Hindawi Publishing Corporation
Journal of Sensors
Volume 2014, Article ID 589249, 7 pages
http://dx.doi.org/10.1155/2014/589249

Research Article

Energy Balance Routing Algorithm Based on Virtual MIMO Scheme for Wireless Sensor Networks

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Received 28 October 2013; Revised 16 December 2013; Accepted 17 December 2013; Published 2 January 2014

Academic Editor: Xinyong Dong

Wireless sensor networks are usually energy limited and therefore an energy-efficient routing algorithm is desired for prolonging the network lifetime. In this paper, we propose a new energy balance routing algorithm which has the following three improvements over the conventional LEACH algorithm. Firstly, we propose a new cluster head selection scheme by taking into consideration the remaining energy and the most recent energy consumption of the nodes and the entire network. In this way, the sensor nodes with smaller remaining energy or larger energy consumption will be much less likely to be chosen as cluster heads. Secondly, according to the ratio of remaining energy to distance, cooperative nodes are selected to form virtual MIMO structures. It mitigates the uneven distribution of clusters and the unbalanced energy consumption of the whole network. Thirdly, we construct a comprehensive energy consumption model, which can reflect more realistically the practical energy consumption. Numerical simulations analyze the influences of cooperative node numbers and cluster head node numbers on the network lifetime. It is shown that the energy consumption of the proposed routing algorithm is lower than the conventional LEACH algorithm and for the simulation example the network lifetime is prolonged about 25%.

1. Introduction

Wireless sensor networks (WSNs) typically consist of a large number of energy-constrained sensor nodes with limited onboard battery resources which are difficult to recharge or replace. Thus, the reduction of energy consumption for end-to-end transmission and the maximization of network lifetime have become chief research concerns.

In recent years, many techniques have been proposed for improving the energy efficiency in energy-constrained and distributed WSNs. Among these techniques, the multiple-input multiple-output (MIMO) technique has been considered as one of the effective ways to save energy. The MIMO technique, including various space-time coding schemes, layered space-time architectures, has the potential to enhance channel capacity and reduce transmission energy consumption particularly in fading channels [1–3].

However, constrained by its physical size and limited battery, individual sensor node usually contains only one antenna. The antenna array cannot be implemented in a single sensor node in the radio frequency range. Fortunately, the dense senor nodes can jointly act as a multiantenna array through messages interchange. Numerical results show that if these sensor nodes can be constructed into virtual MIMO systems, in a certain distance range, they may outperform single-input single-output (SISO) systems in energy consumption [4].

In [2], the authors analyze the energy efficiency and delay performance of virtual MIMO technique for a single-hop system. They show that both energy consumption and delay can be reduced within a certain transmission range. In [5], an adaptive data-rate space-time coding (STC) scheme has been proposed for the IEEE 802.11-based Soft-Real-Time WSNs where enhanced distributed channel access (EDCA) is used at medium access control (MAC) layer and MIMO transceivers are used at PHY layer. Considering the cost of training sequence of space-time coding, [6] provides a more precise model of the energy consumption and proves that cooperative MIMO technology in energy-saving is still effective even considering the extra overhead. Reference [7]

proposes a Trustworthy Energy-Efficient MIMO (TEEM) routing algorithm. Game theory is used to elect healthier cluster heads and cooperative nodes. The authors propose BLAST code based on V layered space-time of the cooperative transmission scheme. This scheme does not require the data exchanges and processes. So it has high energy efficiency [1]. Reference [8] focuses on the combination of data fusion and cooperative communication. It optimizes the energy consumption further by eliminating data redundancy between nodes. Reference [9] proposes an energy-efficient cooperative MIMO scheme, which combines energy-efficient LEACH protocol and cooperative MIMO. The algorithm can well balance the network load and prolong the network lifetime. Although virtual MIMO technology is emphasized in WSNs by many researchers because of its outstanding energy saving potentials, there are still a lot of rooms for improvements.

