Smart Computing Review

A Smart Energy-efficiency Deployment Scheme for Lifetime Enhancement in Large-scale Wireless Sensor Networks

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Abstract*:* The exploitation of an energy-efficiency deployment scheme for green wireless sensor networks (WSNs) is a challenging issue since WSNs have become more complex and have achieved a larger scale. Meanwhile, most of the current deployment schemes cannot be transferred directly into complex networks. Therefore, this paper presents a deployment scheme to address this question and achieve green, networked WSNs. First, a hierarchical structure is proposed to deploy WSNs generally. Then, based on this structure, an energy optimization problem is constructed to realize green WSNs. Next, the question is solved by an optimal path and minimal energy consumption algorithm (OPMECA). Extensive simulations demonstrate that our energy-efficiency deployment scheme is applicable to green WSN deployment through the network lifetime and energy consumption in comparison with other algorithms.

Keywords: Deployment, Energy-Efficiency, Lifetime, Green, Wireless Sensor Networks (WSNs)

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Introduction

In the past three decades, striking developments have occurred in communications and networking technologies, which have yielded many information network architectures. One of the most promising networking paradigms, the Internet of Things (IoT), bridges the gap between cyberspace and the physical world. Thus, the IoT is emerging as the major trend in shaping the development of the next generation of information networks [1-3]. It consists of low-cost information-gathering and information-dissemination devices, such as radio frequency identification (RFID) tags, sensor nodes, actuators, mobile phones, etc., the IoT facilitates fast-paced interactions among the objects themselves as well as between objects and persons, any place, any time, through wired and wireless networks on the Internet. To cope with many of the challenges individuals and organizations face in their everyday lives, the IoT will usher in a wide range of smart applications and services, e.g., remote healthcare monitoring systems, intelligent transportation systems, smart distribution systems, tagged objects and so on.

The above applications could dramatically change the way our societies function, and thus, will have a significant impact on many aspects of people's lives in the next few years. However, the research into the IoT is still in its infancy and there are still a lot of challenges that need to be addressed before realization of the IoT [4]. The deployment of wireless sensor networks (WSNs) is one challenge to be addressed urgently in the IoT, where WSNs achieve a larger scale and become more complex [1]. This means the current deployment schemes will not be applied in the IoT directly. Since large-scale networks include more objects and consume greater power, the construction of green WSNs should also be taken into account. Green networking includes reducing operational costs and power consumption, exploiting environmental conservation and surveillance, and so forth [5-6]. Therefore, the research focus of this paper is to cost-effectively realize green deployment of WSNs.

There are four categories for topological structures in large-scale WSNs: plane, mesh, hierarchy and hybrid. The corresponding deployment schemes are ad hoc, exact, hierarchy and hierarchy+ad hoc, respectively [7-10]. Although the ad hoc scheme is widely adopted in many practical WSN scenarios, such as healthcare and battlefield surveillance [7], the nodes around a sink node most often run out of energy, which shorten network lifetime. Networks deployed with the exact scheme [8] also have a limited lifetime for the same reason as the ad hoc scheme. Therefore, these two schemes would not be fit for large-scale WSN deployment. The hierarchy scheme [9] deploys nodes in a tiered framework, and assumes that sensor nodes (SNs) are only permitted to communicate with a relay node (RN) or base station (BS). But there is no direct communication between the neighbor nodes. So, we can improve routing efficiency dramatically to increase network scalability and extensibility. The hierarchy+ad hoc scheme is similar to the hierarchy scheme, although it allows SNs in the lower layer to communicate directly with their neighbor nodes [10]. This deployment scheme has better functionality in transmitting data. However, it suffers from the same problem as the previous two schemes, and SNs need to be equipped with more complex chips. In this paper, a hierarchy deployment scheme is proposed for green WSNs, and we compare it with the hybrid structure in the experiments.

