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A Redistribution Method to Conserve Data in Isolated Energy-harvesting Sensor Networks

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Abstract. In ambient monitoring applications, the sensing field may be so far away from the data center that causes the direct relay routes between the sensor network and the data center impossible. Typically, in such isolated sensor network, data is stored in a distributed manner and collected by data mule. To improve the efficiency, sensed data is normally stored near the area where the mule will pass by with respect to storage limitation. However, previous researches didn't consider the energy constraint and energy harvesting capability of nodes. The purpose of this paper is to design a solution for fair data storage under space and energy limitation only based on local information. We propose a heuristic Distributed Energy-aware Data Conservation method (DEDC), which considers following two issues: i)where to store data with respect to energy and space storage, ii) how to prioritize the transmission of important data. Simulation has shown that the method is effective, energy efficient and robustness.

Keywords: isolated wireless sensor networks, energy-harvesting, data conservation.

1. Introduction

A Wireless Sensor Network (WSN) is normally composed of lots of sensor nodes which gather environmental data in a continuous or discrete manner. Nodes communicate with their neighbors and forward data to the sink through multi-hop routes. Many aspects, such as routes, channel access, locating, energy efficiency, coverage, network capacity, data aggregation and QoS have been explored extensively. Nowadays, problems studying of practical WSN applications has been a topic of great interest rather than theoretical research. For example, considering WSNs deployed in ambient environment such as habitat monitoring of Great Duck Island [13] and Landslide Prediction in India [16], how to ensure systems work sustainablly are more important. These WSNs are more likely to be isolated from outside world as mentioned in [12] due to many reasons such as high cost of building base stations, sink node failure or adverse condition.

In this paper, the work is motivated by the project of GreenOrbs [11], which is targeted at using mobile wireless sensors for monitoring canopy density in wild mountain areas which are difficult to access. Collecting data from such isolated WSNs may rely on vehicles passing by or a person carrying some special equipments. Furthermore, energy-saving or harvesting strategies can extend the lifetime of these WSNs. We consider data conservation issues in an isolated energy harvesting WSN, in which a data mule is used to collect stored data periodically. In the WSNs, each sensor node has limited RAM and flash storage space and faces the challenge that its battery tend to be flat. In such case, there are many issues have to be considered: i)where to store the received data to prevent data loss with respect to the limited energy shortage as well as space storage, ii) how to reduce communication overheads caused by data redistribution, iii) how to prioritize data by the importance and forward higher priority data as fast as possible. In this paper, a Distributed Energy-aware Data Conservation method (DEDC) is brought forward which allows nodes to decide where to send or to reserve data, and how to exchange with neighbors only based on the local information.

Another motivation of this paper is the project named Cyber IVY [9] which has been proposed and carried out for supplying building surveillance functions. Previously, it has been implemented with HDU Mote using normal rechargeable batteries. Recently, Cyber IVY has moved to a new stage. Nodes are powered by outdoor solar-power and wind power from external units of air conditioners. Data will be collected periodically by a staff(Mule) using handheld device. Therefore, it could be regarded as an isolated energy-harvesting sensor networks.

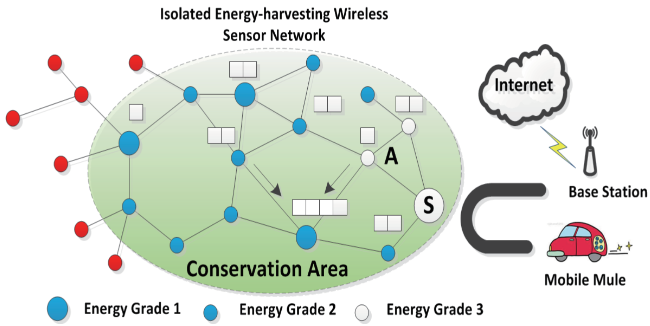

Fig. 1. Typical architecture of DEDC

In this paper, we try to find a method of data redistribution to maximize the network robustness. To make things simple we define conservation area near the sink node to store generated data packets. As shown in Fig.1, red nodes represent those outside the conservation area. The size of a node stand for its energy level. The whole network is isolated and can only be accessed by an external vehicle which will upload sensory data to the Internet via the base station. Inside the network, each node tries to forward packets to neighboring nodes which are one hop closer to the sink and have more energy than itself. That is to say, data packets will be redistributed in the conservation area according to energy level and location.In our method, data packets will always be forwarded to nodes closer to the sink unless the node itself and its closer neighbors will deplete their energy very soon. For node A, it has to fall back its data because its energy grade is near critical level and it cannot find any node suitable to receive the data that are closer than node A.

