The B4-LEACH Cluster based Hierarchical Protocol for Enhanced Cluster Head Workload in Wireless Sensor Networks

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ABSTRACT

In this paper, B4-LEACH, which is a modified version of the LEACH routing protocol, is studied. In B4-LEACH the data load of the cluster head node is decreased by exploiting the existing data flow. The distance over which data is transmitted by the cluster head is reduced. Results obtained from numerical simulations show that compared to the LEACH protocol and its variant, namely the multihop-LEACH protocol, B4-LEACH extends the network lifetime.

General Terms

Wireless Networks, Hierarchical Clustering.

Keywords

Hierarchical routing protocol, LEACH, wireless sensor networks.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) are controlled mainly by unattended sensor nodes, which are commonly deployed in millions, often in regions where human intervention is not possible. These sensors are limited in battery power, thus affecting the lifetime of the WSN. Numerous research studies have been conducted to enhance the network lifetime by tapping into the energy resources of the nodes [2, 4, 8, 10, 12] and B4-LEACH is an example of such contribution [7]. In this paper, which is an extended version of [7], the B4-LEACH protocol is analysed to investigate its effectiveness in enhancing the cluster head workload of the LEACH protocol.

2. WSN HIERARCHICAL ROUTING PROTOCOLS

The battery limitation of sensor nodes in WSNs has triggered various studies in view of optimising the energy consumption in the networks [1, 3]. Routing protocols, which define a set of rules for message packets transfer in networks, have been improved for more efficiency and least amount of energy consumption. These studies have brought about different classification of WSN routing protocols. In their book, Zheng & Jamalipour [13] classify routing protocols as flat based routing, hierarchical routing and location based routing. In the flat based network structure, the different nodes are peers and have common role for task sensing. The location based routing protocols use the location information of nodes for sensor nodes communication. On the other hand, the hierarchical based routing protocols organize the nodes into clusters with some nodes acting as Cluster Head (CH) nodes responsible for collecting data from normal cluster member nodes, and aggregating the data before transmission to the base station (BS). The aggregation and fusion of data decreases the total number of messages that need to be transmitted to the BS. Hierarchical based routing has proved to enhance the network lifetime cycle [10]. Ever since its application in the Low Energy Adaptive Clustering Hierarchy (LEACH) [5] protocol, the hierarchical routing techniques have been in constant evolution. The LEACH protocol is still considered as a basis for improvement in many studies since it provides the general hierarchical routing structure.

3. B4-LEACH

The B4-LEACH protocol is based on concepts of the LEACH, E-LEACH and M-LEACH protocols with modifications as depicted in Figure 1. The E-LEACH and M-LEACH are variations of the LEACH protocol [11]. Amongst the major limitations of the LEACH protocol are the unbalanced energy utilization of the nodes and the extra energy requirement of the CH nodes to forward the data directly to the BS. These limitations are to some extent tackled in the E-LEACH and M-LEACH protocols. The E-LEACH protocol takes the residual energy into consideration for CH selection after the first round. In the M-LEACH algorithm, the distance that the CH has to send data is decreased considerably through multi-hop routing.

B4-LEACH starts with the same set-up phase as in the LEACH protocol with added inter CH node communication as in M-LEACH. The CH nodes are elected based on their residual energy levels. Also, instead of just electing CH nodes, four additional bridge nodes are selected for each cluster. The bridge nodes of each cluster support the CH node of that cluster by acting as relays to the CH node in the steady phase. The bridge nodes are nodes at the four extremities of the cluster. The positions of the bridge nodes are calculated so as to reduce the load on the different CH nodes. Figures 2 and 3 illustrate how the CH nodes energy is spared with the inclusion of the bridge nodes. Figure 2 illustrates a hierarchical model with inter CH communication as proposed in the M-LEACH protocol and Figure 3 is an extract of the communication in the proposed system.

