An Efficient Data Collection and Load Balance Algorithm in Wireless Sensor Networks

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Abstract. The fact of multi-hop data transmission in wireless sensor network will lead serious load unbalance. Considering the limited energy supply, the load distribution will cause great restraints in relative applications. Existing algorithm mostly perform the load balance inside each cluster without considering about the entire network consumption. A cluster-based Balanced Energy Consumption Algorithm (BECA) is proposed by collecting the data more efficiently to avoid heavy traffic nodes so as to achieve global load balance. Simulating results show that BECA can obtain better balance properties and prolong the network lifetime greatly.

Keywords: Wireless sensor network · Load balance · Cluster algorithm Lifetime

1 Introduction

In recent years, wireless sensor network technology has developed rapidly. It has extensive potential application, including environmental monitoring and forecasting, health care, smart home, etc., so as to require the sensor nodes to become low-consumption, low-energy, multi-functional [1–3]. Due to the reason that the energy of the sensor nodes is provided by the battery, the energy supply is very limited. Then how to maximize the lifetime of network is one of most important problems in relative researches. Existing studies have shown [4] that the lifetime of the sensor nodes can be extended by increasing the capacity of the battery or reducing the energy consumption of each node. It is found that, however, the battery capacity can not be significantly improved due to weight and size limitations. Therefore, a method is proposed to reduce the loss of the energy effectively by data collecting and load balancing.

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Data collection is of great importance to wireless sensor network. Some of the existing energy efficiency protocols [5] suggest that sensor nodes data can be delivered to the BS through a path. Most of them apply a cluster-based approach [6], which select some sensor nodes as cluster-heads which collect data from their neighbor nodes, and then they deliver the data to an adjacent cluster-head so that the cluster members consume less energy. Therefore, this method of sending data can greatly reduced energy consumption. In addition, studies have shown that the application of cluster-based algorithm network, its lifetime increased by 8 times than the average network [7].

The existing cluster-based approach allows a small range of energy consumption to balance, but the entire network load is still unbalanced. Currently sent data from the cluster head to the BS, there are two main methods are direct connection and shortest path routing. The direct connection is shown in Fig. 1(b), the node near the BS consumes less energy than those away from the BS. The shortest path routing is shown in Fig. 1(c), a hot spot could transmit sensor data just like a hub, which is usually located near the base station. The above two methods will lead to a part of the network failure prematurely. So the better load balancing could extend the lifetime of the entire network.

In this paper, a cluster-based data gathering algorithm is proposed to solve the problem of unbalanced energy consumption in the network. The Balanced Energy Consumption Algorithm (BECA) is shown in Fig. 1(d), cluster heads are organized into multiple parallel links.

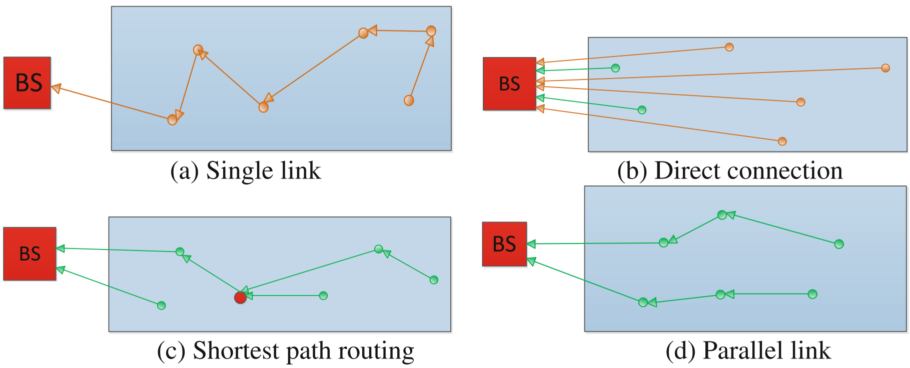

Fig. 1. Inter-cluster routing scheme

2 LEACH and HEED

At present, cluster-based data collection methods are LEACH, HEED and their conversion. There are two parts in these methods. One part is to select a cluster head and recovery system to effectively collect data, another part is an internal cluster system that passes these collected data to the BS. About the communication range, each node in the network is either in a DS [8] or near a DS node. In order to let different cluster-based data collection algorithms compare fairly, DS is applied to all of my algorithmic studies.

