Applied Mathematics & Information Sciences
An International Journal

An Optimal Relay Dispatching Method for Chain-based Wireless Sensor Networks

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Abstract: A sensor network is deployed to monitor and collect the information of environment. The common methods to organize sensors are the cluster and chain architecture. In the chain architecture, each sensor needs to report its gathered data and relay the data of its neighbours to the collector. The sensors which are close to the collector always exhaust their energy faster than the ones in the edge of the chain because of the heavy packet relay task. When these sensors near the collector are out of work, the gathered data cannot be delivered to the collector, and the sensor network loses its functionality even the sensors in the edge are still alive. In this paper, we deduce the optimal relay dispatching model for the chain-based wireless sensor network. All sensors will exhaust their energy at the same time. Sensors use at most three different transmitting power levels to relay the gathered data. The simulation results show that the network can endure longer. The energy consumption on sensors can achieve high balance and the number of hop-relay in the single-hop relay topology can also be reduced.

1 Introduction

A wireless sensor network consists of a large number of sensors. Sensors are usually deployed over the hash area to monitor the area. For example, they are used for military surveillance, forest fire detection, or even outer space exploration [1][2][3]. These tiny devices are battery-powered. They can get the information from the environment, perform simple data processing, and use wireless communication to report the information to the collector. Because the scale of sensor networks is very large, recharging the battery of each sensor is impossible. Therefore, conserving battery energy is important for extended operation periods.

Generally, the communication range of each sensor is limited. Each sensor needs the other sensors to relay its gathered data back to the collector. The large number of sensors causes heavy packet relay overhead in the sensor network. For the battery-powered sensors, evenly distributing the packet relay tasks is the key factor to prolong each sensor's operation time. The method to organize the

sensors will directly influence the distribution of packet relay overheads.

There are many methods to collect data [4-8] in the sensor networks. The direct method which sensors transmit their data to the collector directly is the simplest mechanism. In this method, data may be transmitted over a long distance to reach the collector. The long-range transmission will drain the battery energy of sensors expeditiously. To extend the battery operation time, the cluster-based methods [10][11] is proposed. Sensors are organized as multiple star topology groups. A sensor will be selected as the cluster head to coordinate the sensors in each group and return the data of the group to the collector.

In this kind of methods, the sensors in the same cluster will contend the media to return their sensing results. The traffic collision is severe because the number of nodes in a sensor network is huge. Besides, the cluster heads will suffer heavy computation on aggregating the member sensors'

incoming data. Each cluster head also has a high relay overhead because it has to send data to the sink which locates far away from the interesting area. Thus, the cluster heads exhaust their energy quickly than the members in their groups. Once the cluster heads run out of energy, the network will be departed and lose the environment monitoring ability. So, the cluster architecture cannot bring all sensors into full play.

To reduce the heavy contention between sensors and minimize the number of cluster heads, the chain-based methods which sensors are organized into a chain topology are proposed[9][10][11]. Each sensor has at most two neighbors. Only the sensors at the two ends of the chain have one neighbor. A sensor will be selected as the leader to return data to the collector. Except the sensors at the ends of the chain, each sensor only has two pieces of data to transfer. One is its own data, and the other is the data generated by its adjacent neighbor who is far away to the leader than itself. For the sensors at the two ends of the chain, they only transfer their generated data.

Although the chain-based methods can greatly moderate the contention problem between sensors and reduce the number of cluster heads, the packet transmitting delay increases magnificently. The data generated by the sensors near the ends of the chain will take a long delivering time to reach the leader. Thus, the multi-level chain architecture is proposed [9] to reduce the packet transmitting delay. Sensors are organized into multiple short chains. These chains are layered. Firstly, the local leaders will collect the data of their members. Then, these leaders will reorganize as a high level chain. Sensors organized as a multi-level chain can effectively shorten packet delay.

The leader in the single chain architecture has a heavy packet relaying overhead. Therefore, the ring architecture [10] links the sensors in a circular ring and let sensors be the leader in turn. In the ring architecture, the maximal number of hops to relay a packet will be half length of the ring. The data-gathering mechanism is similar to the chain-based methods.

