AN ENERGY BALANCED DATA DISSEMINATION SCHEME FOR LIFETIME EXTENSION IN WIRELESS SENSOR NETWORKS

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ABSTRACT

In wireless sensor networks, each sensor node has different energy consumption rate due to inequality of event sensing and distance from sink node. Because of different energy consumption rate, energy disparity occurs among the sensor nodes in wireless sensor networks. This energy disparity raises unbalanced energy state between sensor nodes, which results in short lifetime of network. The main problem of unbalanced energy state is that network does not work even though network has enough energy to work. In this paper, we suggest energy balanced data dissemination scheme that utilizes network resources as much as possible and consequently extends network lifetime. We classify energy disparity into two types, same level disparity and different level disparity. We resolve disparity problems by using adaptive report-rate scheme and packet aggregation scheme.

KEY WORDS

Energy balanced data dissemination, Lifetime extension, Packet aggregation, Report-rate, Wireless sensor networks

1. Introduction

Recent advances in Mirco-Electro Mechanical Systems (MEMS) have led to the development of small sensor nodes that are composed of embedded devices like communication boards and sensor boards. These sensor nodes (often called smart sensors) have several capabilities - sensing, computing and wireless communication. Smart sensors can deploy into target field in ad-hoc fashion, construct wireless sensor network and perform the task by itself. Because of these self-configuration capabilities, wireless sensor network (WSN) is very attractive in many fields like military, environmental research and so on [1].

However, smart sensors have several limitations - limited power, weakness (prone to fail) and small computing capabilities. Particularly, limited power make WSN had finite lifetime, because replenishment of the battery is very difficult. The difficulty of battery replenishment is caused by a great number of sensor nodes and the hostile environments of the target fields that made people hard to approach the sensor nodes. Therefore the study of energy efficient scheme to prolong the lifetime in WSN has been a very active area of research.

To prolong the network life, two different kinds of problem have to be solved. One is inefficient energy consumption, and the other is unbalanced energy consumption. Inefficient energy consumption is caused by unnecessary energy consumption like idle listening, overhearing and so on. It lowers overall network energy states and reduced network lifetime. Unbalanced energy consumption is caused by WSNs characteristics like inequality of event sensing and centralized data transmissions. It makes WSN lost its sensing spaces (hole problem) and paralyzes the network functions in spite of available resources that is enough to keep on network functions.

From the node-level point of view, idle listening, overhearing, collision and control packet overhead are main reasons of inefficient energy consumption. And from the network-level point of view, unnecessary duplication of same data packet and always using optimal routing path are main reasons of energy inefficiency. In the case of unbalanced energy consumption, inequality of event sensing, disregard of remained energy and different distance from the sink node are main reasons.

Existing protocols like S-MAC [2], EAR (Energy Aware Routing) [3] suggested appropriate solution to settle energy inefficient problems. However, they didn't consider unbalanced energy consumption and couldn't solve the problems. In this paper, we classify unbalanced energy consumption into two categories, *same level energy disparity* and *different level energy disparity*, and suggest adaptive report-rate scheme and packet aggregation scheme to solve each one of problems and to prolong the network lifetime.

The rest of paper organized as follows. Related works on several protocols to save the energy and prolong the network lifetime are covered in Section II. Section III introduces our novel energy balanced data dissemination scheme, followed by ns-2 simulation study and results in Section IV. We conclude in Section V.

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2. Related Works

To save node energy and prolong the network lifetime, there has been several researches in wireless sensor networks. Most of these researches are medium access protocols like S-MAC, and routing protocols like Directional Flooding [4], EAR, Data Funneling [5]. In the S-MAC [2], they classified major source of energy waste, and suggested proper solution for each problem. Therefore, they made powerful energy efficient medium access control (MAC) protocol. However, though S-MAC is energy efficient protocol, it is hard to consider energy balance of whole node of WSN, because of the characteristics of medium access protocol that concentrates on operation of the individual node.