2.1 The Direct Connection of LEACH

As shown in Fig. 1(b), each cluster head sends sensor data directly to the BS. The algorithm is applied to the LEACH protocol and it cannot balance the loss of energy. The farther away from the base station, the transmission distance is longer, so the cluster head nodes far from the base station to send data will consume more energy. In WSN, inconsistency can lead to premature failure of the node at the far end of the sensing area, which will become a blind spot.

2.2 The Shortest Path Tree of HEED

As shown in Fig. 1(c), the shortest path tree (SPT) is formed by these shortest paths, all cluster heads in HEED deliver data to the BS through the shortest path. Although this method minimizes the loss of energy, the entire network of energy load is still not balanced the loss of energy is still unbalanced. It is worth noticing that the number of data packets which are sent depends on the location of each node in the SPT. The neighbor node of the BS is responsible for restoring all data packets to the BS, and the node near to the root has a heavier traffic load. A hot spot is a very crowded small area for data transmission, which is usually distributed near the BS and its energy consumption is the fastest compared to the rest of the network. When the energy of the area is exhausted, these nodes will become blind spots because they will not be able to transfer data to other nodes.

2.3 Single Link Algorithm

This algorithm is applied to the cluster-based protocol. The single link [7] is shown in Fig. 1(a), which is connected by the cluster heads in the network. Each cluster head communicates only with its neighbor nodes, which sequentially send data to the BS. This algorithm effectively reduces the energy consumption, but because of the distance between the cluster head and the base station, energy waste still exists.

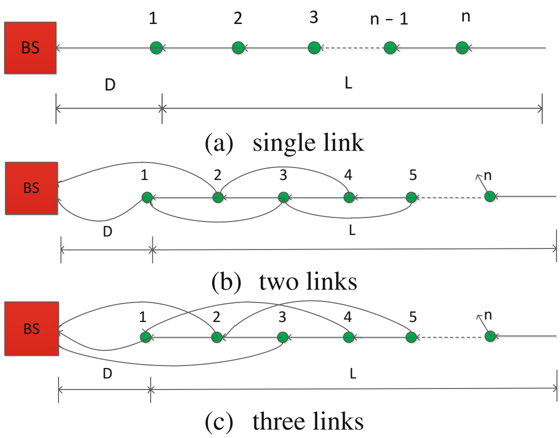

Fig. 2. Link structure in one-dimensional networks

3 BECA

In order to achieve energy efficient and balanced inter-cluster routing we propose BECA algorithm. As shown in Fig. 1(d), cluster heads are organized into multiple parallel links. Although the total energy consumption of the SPT is slightly lower than the BECA network, the maximum energy consumption of a single node is reduced in BECA, so that the network lifetime is extended.

3.1 Intra-link Scheduling Algorithm in One-Dimensional Networks

In the one-dimensional network model, the sensing area is a line of length L. As shown in Fig. 2(a), the base station is located in the leftmost area, n cluster heads are placed from the left to the right on this line. The distance between any two adjacent cluster heads is L/n and the distance from the base station to the node 1 is D, so the distance from the base station to the node n is $D + (n-1)L/n$. In order to form m links, we set nodes $i, m+i, 2m+i, \ldots$ for each link $i(1 \le i \le m)$.

We use a single link solution to explain our inter-link scheduling algorithm. In the first loop, as shown in Fig. 3(a), cluster head 1 transmits one packet to the BS, and cluster head 2 transmits the remaining packets to the BS. In the second loop, as shown in Fig. 3(b), cluster head 1 transmits two packets of the cluster head 2 to the BS, while cluster head 3transmits the remaining packets to the base station. In the r loops, as shown in Fig. 3(c), cluster head 1 transmits r packets to the BS, and like this the cluster head $r+1$ transmits $n-r$ packet to the BS. In the last loop, as shown in Fig. 3(d), there is no separate link and cluster head 1 transmits all n packets to the BS. After the n loops, it repeats from the first loop.

Using a single link, each packet is delivered by a node on average. For any L and D, when n exceeds a certain limit the cost of the relay may exceed the plan. The number of optimal links will be discussed.