However, no matter the single chain or the multi-level chain architecture, they assume that each sensor can aggregate the incoming packets and its own packet into a constant and no size-expanded packet. When the relaying packets cannot be aggregated, the sensors which are close to the leader in the chain will exhaust their energy quickly than those away from the leader. The problem in the

cluster-based method reappears. We cannot bring all sensors into full play even the ring architecture is applied.

In this paper, we consider the scenario that the incoming packets cannot be aggregated. We use a mathematic model to deduce the optimal packet relay dispatching model for the short single chain architecture. All sensors can exhaust their energy at the same time. Based on this model and multi-level chain architecture, we propose the optimal relay dispatching method for the chain-based data gathering sensor network. The simulation results prove that the proposed dispatching method can extend the network operation time and optimally balance the packet relay overhead to all sensors.

The rest of this paper is organized as following. The detail mathematic model of the optimal relay dispatching method is deduced in section 2. The simulation results are discussed in section 3. Finally, we give the conclusion in section 4.

2 The Optimal Relay Dispatching Model

2.1 Preliminary and Assumption

The main idea starts with four sensors arranged in a line topology shown as figure 1. We assume that all sensors have uniform initial energy E and the same data delivering capabilities. Each sensor has three different power levels to transmit data. The maximal transmitting range for the first power levels is d. The second is $2d$, and the third is $3d$. Transmitting packets with a high-power level can deliver a message farther but consumes more energy.

The energy consumption for each transmitting power level is proportional to the distance. The Frii's transformation formula [11] is used shown as (2.1).

$$P_{tx} = (\frac{4\pi d}{\lambda})^2 P_{rx}, \qquad (2.1)$$

where P_{tx} is the transmitting power of the sender, P_{rx} is the signal power detected by the receiver, λ is the wave length of signal, and d is the transmission distance. The Frii's transformation formula implies that the energy to issue a packet is inversely proportional to the square of the distance.

We consider the communication channel is clear and there is no interference during the data transmission period. All sensors need to return their collected data back to the collector periodically. Thus, Every sensor generates the same number of

packets. We denote the number of generated packets as m.

2.2 Optimize the Relay Dispatching

An efficiently dispatching method will balance the packet relay overhead on all sensors and make their energy consumption coincidence no matter their locations are close or far to the collector. The optimal relay dispatching method dispatches the relay packets to different distance receivers to ease the relay overhead. We start with the little example in figure 1 to illustrate the main idea.

As the figure 1 shows, there are four sensors u，v，w，and x. The sensor C is the collector. The link between two sensors implies that they can use the first power level to communicate with each other. The targets that a sensor can use the second power level to communicate are its two-hop neighbors. Similar, the third power level is for the three-hop neighbors.

Except the sensor u, all other sensors need to relay the others' packets. Thus, we let the sensors help relaying packets use the first two power levels to deliver the packets to moderate their energy consumption. For the sensors that do not need to relay packets can use any power level to transfer its packets.

We know that total number of packets generated by each sensor is m. So, the generated packets of sensor u must be equal to the number of packets dispatched to the sensor v, w, and x. The relation is shown as Eq. (2.2).

$$u_v + u_w + u_x = m, \qquad (2.2)$$

In Eq. (2.2), u_v is the number of packets that the sensor u sends to the sensor v. The definitions of u_w and u_x are the same.
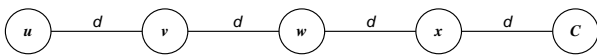

Figure 1: The line topology of the chain-based method. There are four sensors in this topology. They are sensor u, v, w, and x. The node C is the collector. The distance between two adjacent sensors is d.

For the sensor v, the total number of packets which needs to be transmitted includes its generated packets and the ones coming from the sensor u. Sensor v can pass its data to w and x but not C. So, we have the relation in Eq. (2.3). The definitions of v_w and v_x are the same as u_v.

$$v_w + v_x = m + u_v, \qquad (2.3)$$

The sensor w is similar to the sensor v. It sends the packets to the sensor x and the collector C. Sensor w sends the packets generated by itself and those coming from the sensor u and the sensor v. Similarly, the sensor x sends its packets and the ones coming from the sensor u, v, and w to the collector. So, we also have the relations in Eq. (2.4) and Eq. (2.5).