The remainder of the paper is organized as follows. In Section 2, the related work is introduced. In section 3, we introduce the system model. Then the proposed DEDC method is described in detail in section 4, followed by the simulation and experimental evaluations in section 5. Finally, section 6 conclude the paper.

2. Related work

Different from researches on energy efficiency of battery-powered sensor networks, there are two main concerns in the energy-harvesting solution [7]. One is that rather than a limit on the maximum energy, it has a limit on the maximum rate at which the energy can be used. The other is that different nodes may have different harvesting opportunity as well as harvested energy availability. Therefore, besides minimizing the energy consumption and maximizing network operational time, maximizing the utility of the application subject to the harvested energy via routing protocols are evaluated in [6]. They compare the protocols under realistic scenarios and show how parameters of the MAC protocol can be optimized for a given harvesting scenario and network topology. Furthermore, Sharma et al. [15] consider generated energy together with generated data packets to achieve the largest possible data rate. They find conditions for energy neutral operation of the system, while keeping the data queue stable. They also obtain energy management policies which minimize the mean delay of the packets in the queue.

In this paper, we study issues of energy-harvesting sensor networks from the point of view of data conservation, especially in an isolated energy-harvesting sensor network. The main concern is that how and where to store sensory data regarding constrained storage space and useable energy. Data mule, isolated sensor network and energy-harvesting are tree main attributes of this paper. Therefore we evaluate related works from three points of view as shown below.

2.1. Mobile sink

The use of mobile sink(s) is regarded as one of the most successful means of load balancing and efficient data collection. Finding an appropriate route that minimizes energy consumption for data dissemination from source to mobile sink is a major concern. Kim et al.[8] propose SEAD, a Scalable Energy-efficient Asynchronous Dissemination protocol which considers the distance and the packet traffic rate among nodes, to minimize energy consumption in both building the dissemination tree and disseminating data to mobile sinks. In [20], mobile relays are employed not only to carry data packets but dynamically distribute network resources such as energy, computational power, sensing, and communication abilities. The trajectory of the mobile sink is another concern. Alnabelsi et al. have a mobile sink node patrol and collect the data from all the fragments across the network [1]. Dynamic Programming and Integer Linear Programming are introduced to find the optimal route of the mobile sink such that the energy consumption at the sensor nodes and inter-visit time within the fragment are minimized.

2.2. Data collection in isolated or sparse WSN

Isolated WSNs have some features similar to sparse WSNs. The difference is that for isolated WSNs the whole network is isolated from outside world while in sparse WSNs only single node are far from each other. The latter concerns mule discovery process, the data transfer process, data transfer rate and so on. In [14], an architecture to connect sparse sensor networks at the cost of higher latencies is proposed. The main idea is to utilize the motion of the existing entities to provide a low power transport medium for sensory data. Chakrabarti, et al. prove that using mules with predictable mobility [4] can significantly reduce communication power in WSNs. Ref [3] analyzed the optimal ARQ-based data-transfer protocol and provided an upper bound for any ARQ-based data-transfer protocol. In [2], an integrated evaluation of mule discovery and data transfer performance is provided. The results show that low duty cycle is actually feasible for most common environmental monitoring applications. Other means like using mobile ferries to conduct routing in a highly disconnected ad hoc network is discussed in [21]. *Message Ferrying (MF)* [21] is proposed for data delivery in sparse networks which utilizes a set of special mobile nodes to provide communication services for nodes in the network. The main idea is to introduce non-randomness in the movement of nodes. In [5], the authors developed a hybrid routing approach in which both MANET routing and message ferrying are used to explore available connectivity in clusters via gateway nodes. Yu-Chee Tseng et al. brings forward a *Distributed Storage Management Strategy (DSMS)* [19]to buffer data in an isolated WSN which concerns on space limit and data priority. By keeping higher-priority packets closer to the sink area, DSMS can reduce data loss probability and achieve higher efficiency. However, how to buffer packets in isolated energy harvesting WSNs to avoid data loss due to battery being flat remains unsolved.