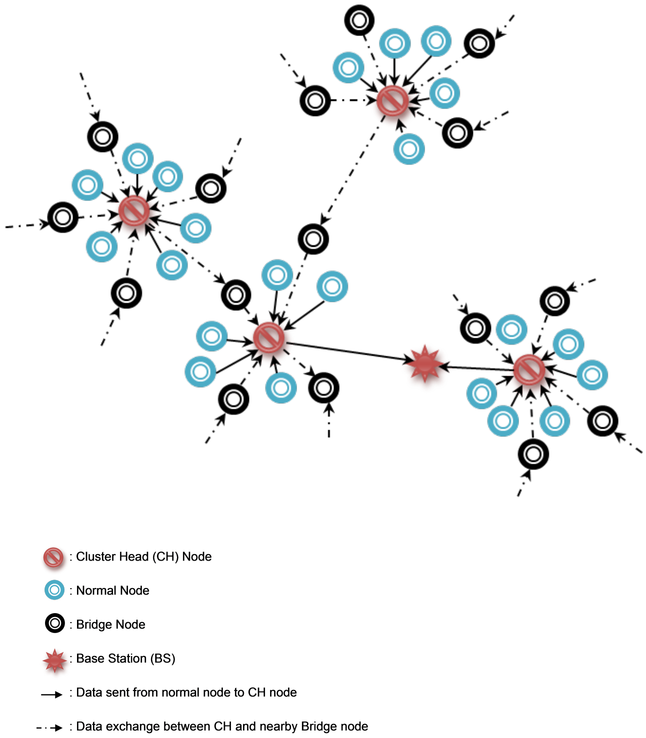

Fig. 1. WSN with Bridge Nodes.

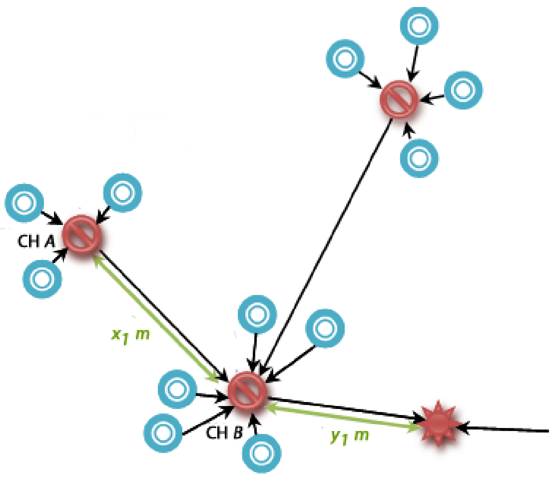

Fig. 2. Inter Cluster Head Communication without Bridge Nodes.

For communication to the BS, the CH A in Figure 2 collects data from its nodes, aggregates the data, and forwards the aggregated data to CH B. CH B in turn aggregates the data of its nodes with the CH A data and then forwards the result to the BS. Assuming that CH A is at a distance of x_1 m from CH B and x_2 m from the BS and CH B is at a distance of y_1 m from the BS as illustrated in Figure 2, CH A must send the data a distance of x_1 m and CH B must send the aggregated data a distance of y_1 m.

In B4-LEACH, as shown in Figure 3, a bridge node is considered for transmission. Assuming that the CH A is at a distance of b_1

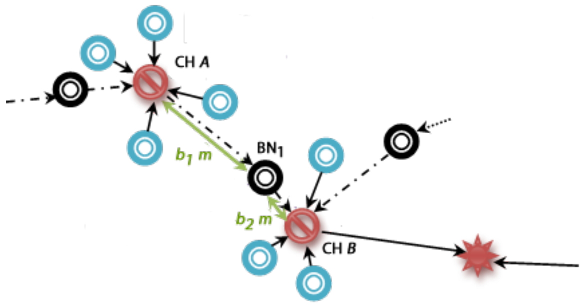

Fig. 3. Inter Cluster Head Communication with Bridge Nodes.