In routing protocol, Directional Flooding [4] reduced unnecessary energy consumption by preventing data spread of wrong direction, it achieved energy efficiency. But it didn't consider energy disparity between sensor nodes, so it couldn't achieve the energy balance. EAR [3] suggested the usage of sub-optimal paths occasionally, and it gained energy efficiency and energy balance in a way. However, because it used stochastic approach to select sub-optimal paths, it couldn't guarantee the spreading of energy consumption, and even if it guarantee energy spreading, it's only effect on same level energy disparity, not different level energy disparity. In the case of Data Funneling [5], it used packet aggregation and data compression. Therefore it solved different level energy disparity in some degree. However, it didn't focus on the energy disparity of whole network and same level disparity. Our energy balanced data dissemination scheme considers not only energy inefficiency but also same and different level energy disparity in flooding fashion.

3. Proposed Algorithms

In wireless sensor networks, energy disparity exists between sensor nodes. Fig.1 shows two kinds of energy disparities, *same level energy disparity* and *different level energy disparity*.

Basically, the disparity is caused by the number of times that each sensor node participates in data delivery - the number of data receiving and sending. In same level energy disparity, the disparity accumulates whenever low energy state node receives packet from neighbor node and transmit to neighbor node first before high energy state node do it. With all high energy state nodes, some low energy state nodes can be discharged first, thus WSN can be lost some sensing area and packet delivery abilities. In Fig. 1, each circle indicates sensor node, LV represents node level, and the number in the circle denotes remained energy. Among the level-3 nodes, if the node that has 40 remained-energy keeps on doing more work than the node that has 90 remained-energy, this sensor network may lose sensing and delivery area corresponding to the 40-energy node. The major reasons for this situation are inequality of event occurring and random selection of transmit node. In the case of inequality of event occurring, we cannot control it because that is characteristics of target fields itself. But, we can control the random selection of transmit node because it comes from general scheme like random back-off or ignoring remained node energy. Therefore, we suggest adaptive report-rate scheme to make high energy state nodes receive and transmit first.

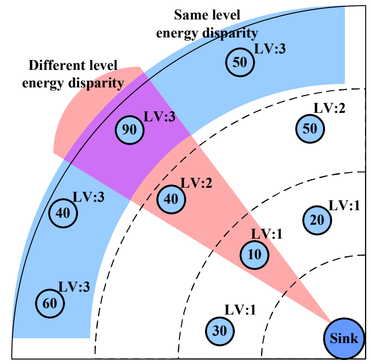


Fig. 1. Two kinds of Energy Disparity in Wireless Sensor Networks (LV : Level, The number in the circle : remained energy)

In different level energy disparity, a small number of sink nodes (generally 1-sink node) and direction of data flow are major reason for disparity. Sink-near nodes have to transmit data packet from high level nodes as well as its own data. Therefore, near and near the sink node, more and more energy consumption. Finally, if sink-near nodes are discharged, with all amount of remained energy in high level nodes, the network is paralyzed and loses functionality. Thus, we suggest adaptive packet aggregation scheme to minimize energy gap between high level nodes and low level nodes. The network lifetime is prolonged with the amount of minimized energy gap.

3.1 Level setup

The suggested two schemes in this paper based on node level which is relative distance from the sink node. Therefore, we have to setup the node level. For the simplicity, we use hop-count as the node level. Fig. 2 shows the level setup process.

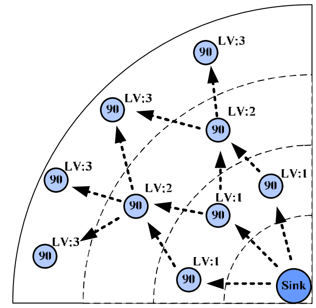
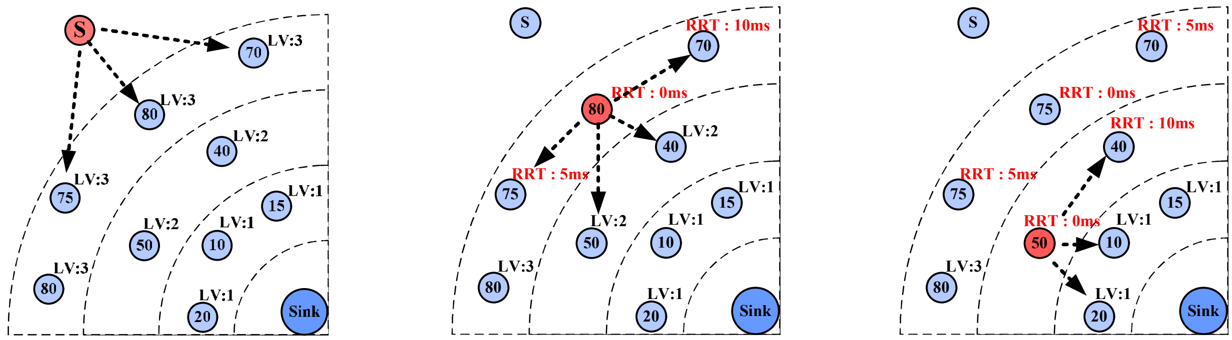