2.3. Data collection in energy-harvesting sensor networks

There are many related work about energy-efficient data gathering or aggregation methods in wireless sensor networks. However, there are not much researches suitable for energy-harvesting sensor networks. In [10], a solution for fair and high throughput data extraction from all nodes is designed in the presence of renewable energy sources. Specifically, the authors seek to compute the lexicographically maximum data collection rate and routing paths for each node such that no node will ever run out of energy. A centralized algorithm and two distributed algorithms are proposed. The centralized algorithm jointly computes the optimal data collection rate for all nodes along with the flows on each link, the first distributed algorithm computes the optimal rate when the routing structure is a given tree; and the second distributed algorithm, although heuristic, jointly computes a routing structure and a high lexicographic rate assignment that is nearly optimal. They prove the optimality for the centralized and the first distributed algorithm, and use real testbed experiments and extensive simulations to evaluate both of the distributed algorithms. In [17], data preservation problem is studied in the intermittently connected sensor networks under energy constraints at sensor nodes. By distributing the data items from low energy nodes to high energy nodes, data can be preserved for maximum possible time. However, the distribution process is uncoordinated as the data item could be put anywhere in the network regardless of the location of sink nodes, which will result in great transmission cost. The centralized algorithm is also hard to be implemented in large scale WSNs.

3. System model

3.1. Data redistribution problem

Large scale wireless sensor network for long-term environmental monitoring as GreenOrbs [11] has more than 700 nodes deployed in a reserved natural forest area for eight months. In such network, changing batteries or building a base station nearby which can directly access Internet is not feasible. So we consider an isolated energy-harvesting wireless sensor network in which data can only be collected by scheduled or non-scheduled data mules. The network is composed of a *sink node* and *static sensor nodes*. Regarding the route of mobile mules, single sink is more generality. Issues related with multi-sink will be addressed in future work. Static sensor nodes are all identical and have same initial energy and storage space. They can continuously monitor the environment and generate data packets periodically or according to events. In this paper, storage limit is not fully taken into account as in such a low duty cycle network, data packets are generated every 15 minutes. As shown in table. 1, a lot of space is still available beyond system and user needs. Each node has means of energy harvesting and the energy source will be flexible, such as wind or solar power. However, the node will be *dead* when its battery is flat. So how to avoid loss of sensory data is more important.

Before data mules collect sensory data, static nodes will store data packets in a distributed manner. Data mules will only visit the specified node *sink* for a period of time. Only during this fixed or random period can the sink forward the

[1] There is also an onBoardFlash free to use which has capacity of 1MB.

Table 1. Flash and Ram usage of HDU Mote (MSP430F1611) of some typical applications

HDU Mote	Flash(total 48KB)[1]	Used Per.	Ram(total 10KB)	Used Per.
Blink	2732B	5.7%	55B	0.5%
HotelMon	19072B	39.7%	1522B	1.5%
MultihopOscilloscope	31228B	65%	3906B	39%
TestNetwork	32374B	67.4%	3218B	32%

data packets to the mule. After that, the mule will move to a base station and upload all the data packets.

3.2. Network model and problem formulation

The principle idea of the paper is to store data safely and reduce transfer latency when data mules arrive. We propose a distributed energy-aware data reservation method to coordinate node action to avoid control packet overheads. To reduce the cost, as mentioned in [19], we set up a *Conservation Area* which is a predefined region adjacent to the sink. Nodes in CA are responsible for storing sensory data of the whole network. The scale of CA is defined by the nodes within the maximum hop-count to the sink so that it can scale from 3 hops to 10 hops. Our proposed method will focus on data dissemination scheduling among nodes in CA. By defining the CA part of the network instead of the whole network we can significantly reduce overhead caused by centralized method. Nodes not in CA will forward their data packets to those in CA. With respect to the single sink strategy the action of other nodes (direction of forwarding data) is accordance with non-energy-constraint system. Therefore, the communication cost can be ignored. Three facts should be considered such as i) Data loss should be minimized all over the network, ii) Packets with higher priority should be delivered earlier, iii) Transfer latency should be minimized in CA. For simplicity, we defined some terms as follows.

