Energy Collaboration Based on Borrowing and Returning Mechanism with Demand Diffusion

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***Abstract*—In wireless sensor networks, the nodes with impoverished energy will reduce transmission reliability because they have not enough energy to send data or are forced to decrease transmission power to save energy. Therefore, this paper proposes energy collaboration based on a borrowing and returning mechanism with demand diffusion to improve network transmission reliability. Firstly, a new transmission protocol is designed. Secondly, energy collaboration sets are formed by broadcasting energy demand from energy-deprived nodes and selected optimal forwarding nodes as well as by diffusion. Again, in energy collaboration sets, in order to encourage nodes to actively participate in energy cooperation, a borrowing and returning mechanism is used to prioritize nodes to select energy cooperation nodes. Finally, the selected energy collaboration nodes transfer energy to energy-deprived nodes according to certain principles. Simulation results show that the proposed method can effectively improve network transmission reliability in diverse energy collections.**

***Index Terms*—Wireless sensor networks, demand diffusion, borrowing and returning mechanism, energy collaboration, transmission reliability.**

I. INTRODUCTION

Wireless sensor networks (WSNs) are used to build large-scale environments such as the Internet of Things and Industry 4.0 due to their strong adaptability [1], [2]. However, once nodes in these networks use up energy, they will interrupt transmissions. To guarantee nodes to work in a long time, researchers proposed to use energy harvesting technology to achieve extra energy replenishment [3]. The technology can convert energy source such as solar energy, wind energy, from environment into steady electrical energy for nodes. Among these energy sources, solar energy is often used as the preferred source in WSNs because of its highest power density [4]. After that [5] proposed a green RF energy harvesting concept and used collect-store-use model to realize energy storage and transfer.

To balance the nodes' energy, energy collaboration is proposed in multi-user networks [6]. Subsequently, an immediate method is proposed for energy collaboration on demand, where the transferred energy must be used by the receiver in current time slot [7]. In large-scale networks, [8] proposed to use a sink node to enable energy cooperation pairing between nodes to maximize transmission rate. [9] proposed to use a sink node to optimize energy collaboration power to minimize average distortion. [10] considered using nodes to obtain energy from a common source to minimize long-term transmission delay. [11] considered optimizing energy collaboration time to extend network lifetime. [12] used three different methods to form optimal forwarding relay and energy supply node pairs for packet forwarding. [13] proposed energy-neutral opportunity cooperation to enhance data transmission rate through energy collaboration in forest monitoring networks.

In above study, various forms of energy collaboration are used in diverse networks to improve related performance, the demand information sharing of nodes are mostly single-hop in energy collaboration. In actual networks, energy collection varies greatly because of nodes placement, surrounding obstacles and other factors, it is impossible to obtain required energy from nearby nodes through only a single-hop. And the nodes are always selfish in collaboration because of their limited energy. So, this paper proposes energy collaboration with demand diffusion, more energy-rich nodes can participate in energy collaboration by diffusing energy demand. To encourage nodes to actively participate in energy collaboration, a borrowing and returning mechanism is introduced to prioritize nodes and select energy collaboration nodes. Finally, the selected nodes transfer energy to energy-deprived nodes according to certain principles. The main contributions are as follows.

- To improve the transmission reliability, energy collaboration based on borrowing and returning mechanism with energy demand diffusion is proposed.
- For energy demand diffusion, a new strategy is developed to seek for the optimal forwarding nodes and the energy collaboration nodes.
- In order to encourage nodes to actively participate in energy collaboration, a borrowing and returning mechanism is introduced to prioritize nodes and select energy collaboration nodes. The selected nodes achieve energy collaboration with energy-deprived nodes according to certain principles.