$$w_x + w_C = m + u_w + v_w, \qquad (2.4)$$

$$x_C = m + u_x + v_x + w_x, \qquad (2.5)$$

In addition, the whole energy of each sensor should be distributed to transferring the packets to different distance. For example, the energy of sensor u is divided into three parts to transfer u_v, u_w, and u_x packets to the sensor v, w, and x. To send u_v packets to its one-hop neighbor sensor v, sensor u uses the first power level to transfer them. The required energy is $u_v(\varphi d^2)$, where φ is a constant coefficient. Similarly, to send u_w packets to the two-hop neighbor w, the required energy is $u_w(\varphi(2d)^2)$. So is the three-hop neighbor x. The energy consumption for transferring u_v, u_w, and u_x must be no more than the total energy E. Therefore, we have the relation in Eq. (2.6).

$$u_v(\varphi d^2) + u_w(\varphi(2d)^2) + u_x(\varphi(3d)^2) \leq E, \qquad (2.6)$$

Note that for simplifying the equation, the energy for sensors to receive packets is not explicitly listed. We can reserve them as basis energy that is not included in E. The energy of sensor v, w, and x, used for transferring packets out should also be less than E. So, we have the Eq. (2.7), Eq. (2.8), and Eq. (2.9).

$$v_w(\varphi d^2) + v_x(\varphi(2d)^2) \leq E, \qquad (2.7)$$

$$w_x(\varphi d^2) + w_C(\varphi(2d)^2) \leq E, \qquad (2.8)$$

$$x_C(\varphi d^2) \leq E, \qquad (2.9)$$

Let $e = E/(\varphi d^2)$. We can rewrite the Eq. (2.6)~(2.9) to the clearer format as Eq. (2.10)~(2.13).

$$u_v + 4u_w + 9u_x = e, \qquad (2.10)$$

$$v_w + 4v_x = e, \qquad (2.11)$$

$$w_x + 4w_C = e, \qquad (2.12)$$

$$x_C = e, \qquad (2.13)$$

Next, we group the Eq. (2.2)~(2.5) and the Eq. (2.10)~(2.13) to (2.14).

$$\begin{cases} u_v + u_w + u_x = m \\ v_w + v_x = m + u_v \\ w_x + w_C = m + u_w + v_w \\ x_C = m + u_x + v_x + w_x \\ u_v + 4u_w + 9u_x = e \\ v_w + 4v_x = e \\ w_x + 4w_C = e \\ x_C = e \\ \forall z \in \{u_v, u_w, u_x, v_w, v_x, w_x, w_C, x_C\}, z \geq 0 \end{cases} \quad (2.14)$$

In Eq. (2.14), we add the condition that all variables u_v, u_w, u_x, v_w, v_x, w_x, w_C, and x_C are no less than zero. Each of these variables indicates the number of packets sent out by a sensor. A negative value is not reasonable. Consequently, the negative result can be explained as the packets flowing back from the sensor closer to the collector. However, if a sensor has the energy to send packets toward the inverse direction, it can directly send packets to the ones closer to the collector. It violates the practical applications so that we will not consider this case in this paper.
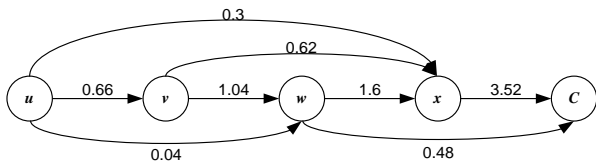

Figure 2: The packet dispatching results for the example in figure 1. The sensor u located at the end of the chain dispatches its packets to the receivers located at the distance d, $2d$ and $3d$. The other sensors can dispatch their packets to the receivers located at the distance d and $2d$. Their dispatching ratios are labeled aside the lines.

We can simply apply the matrix operation to find the solution of Eq. (2.14). It is possible that the Eq. (2.14) may have more than one solution if the last condition is not involved. However, if we require all variables being positive, it is not always possible to find the feasible solution.