Research into energy savings in WSNs has attracted a lot of interest. There are various energy-efficient strategies [11-12], which cannot be used for large-scale WSNs directly. The reasons are as follows. In a larger-scale WSN, data collection, processing and transmission must be much more effective and efficient. To solve the new energy-saving problem in WSNs, we have come up with a comprehensive but simple and efficient, optimization model, and address it through the optimal path and minimal energy consumption algorithm (OPMECA) presented in the fourth section. The OPMECA seeks the best node-deployment solution to reduce system energy consumption and prolong network lifetime at the same time, which differs from the previous studies into energy savings in WSNs.

The remainder of this paper is organized as follows. The second section introduces works related to this paper, and the third section presents a novel deployment structure for placing network elements in WSNs. By investigating a cost-effective solution to arrange objects forming a green networked WSN, we formulate the deployment as an optimization problem in the fourth section, and solve it through the minimal energy consumption algorithm—OPMECA. In the fifth section, the experimental results evaluate the performance of the proposed structure and algorithm. The sixth section concludes this paper.

Related Works

The term “*Internet of Things*” was coined more than 10 years ago by the Auto-ID Labs in the United States (http://www.autoidlabs.org/) where, in parallel, the concepts of “*ambient intelligence*” and “*ubiquitous computing*” were also developed. Since then, there have been some considerable developments, in both academia and industry, in the US as well as in Europe and Asia. Such developments have primarily been dedicated to applying RFID technology to the logistics value chain [13]. Beyond this, sensor networks have been applied in numerous industrial environments for process monitoring [14]. Energy in all its phases (harvesting, conservation and consumption) is a major issue, not only in the IoT area, but for society at large. The development of novel solutions that maximize energy efficiency is paramount. In this respect, current technology is inadequate, and existing processing power and energy capacity are too low to cope with future needs.

Recent studies and deployment strategies [15, 16] of wireless structural health monitoring (SHM) have demonstrated the feasibility of autonomous and continuous structural data collection using a WSN, which is inexpensive and more efficient compared to its wired counterpart. In parallel, the advancement brings some challenges with its implementation. Differing from traditional networks, a WSN achieves a larger scale and becomes more complex. It turns out that the current deployment schemes cannot be reused directly in larger-scale WSNs. In addition, since the IoT would connect more objects and consume more power, green issues should also be taken into consideration while placing more “things” in the IoT. Green networking plays a vital role in deployment strategies—they can reduce emissions and pollution, exploit environmental conservation and surveillance, and minimize operational costs and power consumption. Therefore, how to cost-effectively realize green deployment for larger-scale WSNs has become a crucial problem, which is the focus of this research paper.

Galčík et al. [17] pointed out that the notion of energy-balanced (or load-balanced) routing in the networking community is a well-researched problem and was proven to be NP-hard. Chang [18] presented the Energy-aware, Cluster-based Routing Algorithm (ECRA) for wireless sensor networks in order to maximize a network’s lifetime. ECRA selects some nodes as cluster heads to construct Voronoi diagrams and rotates the cluster heads to balance the load in each cluster. A two-tier architecture (ECRA-2T) was also proposed to enhance the performance of ECRA. Mei and Stefa [19] considered security-related and energy-efficiency issues in multi-hop wireless networks. They proposed a new routing mechanism that transforms any shortest path routing protocol (or approximated versions of it) into a new protocol that does not create congested areas, does not have the associated security-related issues, and does not encourage selfish positioning. Spencer and colleagues [20] developed algorithms to employ decentralized approaches in a software framework. Always using the lowest energy paths may not be optimal from the point of view of network lifetime and long-term connectivity. Shah and Rabaey [11] proposed a technique to occasionally use sub-optimal routing paths to provide substantial gains. A node-centric load-balancing scheme [21] was presented by Podolski and Rettberg, who considered the Chebyshev sum metric to evaluate the quality of the routing algorithm. Chatterjee and Das [22] presented a distributed scheme in the context of data gathering, where nodes are organized into layers and each node selects a parent from its one-hop neighborhood, such that the maximum load stays below a certain threshold.