The paper is organized as follows. Section II gives the system model. Section III presents the proposed transmission

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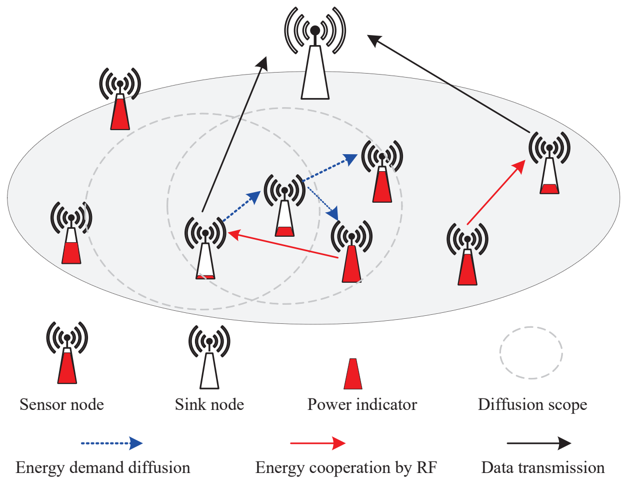


Fig. 1. System model

protocol. Section IV illustrates the simulation results and the discussion. Section V summarizes our work.

II. SYSTEM MODEL

A multi-source single-destination network is shown in Fig.1, which composes of a sink node D and K sensing nodes $S_\kappa\ (\kappa = 1, 2, \dots, K)$. The channel in two nodes obey Rayleigh fading. The instantaneous channel gain between S_κ and D, S_κ and S_q are expressed as $\alpha_{S_\kappa,D}$, $\alpha_{S_\kappa,S_q}\ (\kappa, q = 1, 2, \dots, K, q \neq \kappa)$. In Rayleigh fading model, the square of channel gain follows an exponential distribution, $|\alpha_{S_\kappa,D}|^2$ and $|\alpha_{S_\kappa,S_q}|^2$ are exponential random variables of $\lambda_{S_\kappa,D}$ and λ_{S_κ,S_q}, respectively. All channel assumed to be reciprocal and independent of each other and keep constant for each round of data transmission. The presence of additive Gaussian white noise with a mean of 0 and a variance of σ_N^2 around receivers. The data transmission power of sensing node is set as P. The data transmission rate with per unit of spectrum is set as Ω.

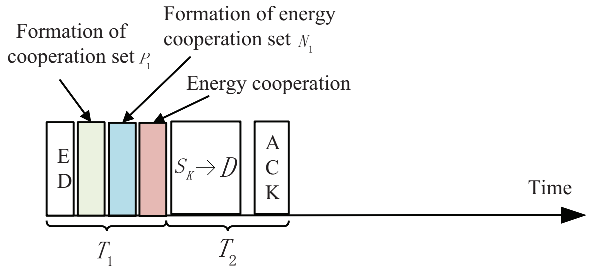
All sensing nodes are stocked both with solar and RF energy harvesting modules, high capacity rechargeable batteries. Under normal situations, nodes can store collected solar energy to the rechargeable battery for data transmission. And the RF energy collection is turned on only when energy collaboration is triggered. Energy Deficiency (ED) frame is an energy demand, which contains number and the minimum energy requirement value of the node. The ED is used by any node to calculate distance between two nodes by knowing the channel status and the location information.

III. ENERGY COLLABORATION WITH DEMAND DIFFUSION

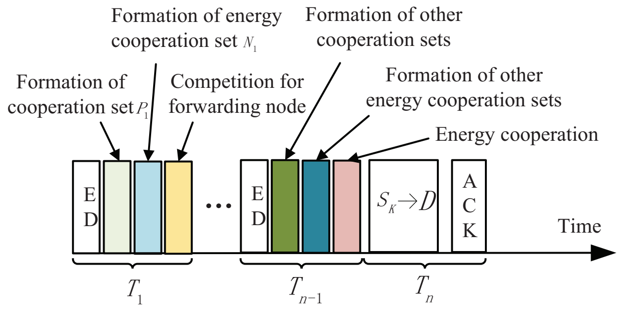
A. Protocol description

In this section, we present our transmission protocol. For the communication process of a sensing nodes, there are three cases for data transmission. As shown in Fig.2, we take the sensing node S_κ as an example, and describe its communication process as follows.