Definition 1. ***Energy threshold*** T *We define energy threshold to justify node energy status. Typically,* $T1$ *equals 65% of total energy.* $T2$ *equals 30% of total energy which represents the lower bound.*

Definition 2. ***Energy harvesting amount*** $A(u)$ *Let* $A(u)$ *be the total amount of energy that has been collected by node* u *for a certain period of time* Δt. $H(u)$ *denotes the energy harvesting capability of node* u *which will be a function of input currency. We use historical knowledge to predict current and future energy harvesting rate. So that* $A(u)$ *could be computed as* $\int_0^{\Delta t} H(u)dt$. *To make things simple, we classify every 5% percent energy as one step* S. Δt *varies from system to system. In the Cyber IVY project, we set* Δt *as 5 minutes. The energy harvesting speed can be seen in Fig. 2 (note that functional voltage is from 1.4 to 2.6).*

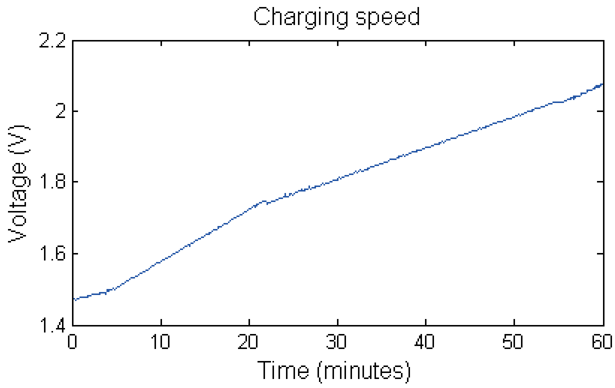

Fig. 2. Energy harvesting speed of node in Cyber IVY

Definition 3. ***Energy grade*** $E(u)$ *Let* $B(u)$ *indicate the residual energy of node* u *and* E_{max} *indicate the maximum energy capacity of a node. We assume all nodes have the same energy draining rate* c *so that the energy grade of a node is* $E(u) = B(u) + A(u) - c\Delta t$*. To normalize the equation, we use:*

$$E(u) = (B(u) + A(u) - c\Delta t)/(E_{max} \times 0.05) \tag{1}$$

It is decided by three facts: residual energy, energy consumption and energy harvesting rate, which will seriously affect the safety of the system. To simplify the node action, We model node energy state into three main grades (levels) which will be sperate by T. $G1 : T1 \leq E(u)$ *means the node have ample power that is greater than threshold* $T1$. $G2 : T2 \leq E(u) \leq T1$ *means energy residua locates between* $T1$ *and* $T2$ *and maintains a balance.* $G3 : E(u) \leq T2$ *means energy locates lower than* $T2$.

Definition 4. ***Sink distance*** $D(u)$ *Each node or packet is some hops away from sink.* $D(u)$ *means the minimum hop count of node* u *to the sink, while* $D(i)$ *stands for the minimum hop count of packet* i *to the sink.*

Definition 5. ***Survive probability of packet*** S *We define survive probability of packet* i *located on node* u *as* $S_{i\to u}(i) = \frac{E(u)}{\lambda(u)D(u)}$ *in which* $\lambda(u)$ *is a function of three factors, namely, communication cost, communication latency and hop count from* u *to the sink. Normally, we let* $\lambda(u) \equiv 1$*. The greater the* S *is the higher chance the data delivered to mobile mules.*

Definition 6. ***System robustness*** R *We define the whole system robustness as*

$$R(CA) = \sum_{u \in CA, i \to u} S_{i\to u}(i)P(i) \tag{2}$$

in which $P(i)$ *denotes the priority of packet* i*. Thus, the sum of all survive probability of all packet times by their priority is maximized.*

$P(i)$ can be defined using many methods. Therefore, the main goal of our proposed method is to maxim Global System Robustness function R in CA.