In the example of figure 1, we set m of each sensor to 1. It implies the total amount of packets. So, we can use percentage to represent the amount of packets sending from one sensor to different receivers. In this example, all variables will be positive if the e is ranged from 3.52 to 3.55. Figure 2 displays the dispatching results of each variable with $e = 3.52$. Sensor u dispatches 66% packets to v, 4% to w, and 30% to x. The total amount of packets sent by sensor v is 166% that is more than 100%. These packets include the ones generated by v and those coming from the sensor u. The sensor v

dispatches 104% packets to w and 62% to x. Similarly, sensor w sends 160% packets to x and 48% to C. The total amount of packets sent by sensor x is 352%. These packets are sent to C completely.

2.3 The Optimal Relay Dispatching Method

The optimal relay model in section 2.2 contains only four sensors. It does not satisfy the practical scenario of a sensor network which consists of a large number of sensors. However, the deduction results give us the idea to organize the sensors into the multi-level chain architecture.

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The chain in figure 1 is the basic element in multi-level chain architecture. We name it as a zero-level (L_0) optimal relay chain. The sensors in a L_0 optimal relay chain are zero-level sensors. For each L_0 optimal relay chain, a L_1 sensor will be assigned to be its local collector. Similarly, for any level k, four L_k sensors create a L_k optimal relay chain and a L_k sensor will be assigned to be their collector.
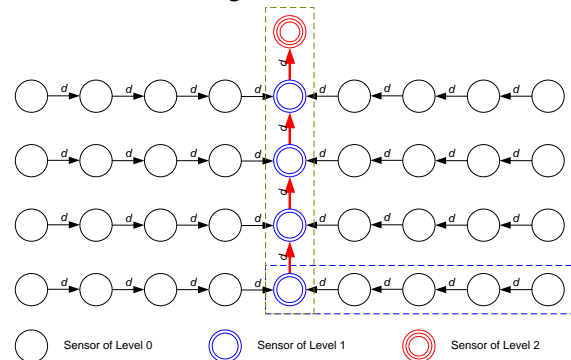

Figure 3: An example of a two-level optimal relay chain. Each L_1 sensor will be the collector of two L_0 optimal relay chains. The degree of the L_1 sensor is 2. The L_1 sensors will organize themselves as a L_1 optimal relay chain.

Consequently, we can assign one L_k sensor to be the common collector of several L_{k-1} chains. We define the *degree* of a L_k sensor as the number of L_{k-1} optimal relay chains that are assigned to it. To create a L_k chain, all sensors in this chain must have the same degree. This constraint will help us to schedule the initial energy for each sensor. We will discuss it in section 2.4. Figure 3 is an example of the L_2 optimal relay chain. The degree of a L_2 sensor is 2.

The architecture of multi-level optimal relay chain is scalable. The number of level can extend

according to the size of interesting area. Furthermore, the topology of the sensor network in the optimal relay method does not necessarily be the grid format. The grid topology in figure 3 is used for exhibiting the chain relation. The practical optimal relay chain of figure 3 can be constructed in the irregular format.

2.4 Schedule the Energy for Sensors

In the multi-level optimal relay chain, the higher level a sensor is the heavier relay overheads it will be. Thus, the sensors in higher levels must be assigned more energy than the ones in lower levels so that they can have more energy to pay the relay overheads. Let E_0 be the starting energy of each L_0 sensor. The initial energy for each L_k sensor can be given according to the Eq. (2.15).

$$E_k = 4\delta_k E_{k-1} + E_0 \qquad (2.15)$$

The δ_k in Eq. (2.15) is the degree of the L_k sensor. In Eq. (2.15), E_0 is the energy used to transfer the packets generated by the L_k sensor itself. The term $4\delta_k E_{k-1}$ is the additional energy assigned for the L_k sensor to relay packets. For example, considering the L_1 sensor in figure 1, its degree is 2. The initial energy for this sensor will be (4*2) $E_0 + E_0 = 9E_0$. By paying adequate energy for the sensors which help the relay task, the addition relay task will not cause these sensors exhausting energy.
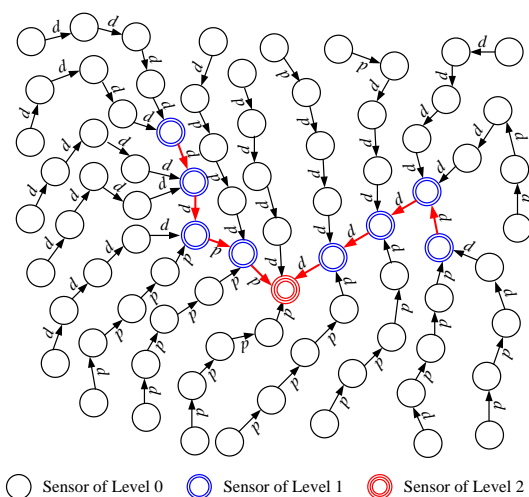
3 Simulation Results