(a) Direct transmission



(b) Energy demand broadcast



(c) Energy demand diffusion

Fig. 2. Communication process of a single sensing node

Case1: direct transmission. S_κ judges whether its energy meets the minimum energy consumption of data transmission before transmission. If its energy is greater than or equal to the required energy, it sends data directly to D and waits for feedback. If an ACK frame returns, as shown in Fig.2(a), it means the data from the current node is successfully received. It is the next node's turn to send data. If a NACK frame feedbacks, S_κ detects its remaining energy. If the energy is greater than or equal to the required energy, the data will be retransmitted. Otherwise, the energy collaboration is triggered.

Case2: energy demand broadcast. When S_κ's energy is less than the required energy, it broadcasts the ED to the nearby at a certain power based on its existing energy. The magnitude of the broadcast power directly affects the number of cooperative nodes. The nodes which get the ED form a collaboration set, called P_1, and the nodes in P_1 that meet energy requirement of S_κ form an energy collaboration set, named N_1. The energy requirement of S_κ and formation of N_1 are shown in Subsection B. If N_1 is non-empty, the nodes in N_1 achieve energy collaboration based on a borrowing and returning mechanism, the mechanism are described in Subsection C. After that, S_κ consumes energy to send data to D. If an ACK frame is received, it means that the data is sent successfully, as shown in Fig.2(b). Otherwise, the data is retransmitted.

Case3: energy demand diffusion. In case 2, when N_1 is empty, it means none of nodes in N_1 satisfy energy requirement of S_κ. Then, the ED need to be diffused with the help of optimal forwarding node to expand finding range of energy collaboration nodes. The determination of optimal forwarding node is described in Subsection B. After diffusion of the ED, the corresponding collaboration set and energy collaboration set are formed. If the energy collaboration set is still empty, diffusion of the ED continues until no node can satisfy energy requirement of S_κ, then an event break is triggered. Otherwise, the nodes in corresponding energy collaboration set achieve energy collaboration based on a borrowing and returning mechanism, the mechanism are described in Subsection C. After that, S_κ consumes energy to send data to D and waits for ACK to reply, as shown in Fig.2(c). If a NACK frame is received, the data is retransmitted.

B. Formation of the energy collaboration set and determination of the optimal forwarding node

1) The Energy collaboration set: The formation of N_1 is similar to subsequent energy collaboration sets, then we use N_1 for further elaboration.

After broadcast of the ED, the nodes that get it form P_1. Any node in P_1 is noted as S_{P_1}. From the ED, location information, channel value $\alpha_{S_\kappa,S_{P_1}}$, actual distance $d_{S_\kappa,S_{P_1}}$ between S_κ and S_{P_1} are known, as well as the minimum required energy $E_{\min\_S_\kappa}(i)$, which meets

$$\begin{aligned} E_{\min\_S_\kappa}(i) = & E_{c\_S_\kappa}(i) + E_{ED\_S_\kappa}(i) - E_{h\_S_\kappa}(i) \\ & - B_{S_\kappa}(i-1) \end{aligned} \tag{1}$$

where $B_{S_K}(i-1)$ is the remaining energy of S_κ in last time slot, $E_{c\_S_\kappa}(i)$, $E_{h\_S_\kappa}(i)$ are transmission consumption and energy collection in current slot, respectively, $E_{ED\_S_\kappa}(i)$ is broadcast consumption of the ED, which can be obtained from the length of ED and transmission power of the node, as shown in equation (5) of [14].

If the energy obtained by the node S_κ satisfies data transmission, the energy requirement for S_κ is expressed as

$$E_{pro\_S_{P_1}}(i) \geq E_{\min\_S_\kappa}(i) \tag{2}$$

where $E_{pro\_S_{P_1}}(i)$ is the energy obtained from S_{P_1}.