This paper presents a hierarchical framework for placing sensor nodes in larger-scale WSNs. Through such tiered framework, it is easy to see that the scale feature of WSNs can be captured so as to enable WSN extensibility. For green WSN deployment, the proposed general hierarchical framework has important research significance. In this WSN framework, we first modeled a green WSN by considering energy consumption, load balance, and system budget as an optimization problem. Then, a minimal energy consumption algorithm was proposed, which leverages the network routing principle to solve the above optimization problem. Finally, the simulation results demonstrate that the proposed model and algorithm are flexible and energy-efficient for WSN deployment. So, our proposed algorithm makes a WSN deployment a green one.

System Framework

In this section, we describe our framework’s network model, the hierarchy structure for the WSN, and the communications model used in this paper.

Generally, a large number of wireless networked objects located over a wide area constitute a WSN. Thus, the WSN has a larger scale and a more complex networking scenario than a regular network [23]. There are many factors influencing sensor node data collection, transmission and processing for large-scale WSNs in wide area outdoor environments, i.e., temperature, humidity, electromagnetic interference, and so on. According to the WSN design principle, we present a three-layered hierarchical architecture for WSN deployment in this paper, which places nodes in a tier network framework.

Fig. 1 shows a system framework for WSN deployment that maximizes the integrated network usability and minimizes its deployment cost. The upper layer (Layer 1: the convergence layer) consists of several BSs that contain a sustainable energy supply and connect to the Internet. RNs are located in the middle layer (Layer 2: relay layer), and SNs are in the lower layer (Layer 3: sensing layer) which is used for placing objects and things (e.g., RFID tags). Both the energy and communication ranges of an RN are larger than those of an SN. We assume that SNs only communicate with the middle or upper layer, and that two neighbor RNs can communicate with each other. A detailed planning chart of the deployment architecture is shown in Fig. 1.

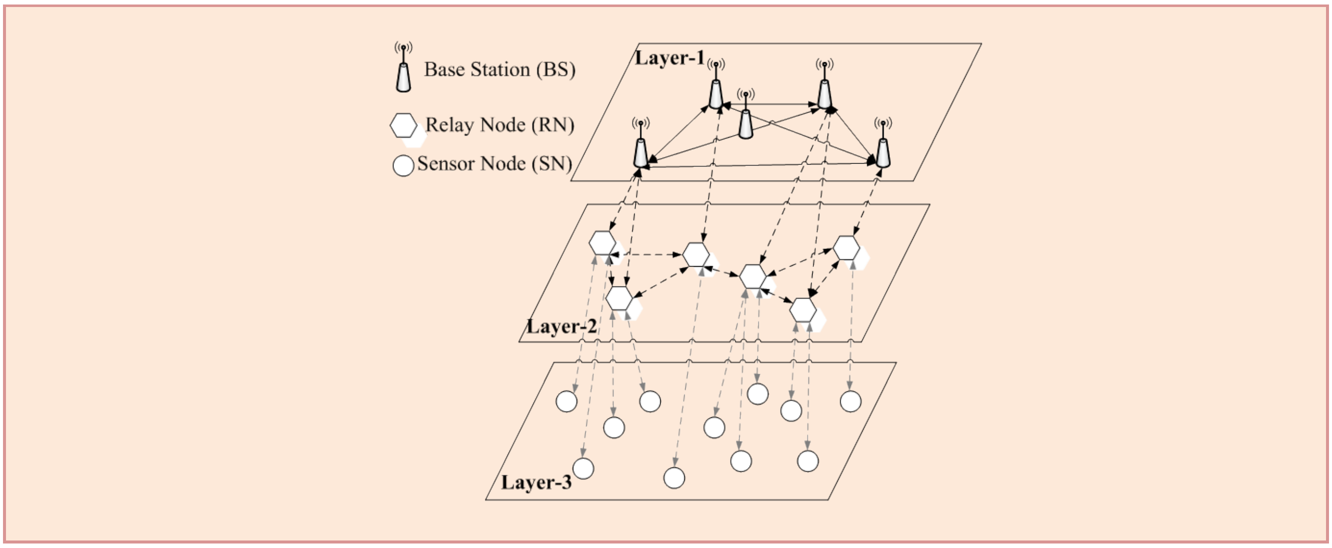

Figure 1. System structure for WSN deployment

In Fig. 1, RNs are assumed to consist of RFID readers and advanced processing and communications units to aggregate the received data collected by SNs, and then to relay the data to a BS. Several BSs interconnect to form a network, which further uploads data to the Internet. This architecture aims toward controlling the cost factor by distributing the sensing and relaying loads over the components of integrated networks in an optimum fashion.