Figure 4: The topology of simulation. The sensors are organized as a two-level multi-level chain. The degree of the L_1 sensors is 2. To fill the area, two L_0 optimal relay chains are added to the L_2 sensor.

This section gives the simulation results. We implement the proposed multi-level optimal relay chain, the single chain of the PEGASIS[9] and the multi-level chain with one-hop relay (denoted as ML-Chain). The topology to evaluate our method is like the figure 4. The sensors are organized as two-level chain architecture. The degree of each sensor is 2. In the following figure, 2LORC is used to represent the proposed method.

In our simulation, the packet size sent by each sensor is 2000bits. Packets will not be aggregated when a sensor relays it. The communication range for the three power levels is 50, 100, and 150 meters. The initial energy is assigned according to the Eq.(2.14) that all L_0 sensors are 440nJ, and all L_1 sensors are 9*440nJ. The constant φ in computing energy is set to 50. The number of deployed sensors is 80. The energy consumption of sensors and the network operation time are evaluated.
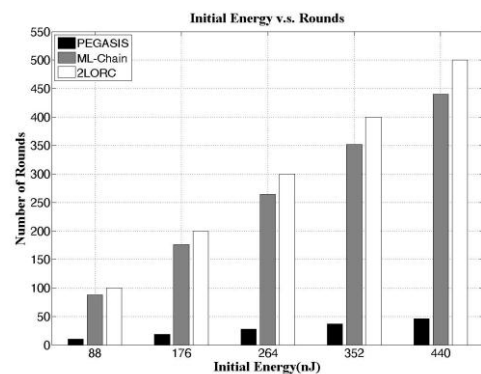

Figure 5: The number of rounds until the first sensor runs out of energy. All sensors in the network will periodically return their collected data to the network collector. Five different initial energy scales are simulated to evaluate the influence of energy to the number of rounds.

Figure 5 shows the number of network operation rounds in different initial energy. A round is defined as all sensors have transferred a packet back to the collector. The number of rounds in figure 5 is computed until one sensor exhausts its energy. A method which has a large number of rounds implies it can lengthen the network operation time. Besides, a method with a large number of rounds also implies it can deliver more packets.

Without the data aggregation, the PEGASIS method endures no more than 50 rounds. The uneven packets relay overhead quickly exhausts the energy of part of the sensors. By applying the multiple-level chain and assigned more energy to the backbone sensors, the ML-Chain can greatly improve the number of rounds. However, without a well schedule on dispatching relay packets, ML-Chain cannot bring the assigned energy into full

play. In our proposed optimal relay model, the multiple-level chain architecture can be improved the number of operation rounds more than 12%. The more initial energy, the more obvious it will be.

Figure 6 shows the average remaining energy of sensors. The labels in the x-axis with a * aside represent the energy of the L_1 sensors. Without scheduling the relay packets dispatching, the PEGASIS chain is worst. The remaining energy of L_1 sensors is still more than 90% but the energy of L_1 sensors is less than half of the initial value. In the ML-Chain, the remaining energy is more balance than the PEGASIS chain. By relaying packets hop by hop, the sensors closest to each local collectors will exhaust their energy first. The corresponding results can be referred in figure 7. For the 2LORC, the average remaining energy is zero. The result proves that 2LORC schedules the energy well and distributes the relay overheads to all sensors evenly but not sacrifices the network operation duration.
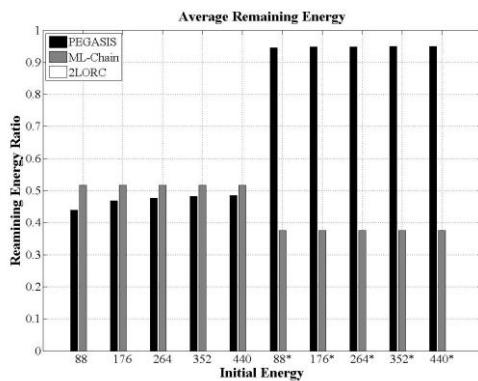

Figure 6: The average remaining energy of sensors. These results are averaged when the first sensor exhausts its energy. The results whose labels of the x-axis with a * aside are only averaged from the L_1 sensors and the ones without a * aside are the average results of the L_0 sensors.