In this paper, based on the virtual MIMO technique, we propose an energy balance routing algorithm which mitigates three shortcomings of the conventional LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol. Firstly, the election probabilities of cluster head node are the same for all eligible nodes in LEACH. To prolong the network lifetime, we propose a new cluster head node selection scheme to balance the energy consumption by accounting for the remaining energy and the last energy consumptions of all sensor nodes. The scheme reduces the chances for the weak sensors to become the cluster heads. Secondly, the SISO structure is used in LEACH where the energy of cluster heads in less favorable locations will drain out quickly. In this paper, the cooperative nodes are selected to form virtual MIMO network structure according to the ratio of remaining energy to distance. The virtual MIMO technique mitigates the uneven distribution of cluster heads and the unbalanced energy consumption. Thirdly, the energy model in LEACH is overly simplified and cannot reflect the true energy consumption in practical WSNs. In this paper, we propose a comprehensive energy consumption model, which considers the energy consumptions for data collection, data fusion, intra-cluster communication, and intercluster communications for MIMO structures. The new model can reflect more realistically the energy consumption of practical WSNs.

The rest of this paper is organized as follows. In Section 2, the system model of WSNs is briefly described. In Section 3, we briefly summarize the conventional LEACH routing algorithm. In Section 4, the improved cluster head selection scheme is presented. In Section 5, we construct virtual MIMO network structure. In Section 6, we construct the proposed energy consumption model. Section 7 shows the numerical analysis. Final conclusion remark is made in Section 8.

2. Network Model of WSNs

Consider a wireless sensor network with N sensor nodes and a sink node. The N sensor nodes will be divided into n clusters (following a certain protocol) for each round of data collection and transmission. All the sensor nodes collect the relevant data and send the collected data to their cluster head nodes. The cluster head nodes will perform data fusion to reduce data redundancy and save transmission energy. Then, the cluster head nodes broadcast the data to the cooperative nodes. Lastly, the cooperative nodes form virtual antenna arrays and transmit the data to sink node in a multihop manner. We abstract the system model as follows [10, 11].

(1) The sink node, located outside of the sensors area, is not energy constraint and is equipped with multiple antennas for cooperative receiving. The number of cooperative nodes is variable.

(2) All sensor nodes, randomly distributed in an M by M meter^2 area, are stationary and time synchronized. They all have enough power to transmit information to the sink node if needed. The nodes can calculate the distance to transmitters according to RSS (received signal strength).

(3) The path loss is inversely proportional to the distance squared. The modulation scheme is BPSK or MQAM for both local and long-haul transmissions.

(4) To simplify the analysis, we ignore the energy consumption of baseband signal processing and assume that communication is in the high SNR regime, in which the Chernoff upper bound can be employed to calculate the required energy per bit at the receiver for a given bit error rate (BER) requirement.

3. LEACH Protocol

The conventional LEACH protocol will be used as a reference and is briefly described in this section.

3.1. Cluster Head Selection in LEACH. At the beginning of each round of data transmission, the cluster head nodes are chosen based on the following probabilistic mechanism. In the rth round, the election probability for the ith node to become a cluster head node is given in LEACH [11, 12] as

$$P(i) = \begin{cases} \dfrac{n}{N - n\,[r \bmod (N/n)]} & \text{if } i \in G \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

where G is the set of nodes that have not been cluster heads in the last $r \bmod (N/n)$ round.

After the n cluster head nodes are chosen, these cluster head nodes will broadcast messages to invite the remaining sensor nodes to join them in order to form the n clusters. Based on the signal strengths of the received broadcasting messages, each remaining sensor node will choose among the n cluster head nodes the one with the strongest signal strength as its cluster head. The information to join a cluster includes node ID, remaining energy, and the distance to cluster head. When all $N - n$ remaining sensor nodes are done with their selections, the n clusters are formed.

After the n clusters are formed, the n cluster head nodes will establish and update the routing table until all cluster head nodes find the optimum path to the sink node.

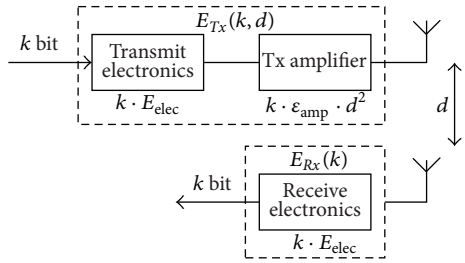

Figure 1: The first order radio model.