According to [15], the energy transferred in time T is

$$E_{pro\_S_{P\,1}}(i) = \frac{\varphi P_{S_{P\,1}}(i) \cdot \left|\alpha_{S_\kappa,S_{P\,1}}\right|^2}{d^m_{S_\kappa,S_{P\,1}}} \cdot T \tag{3}$$

where φ is energy efficiency, m is channel fading factor, T is energy cooperation time, $P_{S_{P_1}}(i)$ is transmission power, $\alpha_{S_\kappa,S_{P_1}}$ and $d_{S_\kappa,S_{P_1}}$ are channel gain and actual distance between S_{P_1} and $S\kappa$, respectively.

The maximum theoretical distance $\widehat{d_{S_\kappa,S_{P_1}}}$ of energy collaboration is obtained from Eq. (1) (2) (3).

$$\widehat{d_{S_\kappa,S_{P_1}}} = \sqrt[m]{\frac{\varphi P_{S_{P_1}}(i) \cdot \left|\alpha_{S_\kappa,S_{P_1}}\right|^2 T}{E_{\min\_S_\kappa}(i)}} \tag{4}$$

if $d_{S_\kappa,S_{P_1}}$ is less than $\widehat{d_{S_\kappa,S_{P_1}}}$, then S_{P_1} join N_1.

2) Optimal forwarding node: when N_1 is empty, none of nodes in N_1 meet energy requirement of S_κ. Then, the ED needs to be diffused. Compared to energy demand broadcast, the diffused node is unsure. And, the choice of the diffused node affects search of energy collaboration nodes. So, in energy demand diffusion, optimal forwarding node should be selected to diffuse the ED to expand search range and increase energy collaboration chance. Optimal forwarding node, named S_r, is determined as follows: all nodes in P_1 set initial value of timers and start them, which satisfy Eq.5. All nodes keep listening until timer value of some node lessens to zero. The node with the smallest initial value of timer competes to be the optimal forwarding node.

$$t_{S_{P\,1-inital}} = \frac{E_{\min\_S_\kappa}(i) - E_{pro\_S_{P\,1}}(i)}{d^m_{S_\kappa,S_{P\,1}}} \tag{5}$$

C. Energy cooperation based on a borrowing and returning mechanism

1) Borrowing and returning mechanism: When any energy collaboration set is non-empty, energy collaboration based on a borrowing and returning mechanism is implemented. For ease of description, energy collaboration sets formed in broadcast or diffusion of the ED are hereafter referred to as N_1. The energy collaboration list is set of the remaining nodes that have achieved energy collaboration with energy-deprived node in previous time slot. The energy value list is set of energy collaboration values between nodes in prior time slot. For any node in N_1, when its energy collaboration list contains S_κ, it forms a borrowing-and-returning set, called BR, otherwise it forms a non-borrowing-and-returning set, named NBR. The borrowing and returning mechanism is described as follows:

When BR is empty, none of nodes in N_1 cooperated with S_κ in prior time slot. All nodes in NBR have identical priority, and some of them are chosen as energy collaboration nodes to transfer energy to S_κ in an energy borrowing method. On the contrary, the nodes in BR query respective energy value table to obtain energy value of prior collaboration with S_κ. Any node in BR is noted as $S_j (j = 1, 2 \ldots J)$, J is the number of these nodes. The energy value of prior collaboration between S_j and S_κ is $E_{coop\_S_j}$, the existing energy of S_j is $E_{own\_S_j}$, which is expressed as

$$E_{own\_S_j} = E_{h\_S_j}(i) + B_{S_j}(i-1) \tag{6}$$

In this condition, the borrowing and returning mechanism is divided into four cases according to energy value, the existing energy of node in BR and the NBR:

Case1: The sum of the energy values meets $\sum_{j=1}^{J} E_{coop\_S_j} \geq E_{\min\_S_\kappa}(i)$ and the existing energy always satisfies $E_{own\_S_j} \geq \frac{E_{coop\_S_j} \cdot d^m_{S_\kappa,S_j}}{\varphi\left|\alpha_{S_\kappa,S_j}\right|^2 T}$. The nodes in BR have the same priority and are all selected as energy cooperation nodes to transfer energy to S_κ in an energy returning method.