Fig. 4. Type 1 communication between normal nodes and the CH.

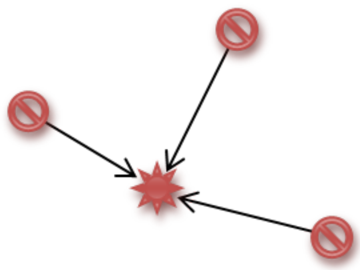

Fig. 5. Type 2 communication between the CH and the BS.

m from BN_1 and that BN_1 is at a distance of b_2 m from CH B as illustrated in Figure 3, then transmitting through BN_1 will imply that the CH A will have to send data through a distance of b_1 m only, thus saving a distance of b_2 m. The brige node BN_1 on transmitting data to its corresponding cluster head CH B, will need to aggregate the data from CH A with its own data and transmit the result a distance of b_2 m.

4. ENERGY CONSUMPTION MODEL OF B4-LEACH

B4-LEACH uses the same radio energy dissipation model as LEACH [6]. There are three main types of communication in B4-LEACH as illustrated in Figures 4 - 7. Type 1 communication is between the normal nodes and the CH. Type 2 communication is between the CH nodes and the BS. Type 3 communication is between the bridge nodes and the CH and type 4 is between the CH and the bridge node.

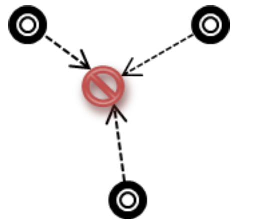

Fig. 6. Type 3 communication from the BN to the CH.

Fig. 7. Type 4 communication from the CH to the BN.

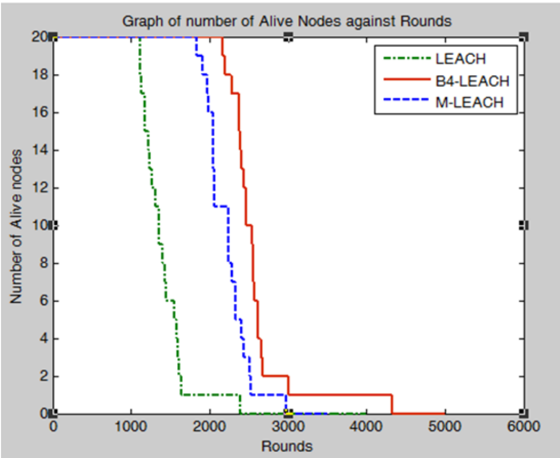

Fig. 8. Graph of alive nodes against rounds for the case of 20 nodes.

5. EXPERIMENTS

Evaluation of the B4-LEACH protocol, as per the numerical simulations carried on MATLAB described in [7], showed the increased lifetime of the WSN through the addition of the bridge nodes. Figures 8 and 9 illustrate the performance of the routing protocols LEACH, B4-LEACH and M-LEACH.

The total remaining energy of the nodes is further investigated over 100 nodes in LEACH and B4-LEACH and the results are illustrated in Figure 11.

From Figures 10 and 11, it can be observed that in B4-LEACH, the nodes retain the energy for a longer period of time compared to LEACH. The number of rounds in B4-LEACH is thus greater than in LEACH, thus allowing more data to be collected over a longer duration. After a thorough analysis of the energy spent in the set up and the steady phase, it is found that a lot of energy is wasted in both phases. Since both LEACH and B4-LEACH use the same setup phase, the energy spent in the two phases is shown only for B4-LEACH. Figure 12 shows that a significant amount of energy is spent in the setup phase. If the setup phase is improved, additional energy would be available for the steady phase, thus