3.2. Energy Consumption Model in LEACH. A radio model proposed in LEACH [11] is shown in Figure 1.

The radio dissipates $E_{elec} = 50\,\text{nJ/bit}$ to run the transmitter or receiver circuitry and $\varepsilon_{amp} = 100\,\text{pJ/bit/m}^2$ is a proportional constant for the power consumption in the transmit amplifier. To transmit a k-bit message for a distance d, the radio expends

$$E_{Tx}(k,d) = k \cdot E_{elec} + k \cdot \varepsilon_{amp} \cdot d^2. \tag{2}$$

To receive this message, the radio expends

$$E_{Rx}(k) = k \cdot E_{elec}, \tag{3}$$

$$E_{CH}(i) = \left(\frac{N}{n} - 1\right) E_{Rx}(k) + k\left(\frac{N}{n} - 1\right) E_{DA} + E_{Tx}\left(k, d_{toSINK}(i)\right), \tag{4}$$

where E_{DA} is the energy consumption of data fusion per bit and $d_{toSINK}(i)$ is the distance between the ith ($1 \le i \le n$) cluster head node and sink node. For simplicity and in average senses, $N/n-1$ is assumed to be the number of general nodes (i.e., non-cluster head nodes) in each cluster.

The jth ($1 \le j \le N/n-1$) general node in the ith ($1 \le i \le n$) cluster expends

$$E_{GN}(i,j) = E_{Tx}\left(k, d_{toCH}(i,j)\right), \tag{5}$$

where $d_{toCH}(i,j)$ is the distance between the ith ($1 \le i \le n$) cluster head node and the jth ($1 \le j \le N/n-1$) general node.

Assume each cluster is a circular region and has the same area. The expectation of $d^2_{toCH}(i,j)$ is

$$E\left[d^2_{toCH}(i,j)\right] = \frac{M^2}{2\pi n}. \tag{6}$$

Then each general node expends

$$E_{GN} \approx k \cdot E_{elec} + k \cdot \varepsilon_{amp} \cdot \frac{M^2}{2\pi n}. \tag{7}$$

In each round, all the nodes expend:

$$\begin{aligned} E_{total} &= \sum_{i=1}^{n}\left[E_{CH}(i) + \left(\frac{N}{n} - 1\right) \cdot E_{GN}\right] \\ &\approx (2kN - kn) E_{elec} + kNE_{DA} + kn\varepsilon_{amp}\overline{d^2_{toSINK}(i)} \\ &\quad + k(N-n)\varepsilon_{amp}\left(\frac{M^2}{2\pi n}\right). \end{aligned} \tag{8}$$

By making the derivative of the function E_{total} equal to 0, the optimal value of n_{opt} can be calculated:

$$n_{opt} = \left\lceil \sqrt{\frac{M \cdot N}{2\pi \overline{d^2_{toSINK}}}} \right\rceil, \tag{9}$$

where $\overline{d^2_{toSINK}}$ is the average of $d^2_{toSINK}(i)$ $(i = 1, \ldots, n)$ and $\lceil x \rceil$ denotes the smallest integer which is greater than or equal to the argument x.

4. Improved Leach Protocol

One of the main shortcomings of LEACH is that the election probabilities are the same for all eligible nodes (if $i \in G$ in (1)). Since different sensor nodes may have different remaining energy and energy consumption rate, if some nodes with low remaining energy and/or high energy consumption rates are selected as the cluster heads, they will die quickly. Obviously, the entire cluster cannot communicate if its cluster head dies. Moreover, the lifetime of whole network will be greatly reduced if some nodes die early.

To overcome the abovementioned shortcoming of LEACH, we include the remaining energy and the last energy consumption of the sensor nodes in the election probability for the ith node (after the rth round of data transmissions):

$$P(i) = \begin{cases} \dfrac{n}{N - n\,[r \bmod (N/n)]} \cdot \dfrac{E_{rem}(i)}{E_{a\_rem}} \cdot \dfrac{E_{a\_cons}}{E_{cons}(i)} & \text{if } i \in G \\ 0 & \text{otherwise.} \end{cases} \tag{10}$$

In (10), $E_{rem}(i)$ is the remaining energy of the ith node and E_{a_rem} is the average remaining energy of the whole network after the last round of data transmission. $E_{cons}(i)$ is the energy consumption of the ith node and E_{a_cons} is the average energy consumption of the whole network during the last round of data transmission. In this selection algorithm, the probability to become cluster heads is proportional to the remaining energy of nodes and inversely proportional to the most recent energy consumption. The proposed model is named improved LEACH algorithm (ILEACH).