Case2: The sum of the energy values meets $\sum_{j=1}^{J} E_{coop\_S_j} \geq E_{\min\_S_\kappa}(i)$ but there is existing energy meets $E_{own\_S_j} < \frac{E_{coop\_S_j} \cdot d^m_{S_\kappa, S_j}}{\varphi \left|\alpha_{S_\kappa, S_j}\right|^2 T}$. The nodes that meet $E_{own\_S_j} \geq \frac{E_{coop\_S_j} d^{\mathrm{m}}_{S_\kappa, S_j}}{\varphi \left|\alpha_{S_\kappa, S_j}\right|^2 T}$ have high priority and are all selected as energy collaboration nodes and transfer energy to S_κ in an energy returning manner. Some of the rest nodes in BR are selected as energy collaboration nodes to transfer energy to S_κ in an energy borrowing manner.

Case3: The sum of the energy values meets $\sum_{j=1}^{J} E_{coop\_S_j} < E_{\min\_S_\kappa}(i)$, and the NBR is non-empty. The nodes in BR have high priority and are all selected as energy collaboration nodes, which transfer energy to S_κ in an energy returning policy. Some of nodes in NBR are selected as energy collaboration nodes to transfer energy to S_κ in an energy borrowing policy.

Case4: The sum of the energy values satisfies $\sum_{j=1}^{J} E_{coop\_S_j} < E_{\min\_S_\kappa}(i)$, but the NBR is empty. The nodes in BR own the same priority, some of them are selected as energy collaboration nodes to transfer energy to S_κ in an energy borrowing way.

After energy collaboration, S_κ finishes data transmission. The nodes involved in energy collaboration process update energy collaboration lists and energy value tables.

2) Energy cooperation strategy: with introduction of the borrowing and returning mechanism, the priority of nodes in N_1 is determined, and various allocations of $E_{\min\_S_\kappa}(i)$ are occurring. Then various energy cooperation strategies are shown as follows.

Case1: energy returning. The final energy transferred to S_κ by nodes in BR is equal to energy previously obtained from it. Any node in BR is noted as S_{br}, whose energy consumption is expressed as

$$E_{share\_S_{br}}(i) = \frac{E_{coop\_S_{br}} d^m_{S_\kappa, S_{br}}}{\varphi \left|\alpha_{S_\kappa, S_{br}}\right|^2 T} \tag{7}$$

Case2: energy borrowing. The sum of energy eventually transferred to S_κ by nodes in BR or NBR is equal to $E_{\min\_S_\kappa}(i)$. The number of nodes in N_1 has an affect on $E_{\min\_S_\kappa}(i)$. Therefore, if there is only one node in N_1, it is chosen as an energy collaboration node regardless of it belongs to BR or NBR, its energy consumption is calculated by replace $E_{coop\_S_{br}}$ with $E_{\min\_S_\kappa}(i)$ in Eq.7. Otherwise, to reduce burden of energy collaboration and ensure transmission reliability of individual nodes in each set, it is necessary to allocate $E_{\min\_S_\kappa}(i)$ reasonably. The allocation problem of $E_{\min\_S_\kappa}(i)$ is shown as