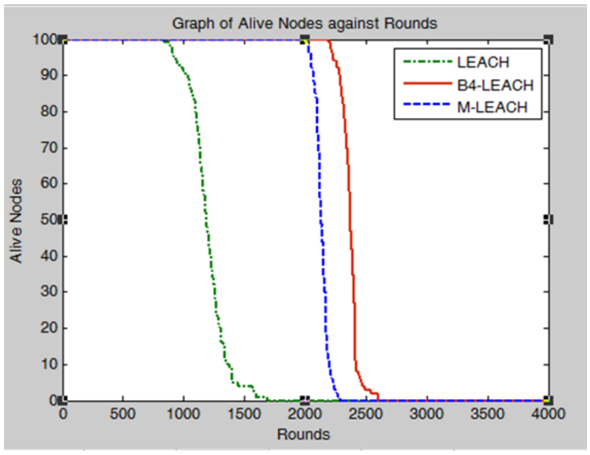

Fig. 9. Graph of alive nodes against Rounds for the case of 100 nodes.

prolonging the entire network lifetime.

The throughput, considered as the average rate of successful message delivery over a communication channel [9] is analysed for both LEACH and B4-LEACH. B4-LEACH provides better throughput and allows more packets to be transferred in longer period of time compared to the LEACH algorithm. Table 5 shows the number of packets sent and network lifetime for the LEACH and B4-LEACH algorithms for the same network.

Table 1. Number of packets sent and network lifetime.

	LEACH	B4-LEACH
Number of packets sent	2116	2479
Last round number	3408	4036

6. OBSERVATION OF DEATH OF NODES IN LEACH AND B4-LEACH

The LEACH algorithm is implemented with ten sensor nodes positioned a shown in Figure 13. The base station is considered to be at a position $(50, 50)$ within the sensor field. The order of death of the nodes in both LEACH and B4-LEACH is analysed.

Table 2 below illustrates the order of death of nodes in LEACH when 10 sensor nodes are deployed.

Table 3 illustrates the order of death of nodes in B4-LEACH when 10 sensor nodes are deployed.

Tables 2 and 3 show that the nodes further from the base stations deplete their energy faster than the nodes closer to the base station. A similar simulation is carried out on LEACH and B4-LEACH, using 100 nodes. Contrary to the result obtained with the 10 nodes, the results (for 100 nodes) indicate that in both LEACH and B4-LEACH, the nodes closer to the base station deplete their energy faster resulting into holes around the base station.

7. CONCLUSION

In B4-LEACH, additional work is added on a node that acts as a bridge. The bridge node needs to perform aggregation on the data from the CH and its own data. Additional load is in the form of

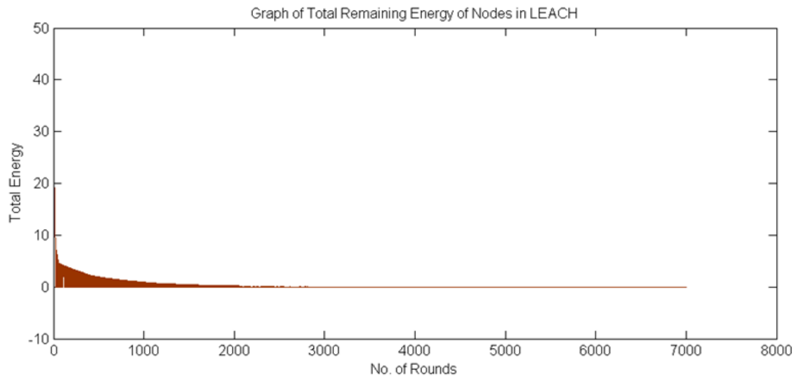

Fig. 10. Graph of remaining energy in LEACH.