5. Virtual MIMO Routing Algorithm

The second main shortcomings of the LEACH algorithm are that the cluster heads are chosen somewhat randomly and may not be the best candidates (in terms of energy saving) for transmitting the collected data to the sink node. We therefore use a virtual MIMO routing algorithm to overcome this shortcoming.

5.1. Cooperative Nodes Selection. After the clusters are formed, some nodes will be chosen as cooperative nodes to construct virtual MIMO. The selection criteria [13] are expressed as:

$$\max_{\text{node } i \in \text{cluster}} \frac{E_{rem}(i)}{d_i}, \quad d_{min} \le d_i \le d_{max}, \tag{11}$$

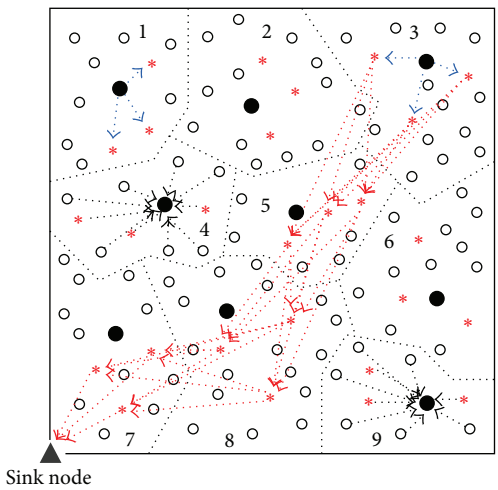

Figure 2: Schematic diagram of data transmission.

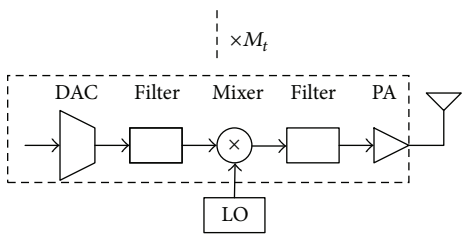

Figure 3: Transmitter circuit blocks.

where $E_{\text{rem}}(i)$ is the node remaining energy. d_i is the distance between the cooperative node and the cluster head node. $d_{\min}$ and $d_{\max}$ are the lower limit and upper limit of d_i.

After the cluster head nodes find the cooperative nodes which satisfy the above criterions, the cluster head nodes will send message to those cooperative nodes and inform them of their roles in the virtual MIMO communication mode. The information contains the ID of the cooperative nodes and their roles in the selected STBC (Space Time Block Code). Then the cluster head nodes begin to assign TDMA slots for all members.

5.2. Data Transmission. Figure 2 is the data transmission schematic diagram of WSNs virtual MIMO, where "▲" represents the sink node, "•" represents the cluster head nodes, "∗" represents the cooperative nodes, and "○" represents the general sensor nodes.

Firstly, each cluster head node broadcasts the request message to its members. All the sensor nodes collect the relevant data and send the collected data to their cluster head nodes in their preassigned time slots. Then the sensor general nodes enter sleep mode to save energy (e.g., shown as cluster-4 and cluster-9). Secondly, the cluster head nodes will perform data fusion to reduce data redundancy and save transmission energy. Then, the cluster head nodes broadcast the data to the cooperative nodes (e.g., shown as cluster-1 and cluster-3). This stage is called the intracluster communication stage. Lastly, the cooperative nodes form virtual antenna array and perform space-time coding

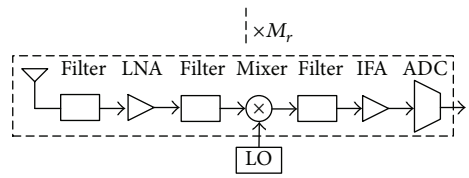

Figure 4: Receiver circuit blocks.

after receiving the data. In accordance with the routing table established previously, the clusters transmit data to the sink node via multihop communication (e.g., shown as cluster-3 → cluster-5 → cluster-8 → cluster-7). This stage is called the intercluster communication stage.