$$\max \sum_{f=1}^{F} \log_2\Big(1 + \frac{\beta_f P_{S_f} \left|\alpha_{S_f, D}\right|^2}{\sigma_N^2}\Big)$$
$$s.t. \quad \begin{cases} \sum_{f=1}^{F} \frac{\varphi(1\text{-}\beta_f) P_{S_f} \left|\alpha_{S_\kappa, S_f}\right|^2}{d^m_{S_\kappa, S_f}} \cdot T \geq E_{\min\_S_\kappa}(i) \\ \widehat{d_{S_\kappa, S_f}} \leq \sqrt[m]{\frac{\varphi P_{S_f}(i) \cdot \left|\alpha_{S_\kappa, S_f}\right|^2 T}{E_{\min\_S_\kappa}(i)}} \\ \beta_f \in (0, 1] \\ \beta_f P_{S_f} \geq E_{ED\_S_f} \end{cases} \tag{8}$$

where S_f is any node in N_1, F is the number of nodes, β_f is power allocation factor, $E_{ED\_S_f}$ is energy consumption of the ED broadcasted by S_f.

From (8), the allocation problem of $E_{\min\_S_\kappa}(i)$ is a convex problem, and it can be solved by general optimization methods. The nodes which meet $\beta \neq 1$ are selected as energy collaboration nodes.

Additionally, in energy demand diffusion, S_r consumes an amount of energy to diffuse the ED. Then it is seen that S_κ borrows some energy from S_r for diffusion. So, energy consumed by S_r to diffuse the ED is also recorded.

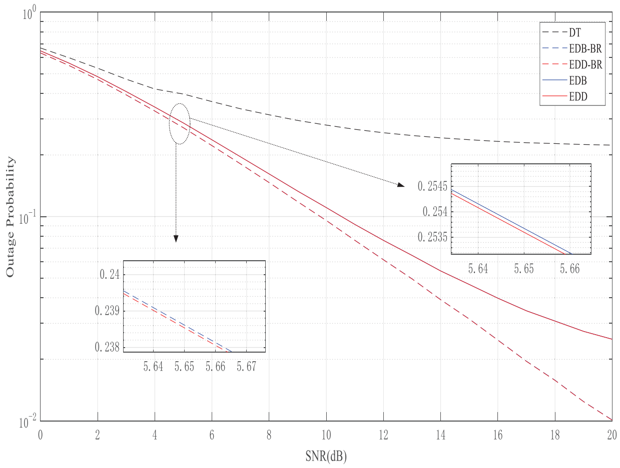
IV. SIMULATION RESULTS

This section verifies the proposed method. The simulation parameters are set as follows: $K = 6$ sensing nodes are randomly distributed in a square area of $A = 2 \times 2$, the coordinates of D is $(2, 2)$. The mean value of channel between nodes is set to 1, and the channel fading coefficient is set to $m = 2.7$. The data transmission rate and energy efficiency are set to $\Omega = 1$bps and $\varphi = 0.2$, respectively. The length of time slot and the number of data transmission rounds are set to $T = 0.001s$ and $I = 100,000$, independently. The energy consumption of each transmission except data transmission, energy demand broadcast or diffusion, energy collaboration is set to 0.

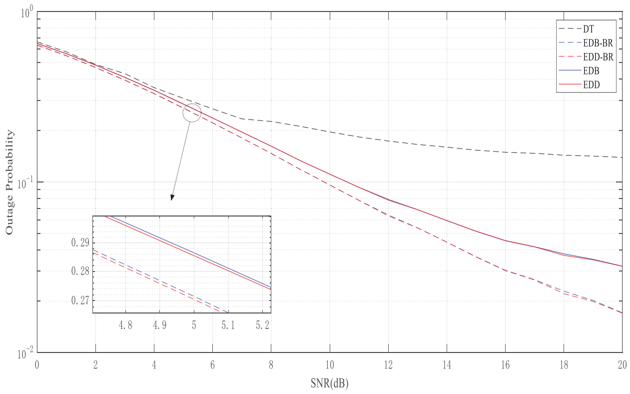
Two typical scenarios for the solar energy collection are considered. One is an uneven energy collection where the average energy collection rate from node 1 to 6 is $7, 7.5, 13, 0.3, 3.2, 1.1$, therefore their solar energy collections are about $1021, 1038, 1362, 33, 123, 112$, respectively. The other is an even but overall smaller energy harvesting, where the average energy collection rate from node 1 to 6 is $5, 1, 4.1, 1.4, 3.2, 2.5$, their solar energy collections are about $30, 13, 28, 20, 25, 23$.

