the first dead node with different number of CHs. In the proposed LEACH-CM protocol, the first node always died at a later time than the LEACH-C protocol, which makes the network more stable in the proposed LEACH-CM protocol.

5. Conclusion

A new routing protocol is proposed in this paper to prolong the network lifetime of WSN. The proposed LEACH-CM protocol uses the k-means algorithm for cluster formation. The inter-cluster traffic flows from the farthest node to its cluster head using multi hope communication to the nearest neighbor nodes toward its cluster head. Once the data are aggregated at each CH, the mobile BS node, in each round, moves to a center point between the CH to collect the outer-traffic data. The center point of the mobile BS node is calculated to minimize the overall transmitted power of the outer-traffic. The results show that the proposed LEACH-CM protocol outperforms the LEACH-C protocol in the total number of rounds (network lifetime), the total energy, and the total amount of transmitted data. The proposed LEACH-CM protocol is also stable. The proposed LEACH-CM protocol is tested under different network topologies and different number of nodes.

6. Recommendations

- Future work will consider testing the proposed protocol using other parameters like the delay in the data transmission from the sensor nodes to the cluster heads through the node neighbors.

- The proposed protocol will also be compared to other hierarchal routing protocols

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