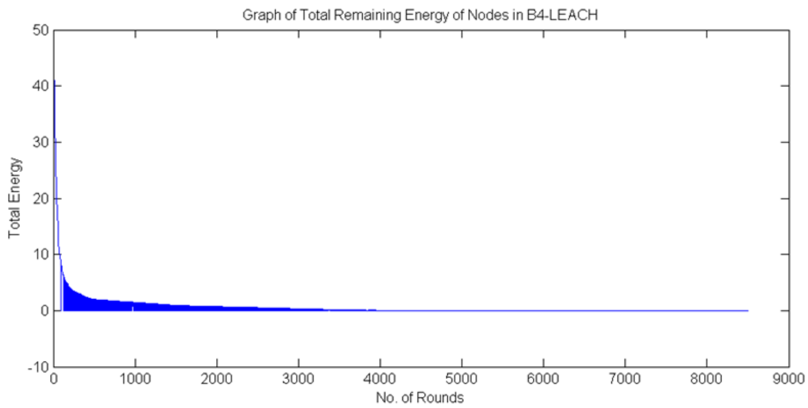

Fig. 11. Graph of remaining energy in B4-LEACH.

processing. Consequently, communication load is decreased from the CH. The CH instead of sending data all the way to the next CH needs only send data to the nearest bridge node of the next cluster. In B4-LEACH priority has been given to increasing processing load to some extent while decreasing the communication load considerably since most energy is spent in communication rather than in processing. The overall network lifetime is thus prolonged. Proper analysis and sharing of the workload of the nodes may further be considered for improved network lifetime.

8. REFERENCES

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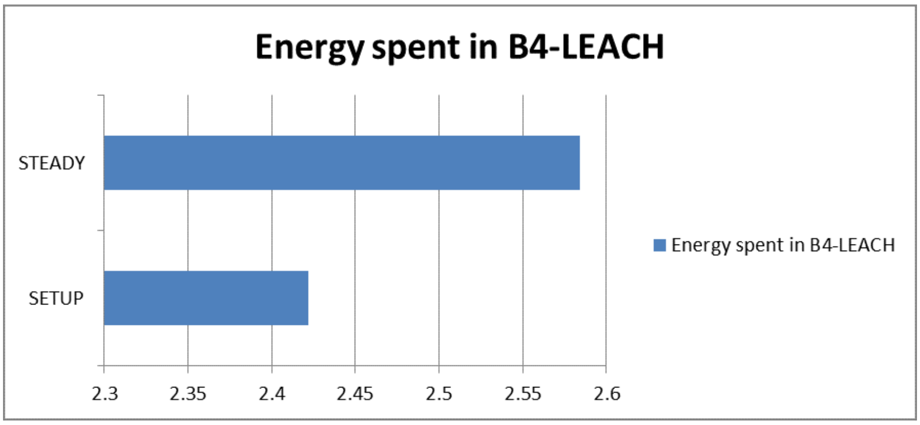

Fig. 12. Energy spent in setup and steady phase of B4-LEACH.

Table 2. Order of nodes death in LEACH.

Order of Node	LEACH				
	Node Number	Coordinate		Distance from BS	Last Round Number
		x	y		
1	8	76.49	99.65	56.27	1596
2	1	80.49	50.28	30.49	1618
3	4	7.52	58.90	43.40	1619
4	2	43.40	70.90	21.92	1706
5	10	13.46	3.55	59.10	1762
6	5	67.42	58.80	19.52	1863
7	9	26.50	79.21	37.49	1870
8	3	55.53	25.50	25.12	1876
9	7	32.38	43.10	18.92	2170
10	6	53.37	47.26	4.34	3407