Figure 7 shows the remaining energy of sensors according to the position. The label Lm-n in the x-axis represents the average energy of those sensors whose locations are in the nth position of the L_m optimal relay chain. If the position of a sensor is at the end of the chain (such as the sensor u in figure 2), n is 0. If the sensor is the one closest to the collector of an L_m optimal relay chain (such as the sensor x in figure 2), n is 3. The remaining energy of sensors in ML-Chain does not consume evenly. When the sensors near the local collector run out of their energy, the sensors at the end of the chain still have 75% energy. This phenomenon appears in both the L_0 and L_1 sensors. For the 2LORC, the optimal packet dispatching effectively balances the relay overheads and makes all sensors exhaust their

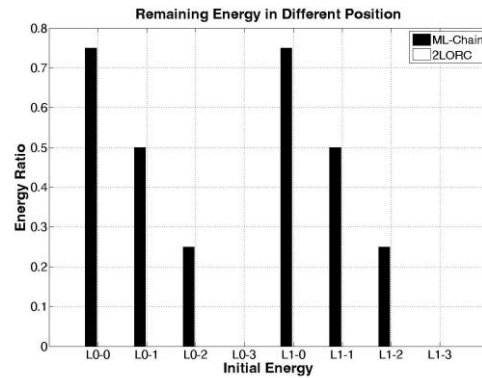energy at the same time no matter they are situated at which location of the chain.

Figure 7: The remaining energy of sensor in the different position. This figure displays the average remaining energy of the sensors according to their positions on the chain. Sensors near the collectors consume energy quickly in the single-hop multi-level chain. However, all sensors exhaust their energy simultaneously in the optimal relay chain.

Finally, we discuss the relay hop of the topology in figure 1. If the single-hop relay is used, the generated packets of sensor u, v, w, and x will pass 4, 3, 2, and 1 hop(s) to reach the collector C. So, their average hop-delay is Avg(4+3+2+1) = 2.5 hops. Now, we consider the sensor u in the optimal relay model that its packets pass four hops to reach the collector. The path $u{\rightarrow}v{\rightarrow}w{\rightarrow}x{\rightarrow}C$ must be used to satisfy the four hops condition. Figure 1 shows that sensor u has 66% packets dispatched to the link $u{\rightarrow}v$. When these packets reach the sensor v, the probability to dispatch them to the link $v{\rightarrow}w$ will be 1.04/1.66. The 1.66 is the total amount of packets sent by v and 1.04 is the ratio of packets passing to link $v{\rightarrow}w$. Similarly, the probability of $w{\rightarrow}x$ is 1.06/2.08 and $x{\rightarrow}C$ is 3.52/3.52. The expected value of the packets passing 4 hops of from the sensor u to the collector is shown as Eq.(2.16).

$$E[u_4] = 0.66 \times \frac{1.04}{1.66} \times \frac{1.6}{2.08} \times \frac{3.52}{3.52} \times 4 \approx 1.2723 \quad (2.16)$$

We let $E[s_j]$ be the expected value of the packets generated by sensor s passing j hops to reach the collector. The $E[u_3]$ and $E[u_2]$ are shown as Eq.(2.17) and (2.18). So, the relay hops of sensor u will be $E_u = E[u_4]+E[u_3]+E[u_2] = 3.0088$.