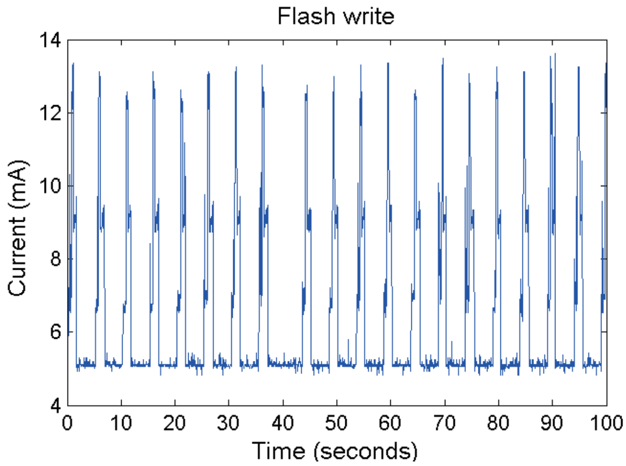

Fig. 3. The energy consumption factor of writing action of onChipFlash

There's no detailed information of currency consumption of OnChipFlash so that we did some experiments and got the following result. Fig. 3 indicates that writing operation takes place on onChipflash for 2.5 seconds every 5 seconds. This is the only routine running on HDU Mote. No radio, no sensing, so the lower current bound is around 5mA. Average flash writing currency is approximately 10mA which is not much compared with external flash. Therefore, node can move data to the flash when necessary while energy cost is reasonable. The final result is shown in table 2.

Table 2. Currency consumption factor

Action	HDU Mote OnChipFlash	OnBoardFlash
Active current(READ)	5mA	4mA
Active current(WRITE/ERASE)	10mA	15mA

4. Distributed energy-aware data conservation method (DEDC)

In isolated sensor networks, such as GreenOrbs, data will be sampled every 15 minutes. The full size of each sample data is 12 bytes. It can support more than 150 hours continuous work only relying on ram of nodes. Storing data in onChipFlash or onBoardFlash are both feasible, which are 1.25 Mbytes in total. Therefore, it is believed that energy is more important than storage space. Communication is the major part of energy consumption. However, because CA is close to the sink, each node out of CA will forward their packets to CA which has the same goal compared with other energy efficient routing protocols. In CA, each node will try to forward data packets to the nodes that are closer to the sink. That is to say, we can use any existing routing protocol to improve the efficiency so that we don't take communication cost into account. In this paper we propose a Distributed Energy-aware Data Conservation method to maximum the maxim Global System Robustness function R in CA. The assumptions are summarized as follows:

- Each node u knows its distance $D(u)$ to the sink and the neighbor set $N(u)$ within one hop; These parameters are easy to obtain when the network was setup and update by broadcasting. We try to make the method distributed so we build our method on local knowledge. One hop is a balance of accuracy and overhead. Centralized method or distributed method needing whole network knowledge is not feasible.
- Each node has sufficient space storage for the application.

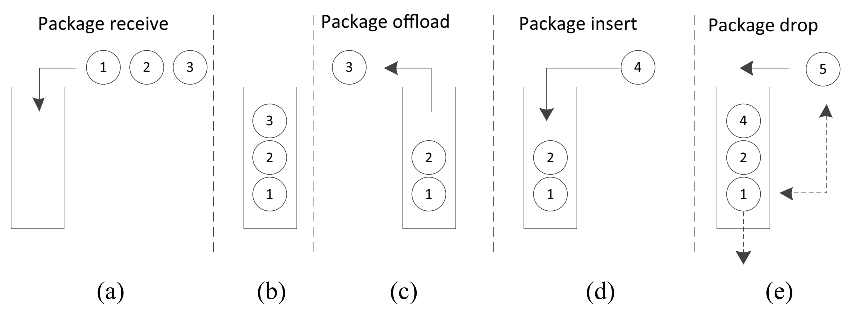

Fig. 4. Organization of storage structure

In practice, data packets always have different priorities. Packets of higher priority deserve greater chance to survive in terms of storage and energy limitation. Normally, besides preassigned priorities, the newer the packet is the higher the priority is. Therefore, DEDC method uses a stack-like data structure to store packet in their memory to ensure newer packet will always be sent earlier. As shown in Fig.4(a), when the buffer is empty three data packets arrive respectively and are stored as shown in Fig.4(b). Fig.4(c) shows that packet '3' will be offloaded first when data is passing on. Newer packet will be inserted from the top of the stack as seen in Fig.4(d). If dropping data is inevitable the newer packet will be compared with the packet at the bottom of the stack. The one with lower priority will be discarded. The structure is easy to implement and has less number of comparison which results in a better time complexity and lower overhead.