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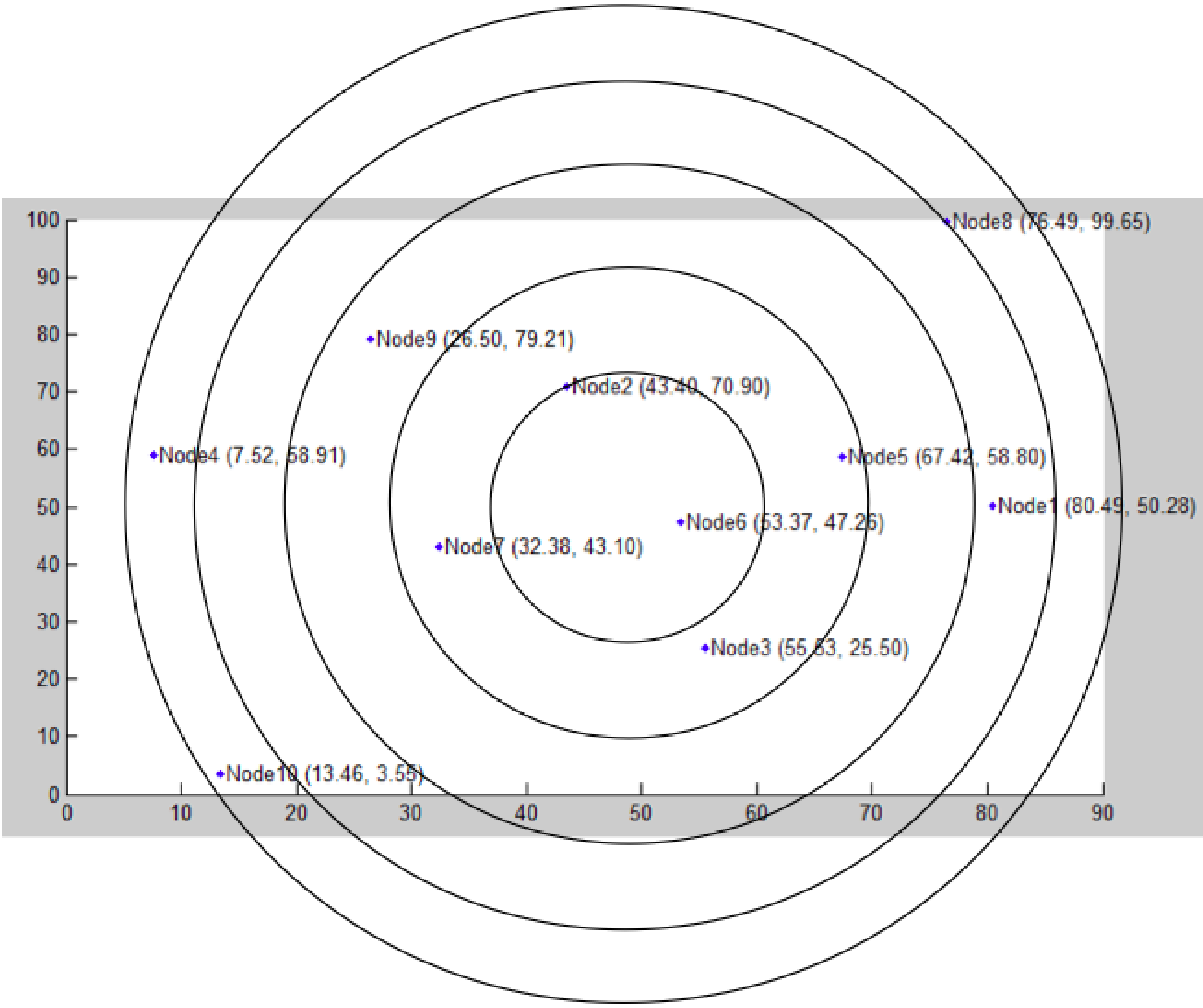

Fig. 13. Nodes positioning in sensor field.

Table 3. Order of nodes death in B4-LEACH.

Order of Node	B4-LEACH				
	Node Number	Coordinate x	Coordinate y	Distance from BS	Last Round Number
1	10	38.84	69.68	22.62	1692
2	9	80.16	45.47	30.50	1927
3	6	85.35	24.63	43.51	1985
4	7	42.66	71.61	22.82	2154
5	2	23.22	9.39	48.65	2278
6	8	48.59	39.15	10.94	2334
7	4	62.89	87.45	39.61	2408
8	3	74.87	1.60	54.42	2680
9	5	64.68	39.05	18.31	3292
10	1	33.42	8.43	44.75	4036