6. Comprehensive Energy Consumption Model

The third main shortcoming of the LEACH algorithm is that its energy consumption model is overly simplified and not practical. Based on some existing models in [2, 12, 14–17], we propose a comprehensive energy consumption model which can reflect the practical energy consumption mechanisms in a more sensible manner.

6.1. Energy Consumption Model between Nodes. References [2, 14] construct the signal paths between the transmitter and receiver, which are shown in Figures 3 and 4, respectively.

M_t and M_r are the numbers of transmitter nodes and receiver nodes, respectively. The power consumption along the transmission path includes the power consumption of the power amplifiers P_{PA} and the power consumption of all other circuit blocks P_C.

P_{PA} is expressed as

$$P_{\text{PA}}(d) = (1+\alpha)\frac{(4\pi)^2 d^{\beta} M_l N_f}{G_t G_r \lambda^2} \times \overline{E_b} R_{\text{bt}}, \tag{12}$$

where α is the effective factor of power amplifier. G_t and G_r are the gains of transmitter antenna and receiver antenna, respectively. λ is the carrier wavelength. M_l is the link margin compensating the hardware variation. N_f is the receiver noise figure defined as $N_f = N_r/N_0$ where N_r is the power spectral density of total effective noise at the receiver input and N_0 is the thermal noise power spectral density. d is the average distance from the nodes to the cluster header. β is the path loss slope; usually $\beta = 2\sim4$. $\overline{E_b}$ is the average required energy per bit at the receiver for a certain BER. $R_{\text{bt}} = bB$ is the bit rate, B is the system bandwidth, and b is modulation grade for MQAM modulation scheme [2, 18].

P_C includes the circuit power consumption at transmitter side $M_t P_{TC}$ and the circuit power consumption at the receiver side $M_r P_{RC}$:

$$P_C = M_t P_{TC} + M_r P_{RC}, \tag{13}$$

with

$$\begin{aligned} P_{TC} &= P_{\text{DAC}} + P_{\text{mix}} + P_{\text{filt}} + P_{\text{syn}}, \\ P_{RC} &= P_{\text{LNA}} + P_{\text{mix}} + P_{\text{IFA}} + P_{\text{filt}} + P_{\text{ADC}} + P_{\text{syn}}, \end{aligned} \tag{14}$$

where P_{DAC}, P_{mix}, P_{filt}, P_{syn}, P_{LNA}, P_{IFA}, and P_{ADC} are the power consumption values for the digital to analog converter, the mixer, the filters, the frequency synthesizer, the low-noise amplifier, the intermediate frequency amplifier and the analog to digital converter, respectively.

So the energy consumption per bit for transmission and reception between the nodes can be expressed as

$$E_{\mathrm{btr}}(d) = \frac{P_{\mathrm{PA}}(d) + P_C}{R_{\mathrm{bt}}} = \frac{P_{\mathrm{PA}}(d) + M_t P_{TC} + M_r P_{RC}}{R_{\mathrm{bt}}}. \quad (15)$$

6.2. Energy Consumption Model in Local Cluster. The intra-cluster communication uses single transmit antenna and is based on BPSK modulation (i.e., $b = 1$). Let its BER be denoted as $\overline{P_b}$. The average energy per bit received correctly is expressed as [12, 15]

$$\overline{E_b}^{\mathrm{SI}} = \frac{N_0}{\left(1 - 2\overline{P_b}\right)^{-2} - 1} \quad (16)$$

which represents the $\overline{E_b}$ in (12) and the superscript SI represents single input (i.e., single transmit antenna). Substitute (16) into (12) and then substitute (12) into (15). Set $M_t = 1$ and $b = 1$. Then, the energy consumption of intra-cluster communication per bit can be expressed as

$$E_{\mathrm{btr}}^{\mathrm{SI}}(d) = E_{\mathrm{btr}}(d)\big|_{M_t=1 \text{ and } \overline{E}_b=\overline{E}_b^{\mathrm{SI}}}. \quad (17)$$

With (17), we are ready to evaluate energy consumption for data collection, data fusion, and data broadcasting in a local cluster.