With the purposes of energy savings and link-load balancing, we formulate the communication model as follows. Let $a(x_1, y_1)$ and $b(x_2, y_2)$ be the two points in Euclidean plane-xoy; let $d(a,b)$ be the distance between a and b, and let $r_1 > 0$ and $r_2 > 0$ be the communication ranges of SNs and RNs, respectively, with $r_2 > r_1$. We denote S, R and B as the sets of s SNs, r RNs and b BSs. Then, we have

$$\begin{cases} no\ communication \quad a \in S \ and \ b \in S; \\ a \to b \quad a \in S, b \in R \cup B \ and \ d(a,b) \le r_1; \\ a \to b \quad a \in R, b \in R \cup B \ and \ d(a,b) \le r_2. \end{cases} \tag{1}$$

In this work, we provide a general deployment scheme that can be applied in various application scenarios, not limited to any specific technical implementation, such as healthcare, environmental monitoring and industrial control. Note that the hierarchical deployment scheme proposed in this paper could promote scalability, increase manageability, and achieve flexibility. Because equipment does not need to run complex routing mechanisms in WSNs, they do not require sophisticated hardware, which reduces the network cost significantly.

Optimization Model of Green WSN

In order to address the new challenges of energy savings in WSNs, this paper presents a comprehensive, efficient, and simple optimization model, which differs from the previous studies of WSNs. In this section, we first give definitions and assumptions used in the paper; then, based on the above system framework, we model the WSN with green requirements as an energy optimization problem, and solve it with the proposed algorithm.

Now, we first give the following assumptions for the system framework. The whole network, WSN $G(N,L)$, is connected; namely, each SN in Layer 3 has a path to a BS, and so does each RN. N and L represent the node set and wireless link set. None of the nodes placed in the framework of the WSN move; i.e., they are at a fixed site. Nodes of the same type have the same attributes, including initial energy, energy consumption parameters, and so on.

■ An Optimization Model for Green WSN Deployment

From the assumptions, a SN can only communicate with an RN, whereas an RN can send/receive data both to/from its neighbor relay nodes as well as to a BS; therefore, WSN $G(N,L)$ is a directed and connected graph. If i and j are able to communicate with each other, they are called neighbor nodes. Let $N(i)$ be the set of i's neighbors, and if A is the adjacency matrix of $G(N,L)$, then

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1|N|} \\ a_{21} & a_{22} & \cdots & a_{2|N|} \\ \vdots & \vdots & \ddots & \vdots \\ a_{|N|1} & a_{|N|2} & \cdots & a_{|N||N|} \end{bmatrix} \tag{2}$$

To address the green WSN's requirements, we consider the following system constraints.

1) Energy Consumption Constraints: The energy consumption of WSNs mainly comes from data sensing, processing and communications. We adopt the following energy consumption model [24] in this paper,

$$\begin{cases} E_{Tx}(l,d) = l(E_{elec} + \varepsilon_{fs} d^2),\ d \le d_0; \\ E_{Tx}(l,d) = l(E_{elec} + \varepsilon_{amp} d^4),\ d > d_0. \end{cases} \tag{3}$$

$$E_{Rx}(l) = lE_{elec} \tag{4}$$

where $E_{Tx}(l,d)$ is the energy consumption of l bits of data transmission between nodes, and E_{elec} is the energy consumption of radio electronics. If transmission distance d is less than the given threshold d_0, the power amplifier loss adopts the free space model; if transmission distance d is greater than threshold d_0, the power amplifier loss adopts the multipath attenuation model. ε_{fs} and ε_{amp} are the needed energy of the power amplifier in the two models, respectively.