For data redistribuiton, nodes of three different energy grades follow different actions and algorithms, but they all obey a fundamental rule:

R1: Denote $E(i)$ to be the energy grade of the last relay node where packet i came from. For each node u, a packet i stops and locates on u only when $\forall v \in N(u)$, $E(v) < min\{E(u), E(i)\}$ where $D(v) < D(u)$.

Each node will attempt to deliver packets to nodes closer to the sink. R1 describes when this approach will stop under certain conditions. It implies that packets are forwarded to nodes which have more energy and closer to the direction of data center. In the case that there are some *strong* nodes in the CA, if we only consider a node's one hop neighbors, packets will be stuck in these nodes because no nodes around them have more energy. Meanwhile, if there are nodes of less energy standing in main data route they will also become bottle neck and block packet transmission. We call both situations the fat energy wall phenomenon and the thin energy wall phenomenon respectively. As shown in Fig.5, there are three nodes in a line and the size of circle represents the energy grade. Fig.5(a) shows two packets i,j are not able to pass through node v because any neighbor nodes of node v have less energy. If node v has lest energy among three node two packets i,j can not pass through node v ether as shown in Fig.5(b). To avoid the existence of energy walls that block packets from going to the sink and store too many packets in its memory, we consider two hop situation in a distributed manner to balance packets load in CA while each node still needs one hop information of its neighbors and packets. At the same time, each node has two actions, namely $PUSH$ and $PULL$, against the fat energy wall and the thin energy wall respectively. However, $PULL$ is a conditional action, only when node raises a request will it be performed. To support two actions, node u not only considers next hop neighbors but also previous hop ones.

To formulate our method we bring forward some basic rules as indicated below:

C1: For each node u, let $v = maxEDN(u)$ be the node with highest energy grade of all neighbors of u where $D(v) < D(u)$, node u moves packet to v when $E(v) \geq E(u)$.

C2: For node $v = maxEDN(u)$, if C1 is not met, node u moves packet i to v if $E(v) \geq E(i)$.

C3: For node u, $v \in N(u)$ and $D(v) > D(u)$. On receiving a packet transferring request from v, if $\exists$ node $w = maxEDN(u)$ and $E(w) > E(v)$, Node u $PULLs$ the packet from v and $PUSHs$ it to w.

C4: If C1, C2, C3 could not be satisfied, node u tries to move packet to $v, v \in N(u)$ if and only if $E(v) > E(u)\ and\ E(u) \in G3$ where $D(v) > D(u)$.

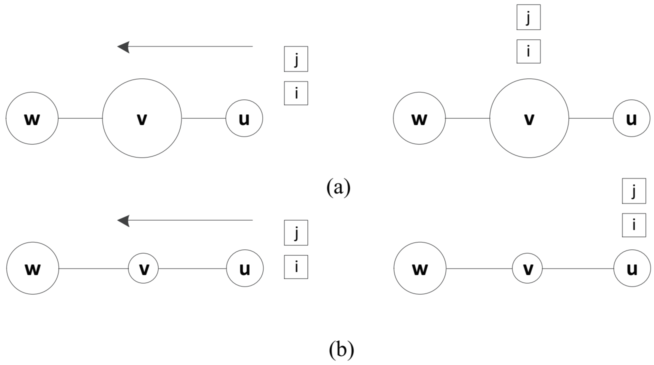

Fig. 5. Two examples of energy wall phenomenon

C5: If C1, C2, C3, C4 could not be satisfied, node u will store the packet in its flash memory.

Whenever a node receives or generates a packet, it will determine its action according to the above conditions. A node will examine these five conditions in a sequence of C1 to C5. Therefore, packets are forwarded to nodes as close to the sink as possible. Nodes use RTS/CTS like protocol to negotiate the process of packet exchanging. Communication cost is reduced as only one hop neighbors are involved.