6.2.1. Energy Consumption for Data Collection. Each sensor node needs to collect k bits and send them to the corresponding cluster head node in each period. The number of nodes of cluster $i (i = 1, \ldots, n)$ is n_i. The distance between the cluster head cluster i and the intra-cluster node j is $d_{\mathrm{toCH}}(i, j)$. So the data collecting energy consumption can be expressed as [12]

$$E_{\mathrm{collect}}(i) = k \sum_{j=1}^{n_i - 1} E_{\mathrm{btr}}^{\mathrm{SI}}\left(d_{\mathrm{toCH}}(i, j)\right)\big|_{M_r=1}, \quad (18)$$

where $E_{\mathrm{btr}}^{\mathrm{SI}}$ is given in (17).

6.2.2. Energy Consumption of Data Fusion. The ith cluster head node will receive data $k(n_i - 1)$ bits in each round. Assume E_{DA} is the energy consumption for data fusion per bit [16]. Then the energy consumption of data fusion is expressed as

$$E_{\mathrm{fus}}(i) = E_{\mathrm{DA}} k (n_i - 1). \quad (19)$$

The data length after data fusion for cluster head node is expressed as

$$k_f(i) = \frac{k \cdot (n_i - 1)}{f_{\mathrm{agg}}(n_i - 1) - f_{\mathrm{agg}} + 1}, \quad (20)$$

where $f_{\mathrm{agg}} \in (0, 1)$ is the data fusion factor [19].

6.2.3. Energy Consumption of Intracluster Communication. The cluster head node i broadcasts $k_f(i)$ bits to N_c cooperative nodes. In order to ensure that all the nodes in the cluster can receive data, choose the maximum distance between the cluster head node i and the cooperative nodes:

$$d_{\mathrm{toCN}}(i) = \max\left\{d_{\mathrm{toCH}}(i, j) \mid j \in S_{\mathrm{coop}}(i)\right\}, \quad (21)$$

where the set $S_{\mathrm{coop}}(i)$ consists of the indexes of all cooperative nodes. The energy consumption of intra-cluster is then expressed as [12]:

$$E_{\mathrm{broadcast}}(i) = k_f(i) E_{\mathrm{btr}}^{\mathrm{SI}}\left(d_{\mathrm{toCN}}(i)\right)\big|_{M_r=N_c}, \quad (22)$$

where k_f is given in (20) and $E_{\mathrm{btr}}^{\mathrm{SI}}$ is given in (17).

6.3. Energy Consumption Model between Different Clusters. The intercluster communication uses MIMO technology. When the BER is less than $\overline{P_b}$, the needed energy per bit is $\overline{E_b}^{\mathrm{MI}}$:

$$\overline{E_b}^{\mathrm{MI}} = \frac{2}{3}\left(\frac{\overline{P_b}}{4}\right)^{1/M_t} \frac{2^b - 1}{b^{1/M_t + 1}} M_t N_0, \quad (23)$$

where the superscript MI stands for multiple inputs (i.e., multiple transmit antennas). Then the energy consumption of cooperative communication between clusters is [15, 17]

$$E_{\mathrm{btr}}^{\mathrm{MI}}(d) = \frac{R_{\mathrm{bt}}^{\mathrm{eff}}}{R_{\mathrm{bt}}}\left[E_{\mathrm{btr}}(d)\big|_{\overline{E}_b=\overline{E}_b^{\mathrm{MI}}}\right], \quad (24)$$

where $R_{\mathrm{bt}}^{\mathrm{eff}}$ is the effective bit rate of the system, which is expressed as [12, 15, 20]

$$R_{\mathrm{bt}}^{\mathrm{eff}} = \frac{(F - pM_t)}{F} \cdot R \cdot R_{\mathrm{bt}}, \quad (25)$$

where F is the block size of STBC and in each block p is the training overhead factor. R is the transmission rate.

Assume the data of cluster i are transmitted $h_i (h_i \geq 1)$ times to arrive at the sink node. The distance of each hop is $d_{\mathrm{hop}}(i, k)$, $i = 1 \cdots h_i$. So the multihop forwarding energy consumption can be expressed as:

$$E_{\mathrm{mhop}}(i) = k_f(i)\left[E_{\mathrm{btr}}^{\mathrm{MI}}\left(d_{\mathrm{hop}}(i, h_i)\right)\big|_{M_t=N_c, M_r=1} + \sum_{k=1}^{h_i - 1} E_{\mathrm{btr}}^{\mathrm{MI}}\left(d_{\mathrm{hop}}(i, k)\right)\big|_{M_t=M_r=N_c}\right], \quad (26)$$

where $E_{\mathrm{btr}}^{\mathrm{MI}}$ is in (24).