Under above condition, we compare different methods to verifies the feasibility of proposed demand diffusion method and the BR mechanism. These methods include direct transmission (DT) in [16], where there is no energy cooperation between sensor nodes, and energy demand broadcast (EDB) in [12], in which sensor nodes transfer desired energy following minimum energy sharing strategy, and energy demand diffusion (EDD), energy demand broadcast with BR mechanism (EDB-BR), energy demand diffusion with BR mechanism (EDD-BR).

Fig.3 shows the outage probability comparison of the system with various schemes. EDD is effective in reducing the system outage probability compared to DT and EDB. The reason is that EDD further expands range of energy-deprived node to find suitable energy collaboration nodes and increase energy collaboration chance. EDD-BR and EDB-BR result in a lower outage probability than EDD and EDB, because the BR mechanism allows nodes to prioritize energy collaboration, i.e. the nodes previously involved in borrowing are the first to return energy, the energy allocation is reduced for remaining participating nodes which in turn gives the remaining nodes opportunity to take part in energy collaboration with multiple



(a) Outage probability in uneven energy harvesting



(b) Outage probability in even energy collection

Fig. 3. Outage probability under various methods in different solar energy collections

energy-deprived nodes, and helps to reduce the number of transmission interruptions in more nodes.

Tables I, II and III give energy remaining percentage in each node under diverse schemes in above scenarios and reduction percentage in outage probability for various methods compared to DT, respectively. In DT, node is powered by solar energy and there are no extra nodes transferring energy when node collects less energy. So, in uneven energy harvesting, the remaining energy percentage is small for nodes 4, 5, 6. And in even energy harvesting, the residual energy percentage is small for nodes 2, 4, 6.

In different solar energy collections, EDD and EDB allow energy-deprived nodes to achieve energy collaboration with the rest of nodes. So from Table I and II, it can be seen that residual energy percentage for each node in both cases is smaller than the corresponding value of DT. Although EDD makes remaining energy percentage in each node lower than that of EDB, Table III shows reduction percentage in outage probability of EDD is higher than that of EDB. It indicates that EDD improves transmission reliability by sacrificing energy of each node compared to EDB in different solar energy harvestings.

TABLE I
RESIDUAL ENERGY PERCENTAGE IN UNEVEN ENERGY HARVESTING

Node	**1**	**2**	**3**	**4**	**5**	**6**
DT	71.735	76.103	85.396	0.064	4.387	0.128
EDB	1.052	1.295	3.094	0.010	0.108	0.016
EDD	1.008	1.205	2.903	0.005	0.095	0.010
EDB-BR	1.237	1.339	8.962	0	0.062	0
EDD-BR	1.195	1.305	8.156	0	0	0

TABLE II
RESIDUAL ENERGY PERCENTAGE IN EVEN ENERGY HARVESTING

Node	**1**	**2**	**3**	**4**	**5**	**6**
DT	5.971	0.200	5.395	0.352	4.608	2.892
EDB	1.256	0.050	2.714	0.109	1.005	0.709
EDD	0.986	0.025	2.645	0.098	0.901	0.668
EDB-BR	1.795	0	3.899	0.082	1.136	0.521
EDD-BR	1.683	0	3.886	0	1.029	0.518

TABLE III
REDUCTION PERCENTAGE IN OUTAGE PROBABILITY IN DIVERSE COLLECTIONS

	uneven energy harvesting	**even energy harvesting**
EDB	88.774	76.949
EDD	88.885	77.008
EDB-BR	94.483	87.724
EDD-BR	95.493	88.782

In diverse solar energy harvestings, the introduction of the borrowing and returning mechanism allows nodes to have behavior of energy borrowing and returning, that is, the nodes previously involved in borrowing are the first to return energy. This method reduces energy allocation of remaining energy collaboration nodes to energy-deprived nodes, and provides energy support to more energy-deprived nodes. As a result, in Table I and II, the introduction of this mechanism under various solar energy collections always gives an uneven residual energy at each node. In addition, Table III shows that this mechanism further reduces system outage probability based on EDD or EDB, which greatly improves transmission reliability.