Fig. 2. Node Level Setup Process

In the beginning of networks deployments, sink node



(a) Source node senses the event and transmits data to its neighbor nodes (S : source node)

(b) Among the receivers, high energy state node transmits first, because it has shortest report-rate time (RRT : Report-rate time)

(c) After data transmission, each sensor node recalculates its report-rate time.

Fig. 3. Adaptive Report-Rate Scheme

floods LEVEL SETUP packet which has level value 0. When node receives LEVEL SETUP packet that has smaller level value than its own level, it sets own level value by plus 1 to level value in the LEVEL SETUP packet. And it floods LEVEL SETUP packet again. When every node in the network receives LEVEL SETUP packet and sets its own level, node level setup is finished.

3.2 Adaptive report-rate scheme

For the sake of energy balancing between the nodes in the same level, the node having more energy (high energy state node) has to work more than its neighbor nodes (low energy state node). To achieve this, we use report-rate time (RRT) which means wait-time before transmission. First, a certain node (source node) senses events, and then transmits data packet to its neighbor nodes. After each neighbor node receives data packet from source node, it waits until report-rate time expire. If node do not receive same data packet during the waiting, it transmits data packet. Or, if node receives same data packet before report-rate time expires, it cancels transmission and drop the packet in the queue. So, by making high energy state node have shorter report-rate time than low energy state node, we can guarantee high energy state nodes do more works. Also, we can prevent packet duplication because low energy state nodes do not transmits same packet. As a result, energy gap between high energy state node and low energy state node is diminished.

To implement this scheme, each node has to calculate report-rate time based on energy value. By subtracting own energy value from energy value of high energy state node, we can decide transmission order. If a node has low energy, it will get bigger number than the number high energy state node. If a node is high energy state node, it gets 0-value. Therefore, we can consider the subtracted number as a transmit order by ascending. By multiplying constant value from this value, we can get report-rate time. Eq. 1 shows how we can get report-rate time based on energy value. In Eq. 1, RTT is report-rate time, E_{high} is energy value of maximum energy state node, E_{own} means own energy of node itself, and C is constant value.

$$RTT = (E_{high} - E_{own}) \times C \tag{1}$$

For calculating the report-rate time by Eq. 1, each node must know energy value of high energy state node among its same level neighbors. Therefore, every node put its energy state into packet header, whenever they transmit data. The energy value presents remained energy after transmission in that time. Each node has energy variable for maximum energy value and checks neighbor's maximum energy when it overhears data packet.

Fig. 3 illustrates how adaptive report-rate scheme works. In Fig. 3-(a), source node senses an event and transmits sensing data to its neighbor sensor nodes. Each neighbor node in level-3 knows energy value of high energy state node, so it can calculate its report-rate time. Before data transmission, each node waits until their report-rate time expires. If it receives same data packet from its neighbor nodes during that time, it just drops data packets. Or it transmits data packets immediately to its neighbor as soon as the timer is expired. All of these situations are described in Fig. 3-(b). Because 80-energy node is high energy state node, it has shortest report-rate time. Therefore, it transmits first, and neighbor nodes do not transmit. Fig. 3-(c) shows recalculation of report-rate time in level-3 sensor nodes after data transmission. The transmission node informs its own energy to neighbors through energy field in data packet header. Then neighbor nodes know energy field, and if there is a change in the largest energy value, it recalculate it report-rate time. In the case of 70-energy node in level-3, it recalculates report-rate time, because there is change in largest energy value (i.e., 80 to 75). As a result, it has 5*ms* report-rate time.

3.3 Packet aggregation scheme

As we mentioned before, the main reason of energy disparity is the number of data receiving and sending. Because the sink-near nodes have to listen and transmit the data packet from high-level sensor nodes, they consume a lot of energy, and then different level energy disparity occurs. We demonstrate this situation by equations.

For demonstration, we assume that network deploys by same density and sensor node is identical, so every node has same transmission range and same energy consumption. And we do not consider energy consumption caused by packet duplication and listening.