6.4. Total Energy Consumption Model. Using (18), (19), (22), and (26), the total energy consumption per round is expressed as

$$E_{\mathrm{total}} = \sum_{i=1}^{n}\left[E_{\mathrm{collect}}(i) + E_{\mathrm{fus}}(i) + E_{\mathrm{broadcast}}(i) + E_{\mathrm{mhop}}(i)\right]; \quad (27)$$

here, the exchanges of short signaling messages are not included.

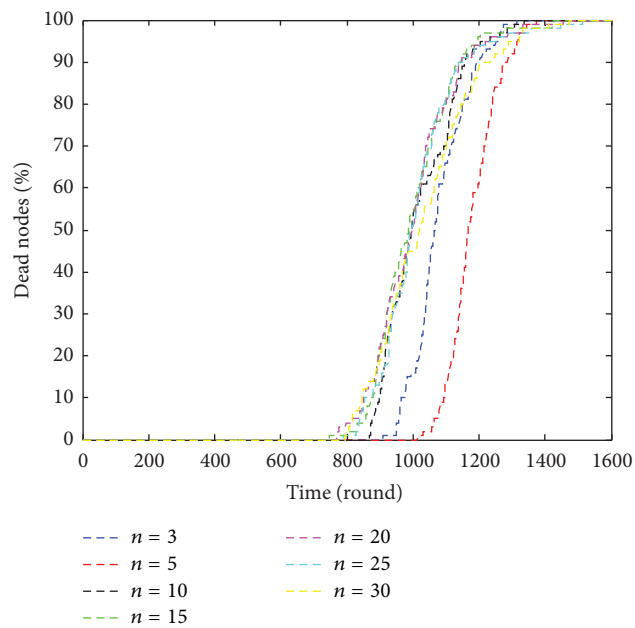

Figure 5: The influence of cluster head node numbers on network lifetime.

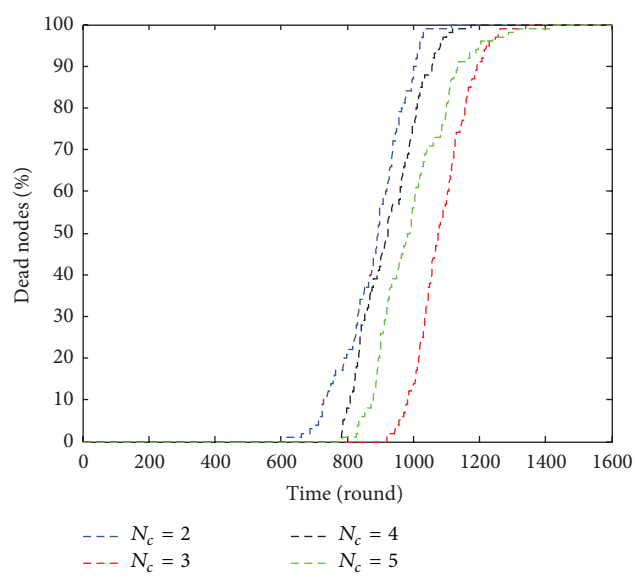

Figure 6: The influence of cooperative node numbers on network lifetime.

7. Numerical Analysis

In Matlab7.0, we distribute randomly 100 nodes (i.e., $N = 100$) in the area of $100 \times 100\,\text{m}^2$ (i.e., $M = 100$ m in (6)). The initial energies of all the sensor nodes are equal and are 100 J. The $k = 2000$ bits, $\varepsilon_{\text{amp}} = 100\,\text{pJ/bit/m}^2$, $E_{\text{elec}} = 50\,\text{nJ/bit}$, and $E_{\text{DA}} = 20\,\text{nJ/bit}$ in (2) and (3). $n_{\text{opt}} = 5$, which can be calculated by (9) in the conventional LEACH model.