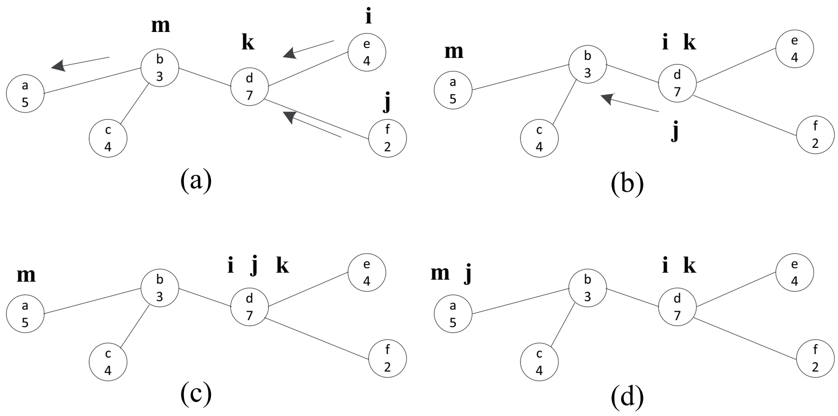

Fig. 6. An example of DEDC method

As shown in the example of Fig. 6(a), there are six nodes in part of the network. Each of which has a name and energy grade in the circle. Four packets i, j, k, m are generated from node b, d, e, f respectively. Regarding condition

C1, node b will forward packet m to node a and node e will forward packet i to node d. Node f will forward packet j to node d and node d chooses to keep packet k. Greedy method that only perform condition C1 will finally stop at the snap as shown in Fig.6(c). Thus, node d becomes a wall which blocks packets going to node a, b, c. Regarding DEDC, node d will try to forward packet j to node b because the energy grade of its last relay node (source node) is less than that of node b as indicated in Fig.6(b). Finally, packet j will be moved to node a and stop there as can be seen in Fig.6(d). Therefore, DEDC has better balance on packet delivery and Survive Probability S in CA.

The Distributed Energy-aware Data Conservation method for each node when receiving or generating a packet is described as following:

Algorithm 1 DEDC method

```
when a packet i is received or generated by node u
FOR each node v ∈ N(u)
 IF C1 is satisfied
  move packet i to node v;
 ELSE IF C2 is satisfied
  move packet i to node v;
 ELSE IF C3 is satisfied
  move packet i to node w;
 ELSE
  CASE energy grade of E(u)
  G1: broadcast its hop count and energy information;
  G2: null operation
  G3: FOR each node w ∈ N(u)
   IF C4 is met
    data fall back to node w
   ELSE
    C5: store data into flash memory.
   ENDIF
  ENDCASE
 ENDIF
```

5. Performance evaluation

To verify the performance of proposed DEDC method we conducted some simulations. First, we test data storage structure of DEDC and compare it with OPT and FIFO algorithms. The simulation environment contains 100 sensor nodes each of which has storage space of 20 data packets (ram together with flash). Each node will generate a data packet every 10 seconds and each packet has a random priority between 0 and 3. Each time when the data mule comes it will fetch all data and the time of this process is ignored. Two algorithms are chosen as competitors. When the storage space of a node is full, FIFO drops data in a First-in-First-Out manner. OPT algorithm will search out the entire storage space to find a packet with lowest priority for substitution. Fig.7 compares the average priorities of the packets collected by data mule when we vary the visiting interval of the mule and CA size. Fig.7(a) shows that as the visiting interval increases, the average priority also increases. It means OPT can collect more high priority packets while the increasing of visiting interval results loss of more and more data packets. Fig.7(b) shows that the average priority decreases as the CA size is enlarged which means increasing of successful transmitting packets. DEDC has similar performance compared with Optimal algorithm in both experiments while it needs less computation power and comparison.

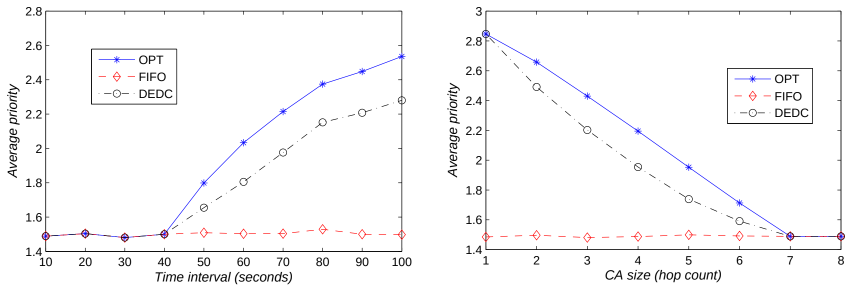

Fig. 7. The comparison of average priorities of packets collected by mules by varying (a) the visiting interval and (b) the different size of CA.