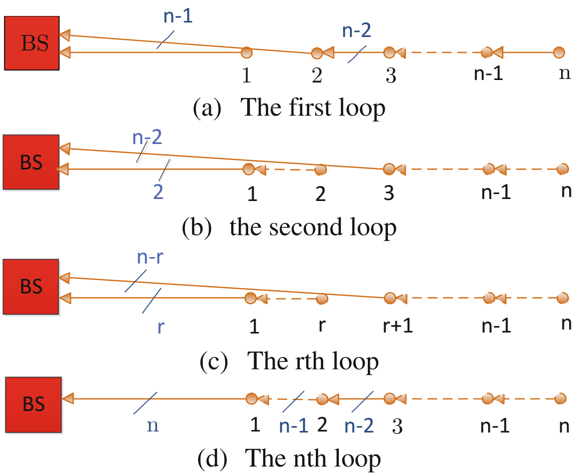

Fig. 3. Intra-chain scheduling

3.2 BECA Performance Analysis

In this part, we will compare the performance of BECA, LEACH and HEED through a one-dimensional network model. The focus of this paper is how to achieve the maximum balance of energy consumption in a single node.

In order to send l bit packet through the length of the distance d, so the transmission and receiving power are:

$$E_{tx}(d) = E_{elec}l + E_{amp}ld^2 \tag{1}$$

$$E_{tx} = E_{elec}l \tag{2}$$

where $E_{elec} = 50\,\text{nJ}/\text{bit}$ is the total energy consumed by the radio to run the transmitter or receiver circuit and the transmit amplifier consumes the total energy is $E_{amp} = 100\,\text{pJ}/(\text{bit.m}^2)$.

In LEACH, the energy consumption of delivering a packet at node k is:

$$E^{dc}(k) = E_{tx}(D + \frac{k-1}{n}L) \tag{3}$$

And the maximum loss of energy is:

$$E^{dc}_{Max} = E^{dc}(n) = E_{tx}(D + \frac{n-1}{n}L) \tag{4}$$

In HEED, the nodes far from the base station are called the upstream node, and the upstream node delivers $n - k$ packets for each node k. The nodes closer to the base station are called downstream nodes, and the downstream node collects $n - k + 1$ packets from each node k. The energy consumed by node k is:

$$E^{\text{spt}}(k) = \begin{cases} (n-1)E_{rx} + nE_{tx}(D), & k = 1 \\ (n-1)E_{rx} + (n-k+1)E_{tx}\left(\frac{L}{n}\right), & k > 1 \end{cases} \tag{5}$$

Suppose $D > 1/nL$. The maximum energy consumption is:

$$E^{spt}_{Max} = E^{spt}(1) = (n-1)E_{rx} + nE_{tx}(D) \tag{6}$$

Now we assume that BECA uses single link. The average consumption per loop of the node k:

$$E^{eedp}(k) = \frac{1}{n}\sum_{r=1}^{n}\left[N^{k,r}_{\text{rx}}E_{rx} + N^{k,r}_{tx}E_{tx}\left(\frac{1}{n}L\right) + N^{k,r}_{tx'}E_{tx}\left(D + \frac{k-1}{n}L\right)\right] \tag{7}$$

Where $N^{k,r}_{rx}$ is the number of packets that received by node k in loop r; $N^{\text{k},r}_{tx}$ is the number of packets that are sent to the next sensor and $N^{k,r}_{tx'}$ is the number of packets sent to BS.

$$N_{rx}^{k,r} = \begin{cases} n-k, & r \le k \\ r-k+1, & r > k \end{cases} \tag{8}$$

$$N_{tx}^{k,r} = \begin{cases} 0, & k = 1 \vee k = r \\ N_{rx}^{k,r} + 1, & \text{otherwise} \end{cases} \tag{9}$$

$$N_{tx'}^{k,r} = \begin{cases} 0, & k \ne 1 \wedge k \ne r \\ N_{rx}^{k,r} + 1, & \text{otherwise} \end{cases} \tag{10}$$