The $d_{\min}$, $d_{\max}$ in (11) are 1 m and 50 m, respectively, for new cluster head selection scheme. In (12), $\alpha = 0.47$, $\lambda = 0.12$ m, $G_t G_r = 5$ dBi, $N_f = 10$ dB, $M_l = 40$ dB, $\overline{E_b} = 5$ nJ/bit, $\beta = 2$, and $R_{\text{bt}} = bB$, where $B = 10$ kHz and $b = 1$. In (14), $P_{\text{LNA}} = 20$ mW, $P_{\text{syn}} = 50$ mW, $P_{\text{filt}} = 2.5$ mW, $P_{\text{mix}} = 30.3$ mW, $P_{\text{ADC}} = 10$ mW, $P_{\text{DAC}} = 10$ mW, and $P_{\text{IFA}} = 20$ mW. In (16) $\overline{P_b} = 10^{-3}$, $N_0 = -171$ dBm/Hz. In (20) $f_{\text{agg}} = 0.7$. In (25) $F = 200$, $p = 2$, and $R = 0.75$ [2, 12, 17, 20].

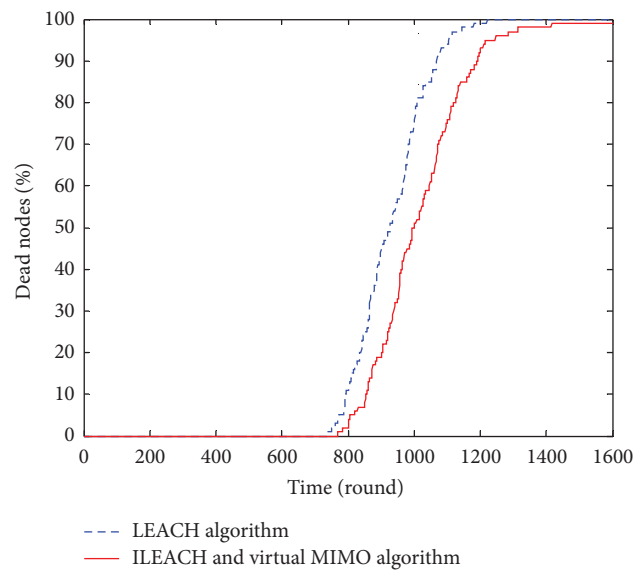

Figure 7: Energy consumption of the conventional and proposed algorithm.

Figure 5 shows the influence on the network lifetime caused by changing the number of cluster head nodes in the proposed algorithm. The horizontal axis represents the number of data transmission rounds. The vertical axis represents the percentage of dead nodes at the end of each data transmission round. We find from this simulation that, when the number of cluster head nodes $n = 5$, the maximum network lifetime is obtained. The simulation result is consistent with the optimal number n_{opt} of cluster head calculated using (9).

Figure 6 shows the influence on the network lifetime caused by changing the number of cooperative nodes in the proposed algorithm. We find from this simulation that, when the number of cooperative nodes $N_c = 3$, the maximum network lifetime is obtained. With the increase of the cooperative nodes, the lifetime of the network decreases slightly.

Using the energy consumption model shown in (27), Figure 7 shows the energy consumption of the conventional LEACH routing algorithm and the proposed routing algorithm based on ILEACH and virtual MIMO. The proposed algorithm can prolong the network lifetime about 25% than the conventional algorithm.

8. Conclusion

The paper proposes a novel practical energy model and an improved energy balance routing algorithm based on the virtual MIMO technique. The proposed algorithm has three improvements over the conventional LEACH routing

algorithm. Firstly, the proposed comprehensive energy model represents better the true energy consumption mechanisms of practical WSNs. Secondly, the proposed cluster head selection scheme makes better selections of cluster heads to balance the energy consumption among different sensors nodes. Lastly, the proposed virtual MIMO structure mitigates the uneven cluster head distributions. Numerical simulations demonstrate that our proposed approach is effective in reducing the energy consumption and therefore prolonging the network lifetime.

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Acknowledgments

The work in this paper was partly supported by the National Natural Science Foundation of China (no. 51077010), China Scholarship Council (no. 2012-3043), Educational Department of Jilin Province (2009-101), and Innovation Foundation of Northeast Dianli University.

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