First, we have to get average packet transmission counts per node in *i*-th level (Tx_i). Dividing total packet transmission count in *i*-th level by the number of nodes in *i*-th level, we can get this value. The number of nodes in *i*-th level n_i is followed. In equation, *r* indicates transmission range and *d* is node density

$$n_i = \pi \cdot r^2 \cdot d \cdot (2i-1) \tag{2}$$

Total packet transmission count in *i*-th level classified into originated data transmissions and relayed data transmissions. If we assume each node has uniform send-rate (SR), we can get total number of data transmission per second in eq. 3.

$$\begin{aligned} TC_{i,originated} &= n_i \times \frac{1}{SR} \\ TC_{i,total} &= \sum_{k=i}^{n} TC_{k,originated} \end{aligned} \tag{3}$$

$TC_{i,originated}$ is packet transmission count generated by *i*-th level sensor nodes (originated data transmission). In *i*-th level, the node transmits not only its own packet but also higher level packets, we can get total packet transmission count $TC_{i,total}$ by sum of higher level originated data transmission count.

Average packet transmission count per node is obtained from eq.2. and eq. 3. Eq. 4 shows average packet transmission count in *i*-th level, Tx_i.

$$Tx_i = TC_{i,total} / n_i \tag{4}$$

Second, we introduce energy model to demonstrate energy efficiency and balance. We use First order radio model [6]. Eq. 5 introduces First order radio model.

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2 \tag{5}$$

In eq. 5, *k* is packet length and *d* is distance from sender to receiver. E_{elec} is energy consumption per bit in electronic circuit and E_{amp} is energy consumption in amplifier. In our case, we divide packet length *k* into header length *h* and data unit length *m* ($k = h + m$).

Finally, we can compare the highest level ($i = n$) node energy and the lowest level ($i = 1$) node energy. Eq. 6 shows different level energy disparity between the highest level and the lowest level.

$$\begin{aligned} E_{1,comsume} &= Tx_1 \times E_{Tx}(k,d) = Tx_1 \times E_{Tx}(h+m,d) \\ E_{n,comsume} &= Tx_n \times E_{Tx}(k,d) = Tx_n \times E_{Tx}(h+m,d) \\ E_{disparity} &= E_{1,comsume} - E_{n,comsume} \\ &= \frac{n^2-1}{SR} \times E_{Tx}(h+m,d) \end{aligned} \tag{6}$$

In Eq. 6, $E_{i,consume}$ means energy consumed at *i*-th level. $E_{disparity}$ means energy disparity between different levels. If we calculate $E_{disparity}$ by eq. 6, we can get 3.3*mJ* energy disparity between level-1 and level-7 (Table 1).

To solve this problem, we reduce the number of data transmission in low-level nodes, especially sink-near nodes. To minimize the number of data packet, we use packet aggregation scheme that packs several packets into one packet. Data packet consists of packet header and data unit. In general networks, each packet header has different packet header contents (i.e. source node, destination node), however, in WSNs, each packet header has almost same contents. This is because the destination of the packet is sink-node, and source node address does not have any mean to networks. The only interest of network is the data unit in the packet. So, by means of packet aggregation, we can reduce several same packet headers into one, therefore, we can save energy. Besides, reducing the number of packet in the networks, the network traffic decreases. Therefore we can reduce transmission delay by packet aggregation. Generally, aggregation scheme increases data transmission delay because nodes have to wait data packet for aggregation. But we solve this problem by reducing network traffic. Because the network traffic concentrates on low level, we can get more energy saving in low level, and solve different level energy disparity.

$$\begin{aligned} E_{1,comsume} &= \frac{1}{3} \cdot Tx_1 \times E_{Tx}(k,d) = \frac{1}{3} \cdot Tx_1 \times E_{Tx}(h+3m,d) \\ E_{n,comsume} &= \frac{1}{3} \cdot Tx_n \times E_{Tx}(k,d) = \frac{1}{3} \cdot Tx_n \times E_{Tx}(h+3m,d) \\ E_{disparity} &= E_{1,comsume} - E_{n,comsume} \\ &= \frac{1}{3} \cdot \frac{n^2-1}{SR} \times E_{Tx}(h+3m,d) \end{aligned} \tag{7}$$