Computing the relay hops of sensor v, w, and x are similar. We list them in Eq.(2.19). The average relay hops in the optimal relay model will be Avg($E_u +E_v +E_w +E_x$) = 1.9999. This result shows that the proposed model can also shorten the hop-delay more than 0.5 hops of the single-hop relay method.

$$E[u_3] = \begin{pmatrix} 0.66 \times \dfrac{1.04}{1.66} \times \dfrac{0.48}{2.08} \\ +0.04 \times \dfrac{1.6}{2.08} \times \dfrac{3.52}{3.52} \\ +0.66 \times \dfrac{0.62}{1.66} \times \dfrac{3.52}{3.52} \end{pmatrix} \times 3 \approx 1.1181 \qquad (2.17)$$

$$E[u_2] = \left(0.3 \times \dfrac{3.52}{3.52} + 0.04 \times \dfrac{0.48}{2.08} \right) \times 2 \approx 0.6185 \quad (2.18)$$

$$\begin{cases} E_v = E[v_2] + E[v_1] \approx 2.2217 \\ E_w = E[w_2] + E[w_1] \approx 1.7692 \\ E_x = E[x_1] = 1 \end{cases} \qquad (2.19)$$

4 Conclusions

In this paper, we proposed an optimal relay dispatching method for chain-based data collecting sensor network. We used different transmitting power level to dispatch the relay packets to different receivers. By arranging and controlling the amount of packets to different receivers, we can balance the packet relay overheads to each sensor. We use a mathematic model to deduce the optimal packet distribution. Both the available energy and the number of packets are considered while determining the receivers in the different range. We extend this model to multi-level chain-based data gathering sensor networks. The proposed method can easily be applied to different scale of sensor network. All sensors can consume their energy evenly. The sensors near the collector are no longer suffering heavy relay loading. Simulation results show that the method with optimal relay model can endure longer to collect data. The relay overhead on the energy is more balance than the single chain method and the multi-level chain with single-hop relay. The number of delay hops is less than the single-hop relay method.

Acknowledgements

References

[1] B.A.Warneke, and K.S.J.Pister, "MEMS for the distributed wireless sensor networks", *Proceedings of the 9th International Conference on Electronics, Circuits and Systems*, **(2002)** pp.291-294.

[2] V.Rajaravivarma, Y.Yang, and T.Yang, "An overview of wireless sensor networks and applications", *Proceedings of the 35th Southeastern Symposium on System Theory*, **(2003)** March, pp.432-436.

[3] I.F.Akyildiz, W.Su, Y.Sankarasubramaniam, and E.Cayirci, "A survey on sensor networks", *IEEE Communications Magazine*, **(2002)** August, pp.102-114.

[4] P.M.Younis, M.Youssef, and K.Arisha, "Energy-aware routing in cluster-based sensor networks", *Proceedings of 10th Modeling, Analysis and Simulation of Computer and Telecommunications Systems*, **(2002)**, pp.129-136.

[5] B.Dey, and S.Nandi, "A Scalable Energy Efficient and Delay Bounded Data Gathering Framework for Large Scale Sensor Network", *Proceedings of International Conference on Emerging Applications of Information Technology (EAIT)*, **(2011)** February 19-20, pp.227-230.

[6] S.Lindsey, and C.S.Raghavendra, "PEGASIS: Power efficient gathering in sensor information systems", *IEEE Aerospace Conference*, **(2002)** March, pp.3-1125~3-1130.

[7] S.Lindsey, C.Raghavendra, and K.M.Sivalingam, "Data gathering algorithms in sensor networks using energy metrics", *IEEE Transactions on Parallel and Distributed Systems*, **(2002)**, pp.924-935.

[8] K.Du, J.Wu, and D.Zhou, "Chain-based protocols for data broadcasting and gathering in the sensor networks", *Proceedings of International Parallel and Distributed Processing Symposium*, **(2003)**, pp.22-26.

[9] L.Yuan, Y.Zhu, and T.Xu, "A Multi-Layered Energy-Efficient and Delay-Reduced Chain-Based Data Gathering Protocol for Wireless Sensor Network", *Proceedings of International Conference on Mechtronic and Embedded Systems and Applications*, **(2008)** October 12-15, , pp.13-18.

[10] S.C.Huang, R.H.Jan, and W.Yang, "RICA - A ring-based information collection architecture in wireless sensor networks", *International Journal of Sensor Networks*, **(2006)**, vol.1, no.3/4, pp.190-199.

[11] H.T.Friis, "A note on a simple transmission formula", *Proceedings of IRE*, **(1946)**, pp.254-256.

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