Combined with (10):

$$E^{eedp}(k) = \begin{cases} \frac{(n-1)}{2} E_{rx} + \frac{n+1}{2} E_{tx}(D), & k = 1 \\ \frac{(n-k)(n+k-1)}{2n} E_{rx} + \frac{(n-k+1)(n+k-2)}{2n} E_{tx}\left(\frac{1}{n}L\right) + \frac{n-k+1}{n} E_{tx}\left(D + \frac{k-1}{n}L\right), & k > 1 \end{cases} \tag{11}$$

$$E_{Max}^{eedp} = \max_{1 \le k \le n} E^{eedp}(k) \tag{12}$$

Now let $n = 4$, $L = 200$, $D = 100$, $l = 2000$ in one dimension network. As shown in Fig. 4, comparing the maximum and minimum values of the energy consumption of the three algorithms, it can be seen that the BECA is better than the other two algorithms in terms of balancing the energy consumption of nodes.

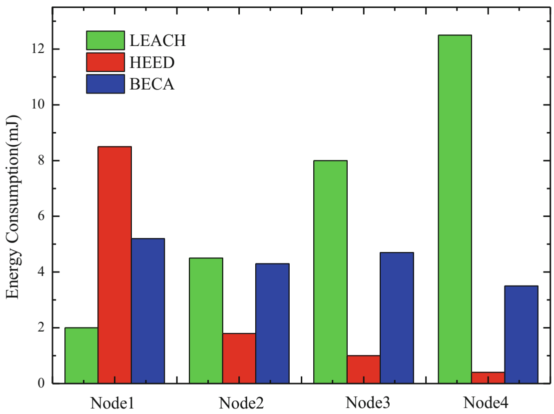

Fig. 4. Distribution of energy consumption of four cluster heads in one-dimensional networks

Let's consider using m links in BECA. We assume $n = n'm$. The link i contains nodes $i, m+i, \ldots, (n'-1)m+i$. The energy consumption of each node $k = k'm + i$ is:

$$E^{eedp}(m, k) = \frac{1}{n'}\sum_{r=1}^{n'}[N_{rx}^{k',r}E_{rx} + N_{tx}^{k',r}E_{tx}(\frac{1}{n'}L) + N_{tx'}^{k',r}E_{tx}(D + \frac{k-1}{n}L)] \tag{13}$$

$N_{rx}^{k',r}$, $N_{tx}^{k',r}$ And $N_{tx'}^{k',r}$ can be obtained from Eqs. (8–10). So,

$$E^{eedp}(m, k) = \begin{cases} \frac{(n'-1)}{2}E_{rx} + \frac{n'+1}{2}E_{tx}(D), & k = 1 \\ \frac{(n'-k')(n'+k'-1)}{2n'}E_{rx} + \frac{(n'-k'+1)(n'+k'-2)}{2n'}E_{tx}(\frac{L}{n'}) + \frac{n'-k'+1}{n'}E_{tx}\left(D + \frac{k-1}{n}L\right), & k > 1 \end{cases} \tag{14}$$

$$E_{Max}^{eedp}(m) = \max_{1 \le k \le n} E^{eedp}(m, k) \tag{15}$$

LEACH, HEED and BECA in the one-dimensional network performance with change of *L*, *D* and *n*. We calculate the maximum energy consumption of single nodes in three algorithms respectively to compare the load balancing of different algorithms.

The *L* = 200, *D* = 100, *l* = 2000, the number of cluster heads *n* decreases from 2 to 32. Each *n* corresponds to an optimal number of links *m*, such as BECA (with *m* links) superior to LEACH and HEED. The value of n is greater, the number of links *m* is more, as shown in Fig. 5, the energy consumption is smaller. As shown in Fig. 6, as *D* increases, the value of *m* is greater, the energy saving effect is better. When *n* = 8, BECA-8 and LEACH the same. Figure 7 shows that the value of *L* is greater, the number of links is greater, so the energy consumption is more.