If we aggregate three packets into one packet in *i*-th level, the transmission count Tx_i decreases by one-third. Because of transmission count decreasing, sensor node can save energy. However, because of packet aggregation, packet length *k* is increased from ($h + m$) to ($h + 3m$), and these increase energy consumption. Eq. 7 shows this. Comparing Eq.6 and Eq.7, we can calculate minimized energy gap

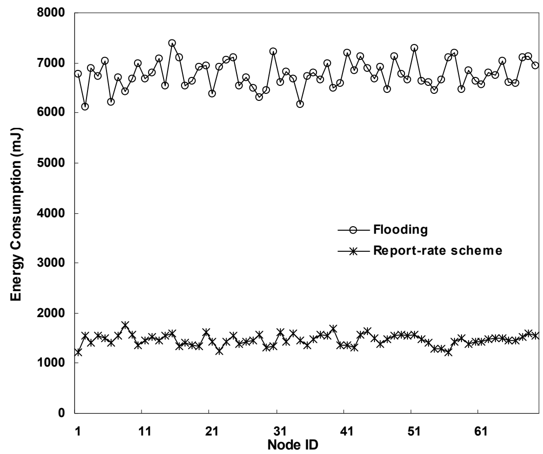


Fig. 4. Energy Consumption in Same Level (level-3)

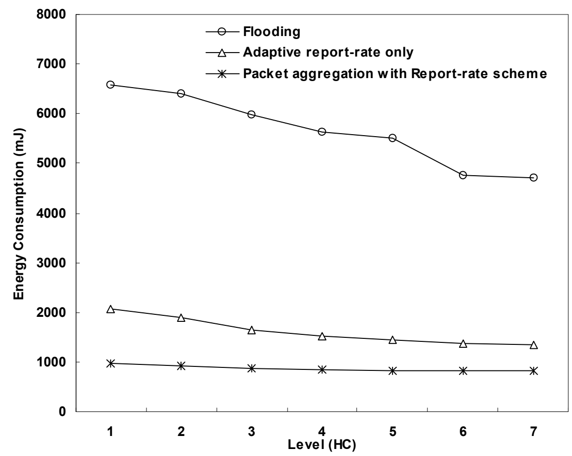


Fig. 5. Energy Consumption in Different Level

between the highest level node and the lowest level node. Eq.8 shows amount of minimized energy gap (E_{gap}).

$$\begin{aligned} E_{gap} &= \frac{n^2-1}{SR} \times E_{Tx}(h+m,d) - \frac{1}{3} \cdot \frac{n^2-1}{SR} \times E_{Tx}(h+3m,d) \\ &= \frac{n^2-1}{SR} \times (E_{elec} + E_{amp} \times d^2) \times \{(h+m) - \frac{1}{3} \cdot (h+3m)\} \quad (8) \\ &= \frac{n^2-1}{SR} \times (E_{elec} + E_{amp} \times d^2) \times \frac{2}{3} h \end{aligned}$$

To understand easier, we show transmission count and energy saving according to each level, in Table. 1. To obtain this value, we assume following conditions. Transmission range r is *10m*, E_{elec} is *50nJ/bit*, E_{amp} is *0.1nJ/bit· m*^{2}, header length h is *56 bits*, and data unit length m is *232 bits* [7].

From Table. 1, we can see that all sensor nodes in every level save energy. Besides, lower the level, sensor nodes have more energy saving. This is because network traffic concentrates on lower level. Also, energy disparity is reduced from *3317.76 µJ* to *1536 µJ*. This means that we prolong network lifetime by amount of *1781.76 µJ*.

Table. 1. Transmission Count and Energy Saving

	Transmission Count (Tx_i)		Energy Consumption (μJ)		
Level	General	Pkt.Agg.	General	Pkt.Agg.	Saving
1	196	65	3386.88	1560.00	1826.88
2	64	21	1105.92	504.00	601.92
3	36	12	622.08	288.00	334.08
4	23	8	397.44	192.00	205.44
5	12	4	207.36	96.00	111.36
6	9	3	155.52	72.00	83.52
7	4	1	69.12	24.00	45.12

Now we explain the process of packet aggregation. First we have to decide *aggregation count*. Aggregation count means how many packets pack into one packet. Usually, aggregation count is maximized as much as possible. Generally, as the packet size is long, communication error increases. So, we can not use very large aggregation counts. In this paper, we use packet aggregation count by 3. Next, each node waits for three times of packet send rate (in our simulation) before transmission. For example, if send rate is *0.25s/packet*, each node waits for *0.75 seconds*. The node transmits aggregated packet as soon as three packets are accumulated during this time. If node does not accumulate three packets during this time, it transmits packet when waiting time expires. Because the network traffic concentrates on low level, non-aggregated packet is aggregated near and near the sink node.