In identical strategy, the overall energy difference between nodes in uneven solar energy harvesting is larger than that in even solar energy harvesting. Therefore, in uneven solar energy harvesting, the opportunity for energy collaboration is increased when individual nodes broadcast or diffuse energy demand and utilize the borrowing and returning mechanism, and with the same policy, the reduction percentage in outage

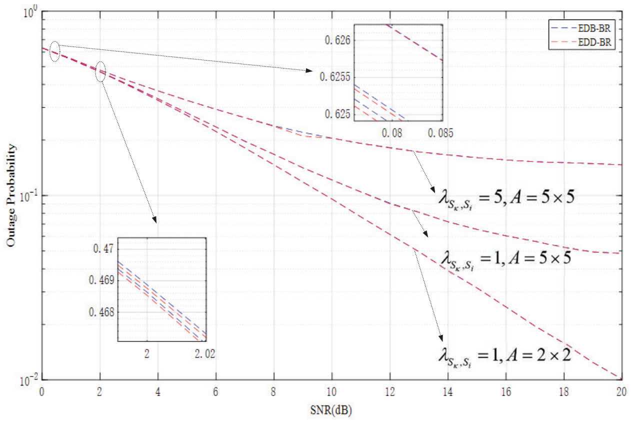


Fig. 4. Outage probability under different parameters in uneven energy harvesting

probability during uneven solar energy harvesting is significantly greater than that in even solar energy harvesting.

To verify the effect of network size and channel state on transmission reliability, the outage probability of various network sizes and channel states in uneven solar energy harvesting are shown in Fig.4.

The network size affects the extent to which sensing nodes are distributed. The larger network size is, the more dispersed distributions of nodes are. As energy-deprived nodes experience energy demand broadcast or diffusion and the borrowing and returning mechanism, the chance of finding suitable energy collaboration nodes decreases, at the same time, some energy-deprived nodes are unable to achieve energy collaboration and cause transmission interruptions. As a result, the overall outage probability increases as enlargement of network size in a given channel state between sensing nodes.

The channel state between nodes is related to the ability of receiving the ED sent by energy-deprived nodes. As λ_{S_κ,S_i} between random sensing nodes increases, the nodes differ in the ability of receiving the ED broadcasted by energy-deprived nodes, and the similarly nodes differ in the ability of receiving the ED diffused by optimal forwarding nodes. Although energy demand broadcast or diffusion expands range of energy-deprived nodes to find suitable energy collaboration nodes, the increase of λ_{S_κ,S_i} causes fewer nodes to receive the ED. And it leads to fewer nodes to meet energy requirement of energy-deprived nodes, then more transmission interruptions occur. Therefore, in a given network size, as λ_{S_κ,S_i} enlarges, the overall outage probability increases.

V. CONCLUSION

To improve transmission reliability of an energy harvesting wireless sensor network, energy collaboration based on a borrowing and returning mechanism with demand diffusion is proposed. When energy-deprived nodes in network are unable to achieve data transmission, energy demand diffusion is used to expand search range of energy collaboration nodes and increase energy collaboration chance. To encourage nodes to participate in energy collaboration, a borrowing and returning mechanism is proposed to prioritize each node and select energy collaboration nodes. Finally, the selected nodes transfer energy to energy-deprived nodes according to a certain strategy. Then energy-deprived nodes complete data transmission successfully. Simulation results verify the effectiveness of the proposed scheme.

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