The metrics of evaluating algorithms in related work [12][18] is total redistribution cost which implies energy cost for data transfer. Data pakcets are stored distributively in the whole network without consider of cost of future collection. In our work, data mule will only visit the sink node of the network for a short period of time so that data should be offloaded to buffer area near the sink node through energy-efficient route. Our goal is to ensure data is distributed near the sink node regarding priority and storage safety. As we define $\lambda(u) \equiv 1$ so that Survive Probability of packet is seriously affected by network size. Two methods are chosen as competitors, Greedy method only forward packets to nodes which have more energy and closer to the sink, Non-schedule method will keep packets where they are generated. As shown in Fig.8, all three methods turn to achieve less System Robustness when the number of nodes increases. This is because that packets are more likely to be stored far away from the sink. However, DEDC outperforms Greedy method and Non-schedule method because it has better balance between data safety and data transmission overhead. When network scale increase Greedy method tends to encounter energy wall phenomenon and Non-schedule method will lead high data transmission latency.

We randomly generate 500 packets and let the data mule collect data only for a short period of time and evaluate the successfully delivered packets while the network size increases. As shown in Fig.9, transmitted packets decrease

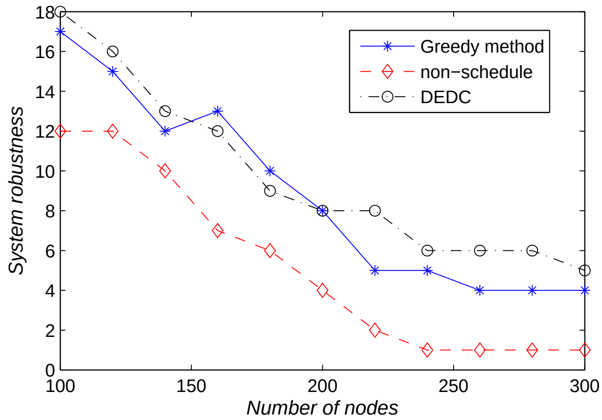

Fig. 8. System robustness of different network size

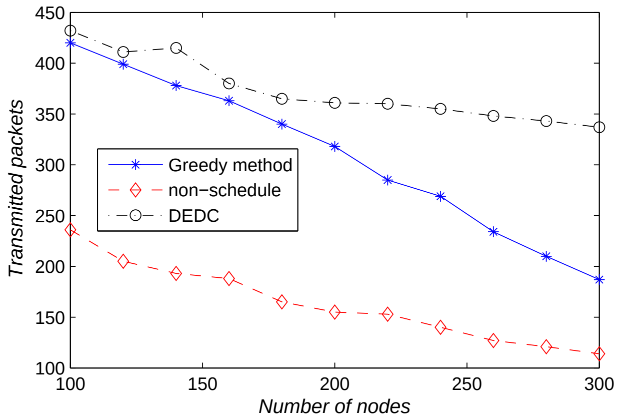

Fig. 9. Transmitted packets of different network size

because more and more packets are stored far from the sink when the number of nodes increase. However, DEDC has a lower drop rate so that it achieves best performance because more packets are closer to the sink.

6. Conclusions

In this paper, a Distributed Energy-aware Data Conservation method (DEDC) has been introduced which helps to extend the lifetime and achieve reasonable packet delivery performance in isolated wireless sensor networks. This scheme allows nodes to decide where to send, to reserver on itself or exchange with neighbors based only on local information. The method is evaluated through theocratical analysis and simulation. It has been proved to be efficient, which has achieved the following advantages: i)an improved data packet storage scheme has been provided with respect to limited energy, ii) the communication overheads caused by data redistribution has been reduced, iii) high priority data can be delivered earlier which helps in network balancing.

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