From (3) and (4), the data from node i to node j in one time unit is equal to the data rate from i to j. Therefore, according to the free space model, the energy consumption per time unit of each type of node can be calculated as follows:

$$E_S = \sum_{i \in S} E_{elec}^S l + \sum_{i \in S} \sum_{j \in R} a_{ij} f_{ij} l (E_{elec}^S + \varepsilon_1 d_{ij}^2) \tag{5}$$

$$E_R = \sum_{i \in S \cup R} \sum_{j \in R} a_{ij} f_{ij} l E_{elec}^R + \sum_{k \in B \cup R} \sum_{j \in R} a_{jk} f_{jk} l (E_{elec}^R + \varepsilon_2 d_{jk}^2) \tag{6}$$

$$E_B = \sum_{j \in R} \sum_{k \in B} a_{jk} f_{jk} E_{elec}^B l \tag{7}$$

where E_S, E_R and E_B denote the energy consumption of SNs, RNs, and BSs, respectively and E_{elec}^S, E_{elec}^R and E_{elec}^B are the corresponding energy consumptions. f_{ij} denotes the data rate of node i sending data to node j.

Likewise, according to the multipath attenuation model, we have

$$E_S = \sum_{i \in S} E_{elec}^S l + \sum_{i \in S} \sum_{j \in R} a_{ij} f_{ij} l (E_{elec}^S + \varepsilon_1 d_{ij}^4) \tag{8}$$

$$E_R = \sum_{i \in S \cup R} \sum_{j \in R} a_{ij} f_{ij} l E_{elec}^R + \sum_{k \in B \cup R} \sum_{j \in R} a_{jk} f_{jk} l (E_{elec}^R + \varepsilon_2 d_{jk}^4) \tag{9}$$

$$E_B = \sum_{j \in R} \sum_{k \in B} a_{jk} f_{jk} E_{elec}^B l \tag{10}$$

2) Link Flow Balancing Constraints: BSs interconnected by wired links have more bandwidth compared with RNs and SNs in the WSN. Hence, we assume the bandwidth is constrained at SNs and RNs, but not at BSs. An RN could communicate with its neighbor RNs or SNs. Therefore, the wireless links of a RN should meet the following criteria:

$$a_{ij} f_{ij} + a_{jk} f_{jk} \le f_{\max},\ i \in S,\ j,k \in R \tag{11}$$

Similarly, the wireless links at each SN and BS need to satisfy

$$a_{ij} f_{ij} \le f_{\max},\ i \in S,\ j \in R \ or\ i \in R,\ j \in B \tag{12}$$

From the analysis, we deduce that RNs undertake most of the network load to deploy a relay layer between the sensing and convergence layers. Because of relatively strong performance, the relay layer could balance the link flows of our proposed deployment scheme.

3) System Budget Constraint: In consideration of the comparatively expensive cost of RNs and BSs, the deployment of a WSN must be as cheap as possible. On the other hand, the number of BSs is fixed, so consequently, the system budget constraint is

$$0 < H_S s + H_R r < H \tag{13}$$

where H_S and H_R are the monetary costs of sensor nodes, and relay nodes, respectively, and H is the system budget. s, r and b denote the cardinality of set S, R and B, respectively. Generally, $b = 1$ means there is one Base Station in the network.

The goal of deploying a green networked WSN is to determine the number and location of RNs while satisfying energy-saving and budget constraints. With the above system constraints, we are now ready to present the optimization model for green WSN deployment. The main purpose of this paper is to reduce energy consumption to achieve a green WSN. Hence, the optimization model for green WSN deployment is defined as follows:

$$\begin{aligned}
&\min(E_S + E_R + E_B)\\
&s.t.\ E_S = \sum_{i\in S} E^S_{elec} l + \sum_{i\in S}\sum_{j\in R} a_{ij} f_{ij} l (E^S_{elec} + \varepsilon_1 d^m_{ij}),\\
&\quad E_R = \sum_{i\in S\cup R}\sum_{j\in R} a_{ij} f_{ij} l E^R_{elec} + \sum_{k\in B\cup R}\sum_{j\in R} a_{jk} f_{jk} l (E^R_{elec} + \varepsilon_2 d^m_{jk}),\\
&\quad E_B = \sum_{j\in R}\sum_{k\in B} a_{jk} f_{jk} E^B_{elec} l,\\
&\quad a_{ij} f_{ij} + a_{jk} f_{jk} \le f_{\max},\ i \in S,\ j,k \in R,\\
&\quad a_{ij} f_{ij} \le f_{\max},\ i \in S,\ j \in R \ or\ i \in R,\ j \in B,\\
&\quad 0 < H_S s + H_R r < H,\ \ m = 2\, or\, 4.
\end{aligned} \tag{14}$$

Problem (14) is NP-hard, and the reason is as follows. As a general practice, we map the consumption energy for the node pair to a weight on each edge. In consequence, this problem of finding the minimum energy consumption for the entire system becomes a Steiner tree problem that is NP-hard. In this tree structure, BSs and partial RNs are the destinations, and the remainder nodes are Steiner points.

■ A Minimal Energy Consumption Algorithm

In this section, we exploit a heuristic algorithm to solve problem (14). SNs are deployed in a large-scale network, and the network topology is unknown to each node. But nodes can achieve their own locations with a positioning function. The nodes (SNs and RNs) communicate only with the surrounding neighbor RNs, and exchange information with them. The core idea of this proposed algorithm is to select the RNs closest to the destination node as the next RNs. Therefore, it is a kind of greedy algorithm, in which the chosen node or path to join the multicast tree would every time bring the multicast tree closer to the destination node.

First, the nodes find a destination node via flooding broadcast and return the location information of the destination node. The multicast tree construction starts from the source node to find the optimal topology tree, and the final destination is the BS. The proposed algorithm first generates a destination node list and calculates the distance between the current node and the destination node. The nodes exchange data with the neighbor RNs, and select a neighbor RN with the shortest distance to all the destination nodes as one of the next-hop RNs. If the distance between one of the destination nodes and the selected RN is larger than the distance between the destination nodes and this node, the multicast tree needs to fork to find all the destination nodes. Therefore, we need to find a bifurcation point in the neighbor nodes of the original node. In accordance with the previous rules, the steps of the algorithm iterate until the multicast tree covers all the destination nodes. Then, the multicast tree is built.

The steps of Algorithm 1 are as follows:

Algorithm 1: The Optimal Path and Minimal Energy Consumption Algorithm (OPMECA)

```
Input: $S$ , $R$ , $B$ , and the set of destination nodes $V$ .
Output: The multicast tree $T$ and minimal energy consumption min( $e$ ).
(1) The data structure initialization. Start from $s$, and join the initial spanning tree $T$ ;
(2) The distance comparison. Compare the distances between neighbor RNs and destination node; choose a neighbor RN with the shortest distance to all the destination nodes as one of the next-hop RNs, and join tree $T$ .
(3) The bifurcation judgment. If the distance between the chosen RNs and a destination node turns larger after forwarding, namely, $d_{v_i - r_{i-1}} < d_{v_i - r_i}$ , then the multicast tree needs to fork and join node $v_i$ into the sets of bifurcation points $B_i$ .
(4) If $B_i$ is nonempty, repeat steps (2)-(3). Select the other RNs from neighbor RNs as the next-hop RN until all the destination nodes join tree $T$ .
(5) Judgment. If all the destination nodes join tree $T$ , the algorithm returns the tree $T$ ; otherwise, iterate steps (2)-(3).
(6) Every RN selects the shortest path to one BS according to steps (2)-(4).
(7) Judgment. If all the destination nodes join tree $T$ , the algorithm returns the tree $T$ ; otherwise, iterate step (6).
(8) Assign edge weight (energy consumption) for the data transmission, and sum the total weight on each edge, denoted as min( $e$ ) .
(9) Return $T$ and min( $e$ ).
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We devised the OPMECA as shown in Algorithm 1 in order to solve problem (14). The basic idea behind the OPMECA is to first apply a multicast routing optimization algorithm to select the RNs, then construct a minimal spanning tree to associate with each edge a weight through mapping the energy consumption of the connected node pair. Finally, the OPMECA solves the problem.

The OPMECA runs in offline computation mode; dealing with link failures after the WSN has been formed is not a function of the algorithm. It restrains network overhead. Now, we show the worst-case time complexity of OPMECA by the following theorem.

Theorem 1: The worst-case time complexity of OPMECA is $\mathrm{O}(m(m+n))$.

Proof: The first for-loop from (3) to (6) spends $\mathrm{O}(m(m+n))$ time to establish tree T . Steps (7)-(8) consume $\mathrm{O}(|A|)$ time to assign edge weights, while the for-loop from (2) consumes $\mathrm{O}(|A|)$ time, at most. Therefore, the worst-case time complexity of the OPMECA is $\mathrm{O}(m(m+n)+2|A|)=\mathrm{O}(m(m+n))$.

On the basis of the OPMECA, it is easy to calculate network lifetime. The network lifetime is defined as the time span from when a network starts operation to when energy depletion first occurs in a node. Using such a definition, we can examine the worst-case network lifetime, which offers in-depth insight for the entire WSN's performance. The network lifetime of the entire WSN is

$$T^L = \min\{\frac{E_1}{e_i}, \frac{E_2}{e_j}\} \tag{15}$$

where E_1 and E_2 are the initial energies of sensor and relay nodes.

Through the construction of spanning tree T in the OPMECA, the number and location of RNs are thus determined. The green networked WSN can eventually be deployed according to tree structure T.

■ Performance Evaluation