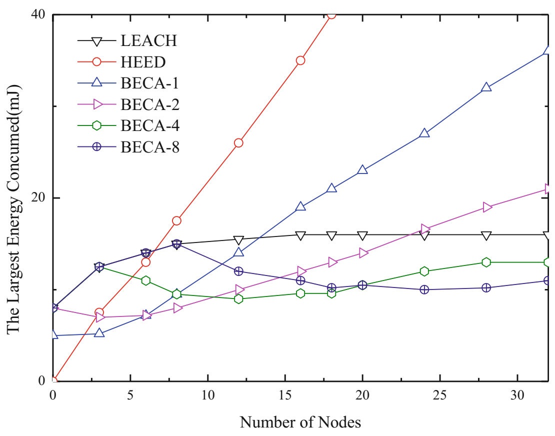

Fig. 5. The largest energy consumption of single-node in one-dimensional networks (*L* = 200, *D* = 100, *l* = 2000)

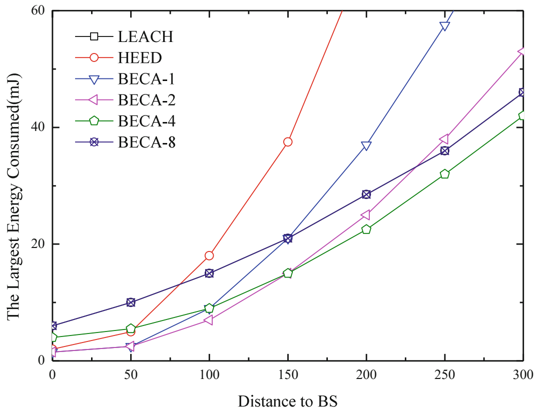

Fig. 6. The largest energy consumption of single-node in one-dimensional networks (L = 200, n = 8, l = 2000)

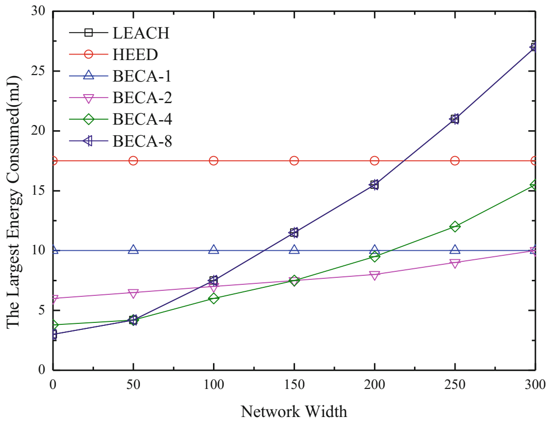

Fig. 7. The largest energy consumption of single-node in one-dimensional networks (D = 100, n = 8, l = 2000)

4 Conclusion

In this paper, the BECA algorithm can effectively utilize the energy and reduce the energy loss and prolong the network lifetime. In contrast, the cluster head in the LEACH algorithm away from the BS bear a higher energy loss, resulting in some nodes premature failure, reducing the WSN network life. In the HEED algorithm, the BS will form a hot spot around it, and WSN will fail due to the existence of hot spots. The BECA algorithm not only solves the hot issues, but also reduces the problem that single node-constrained and premature failure due to unbalanced energy consumption in WSN.

References

1. Hergenroeder, A., Wilke, J., Meier, D.C.: Distributed energy measurements in WSN testbeds with a sensor node management device. Schloer, Hannover (2010)
2. Zhang, Y., Yang, J., Li, W.J.: An authentication scheme for locating compromised sensor nodes in WSNs. J. Netw. Comput. Appl. **33**, 50–62 (2010)
3. Wu, K., Dreef, D., Sun, B.: Secure data aggregation without persistent cryptographic operations in wireless sensor networks. Ad Hoc Netw. **5**, 100–111 (2007)
4. Wang, C., Xing, L., Vokkarane, V.M.: Reliability and lifetime modeling of wireless sensor nodes. Microelectron. Reliab. **54**, 160–166 (2014)
5. Ran, G., Zhang, H., Gong, S.: Improving on LEACH protocol of wireless sensor networks using fuzzy logic. JICS **7**, 213–218 (2010)
6. Li, J., Shi, X.: Improved HEED routing protocol in wireless sensor networks. Comput. Eng. Appl. **43**, 165–167 (2007)
7. Hu, J.H., Liu, X.C., Tan, Z.F.: Improved scheme based on PEGASIS algorithm. Microelectron. Comput. **11**, 36–40 (2014)
8. Zhang, J., Xu, L., Zhou, S.M.: Constructing connected dominating set based on crossed cube in WSN. In: International Conference on Intelligent Networking and Collaborative Systems, pp. 443–447. IEEE, Xi'an (2013)