4. Simulations And Results

In this section we evaluate the performance of our scheme through ns-2 simulator. We use the following model for our simulation.

- The number of sensor nodes are *300*.
- Sensor nodes deployed in a confined space of *1000m × 1000m*
- We use 1-sink node, *7*-source nodes.
- Total simulation time is *20* seconds.
- Initial node energy is *10000 Joules*.
- Node's energy model in the current ns-2 is utilized.

We measure the energy balance in two aspects, same level and different level. To measure same level energy balance, we use energy distribution and the standard deviation in level-3. And, to measure different level energy balance, we show energy gap between the highest level and the lowest level. And then, as mentioned before, we show average transmission delay to explain transmission delay problem in aggregation.

Fig. 4 shows energy consumption in same level (level-3).

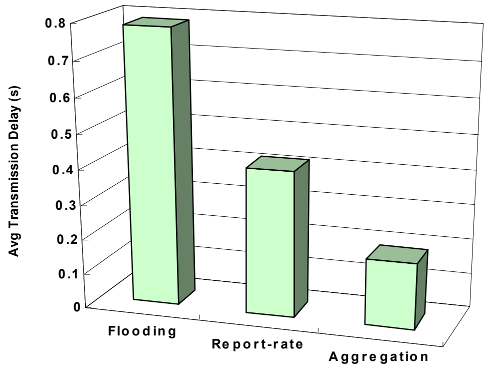


Fig. 6. Average Transmission Delay

The upper line shows energy consumption for flooding, and lower line shows energy consumption for adaptive report-rate scheme. As shown in the figure, the variation of adaptive report-rate is smaller than flooding. The standard deviation is *0.077* for flooding and *0.012* for adaptive report-rate scheme. This means that adaptive report-rate scheme achieves the energy balancing among the same level nodes. As a result, report-rate scheme prevents network from losing communication and sensing capabilities. Also, adaptive report-rate scheme enhances the energy efficiency as shown in Fig. 4.

In Fig. 5 shows energy consumption between different level sensor nodes. We compare performance among flooding, adaptive report-rate scheme and packet aggregation scheme with report-rate scheme. In packet aggregation scheme, most important effect is that energy gap is reduced between highest level node and lowest level node. The energy gap is *1.89 J* in flooding and *0.73 J* in adaptive report-rate scheme after *20* seconds. However, in packet aggregation scheme with report-rate, the energy gap is only *0.15 J* after simulation. This means that we can utilize *1.74 J* to prolong the network lifetime. If the unbalanced energy state keep going, sink-near node cannot transmits the data to sink. As a result, network is paralyze and cannot use *1.74 J*. However, by using the packet aggregation, we can utilize *1.74 J*, and therefore network lifetime is increased. Also, overall network energy state is improved. Notice that this result comes from *20* seconds simulation. Therefore, as the time goes by, amount of utilizing energy is increased and network lifetime can be more extended.

In Fig. 6, average transmission delay of packet aggregation is lower than flooding and report-rate scheme. Though aggregation scheme increases transmission delay generally, packet aggregation scheme decreases transmission delay because of reducing the network traffic. In our case, we use aggregation count by 3, therefore, network traffic decreases by almost one-third. As the network traffic is reduced, contention and collision is also reduced. This makes data packet relay faster than before. Therefore, network transmission delay can be decreased.

In short, the proposed scheme is capable of saving energy against unnecessary duplicated data packets and capable of balancing the energy consumptions among the same level nodes and different level nodes.

5. Conclusion

In this paper, we present an energy balanced data dissemination scheme in wireless sensor networks. In this scheme, energy consumption of same level nodes is adjusted by report-rate time, and energy gap of different level is minimized by packet aggregation. Our work is motivated by unbalanced energy state in wireless sensor networks. Using proposed scheme, we can get energy balanced effects as well as energy efficiency. We believe that our proposed scheme can prolong the lifetime of wireless sensor network effectively.

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