In this section, we evaluate the performance of the deployment scheme presented in this paper through Matlab7.1 simulation. Numerical experiments and a comparison with other algorithms are given in the following. The nodes in each topology are distributed in a region 100×100m^2. The parameters are configured as follows. We set $E_{elec} = 50nJ/bit$, $E_{elec}^B = 2E_{elec}^R = 4E_{elec}^S = 4E_{elec}$, $\varepsilon_1 = \varepsilon_2 = 100\,pJ/bit/m^2$, $f_{ij} = 100kbps$ for SNs, $f_{jk} = 200kbps$ for RNs, and $f_{\max} = 100kbps$. We examine the variation of WSN energy consumption and network lifetime with parameters such as communications radius and the number of SNs.

Figs.2 and 3 compare the network lifetime of our proposed hierarchical deployment scheme and a common hybrid scheme with various communications ranges (when $s = 300$ and $s = 600$), which prove the proposed algorithm's robustness. SNs are allowed to communicate directly with their neighboring nodes (SNs and RNs) in the hybrid structure.

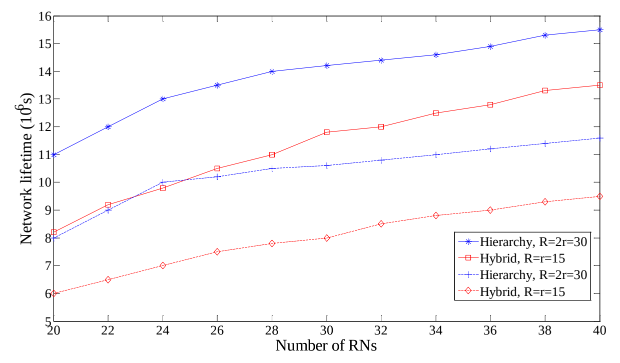

Figure 2. Network lifetime comparisons for the topology, (or) and

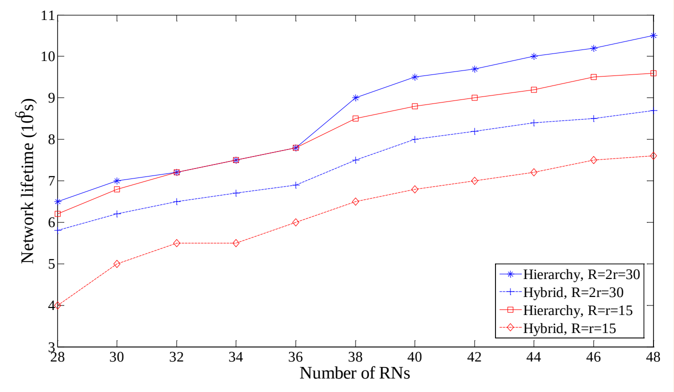

Figure 3. Network lifetime comparisons for the topology, (or) and

From Figs.2 and 3, we find that the network lifetime of a WSN deployed in the hierarchical scheme is longer than that of a WSN deployed in the hybrid scheme. In the hybrid scheme, SNs near RNs consume more energy than other nodes, and may be overloaded. Therefore, the network lifetime would be shorter than a WSN with a hierarchical structure. Nevertheless, in this proposed deployment scheme, SNs send data to their neighbor RNs, then the RNs forward the data to an RN or a BS. As a consequence, the hierarchical scheme not only balances the network load of the nodes, but also reduces node energy consumption. Thus, it extends network lifetime.

In Figs. 2 and 3, the more RNs that are deployed, the longer the network lifetime; increasing the communications radius of RNs would prolong the network lifetime as well. It is interesting to note that the network lifetime shortens when the number of SNs increases. Because more SNs result in more network traffic, which leads to a shorter network lifetime, the hierarchical scheme is better than the hybrid scheme with respect to network lifetime, and it is preferable for green deployment of WSNs.

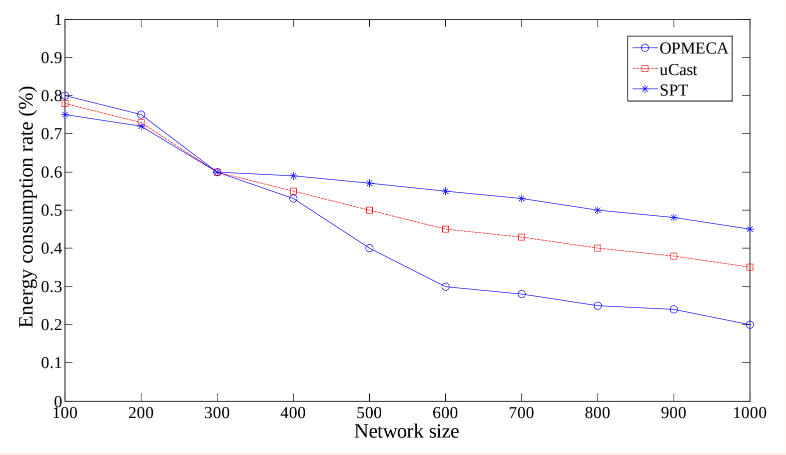

Figure 4. Energy consumption rata comparisons for the different network sizes

Fig. 4 gives a comparison of energy consumption rates for networks with different sizes. As network size increases, the OPMECA optimizes minimal tree T, and the result is better than the heuristic algorithm-uCast [25]. Then, the average energy consumption of the OPMECA is reduced. Since SPT [26] is applicable to the unicast network, its energy consumption rate is better than the OPMECA and uCast when the network size is small. Therefore, the optimal space of SPT is straight, and the average energy consumption increases as the network scale increases.

Conclusion

Developing green deployment schemes for WSN plays a vital role in their massive implementation. In this paper, we first give a hierarchical system framework for WSN deployment that makes the WSN scalable and extensible. Then, we formulate the model as an optimization problem, which is constrained in terms of energy consumption, link-flow balance, and system budget model on the basis of the presented framework. Finally, we propose the OPMECA algorithm to address this optimization problem. Extensive experiments show that the proposed scheme can work more flexibly and energy-efficiently compared to other deployment schemes; and it is applicable to green WSN deployment. Studying the other energy consumption models with consideration to coverage, connectivity and energy efficiency in the WSN is our future work.

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