Research on Cluster Routing Technique for Energy Balancing in Wireless Sensor Networks Based on Optimized Pruning Technique

Li Dongliang[1], Byung-Won Min[2*]
[1]Ph.D. Student, Division of Information and Communication Convergence Engineering, Mokwon University
[2]Professor, Division of Information and Communication Convergence Engineering, Mokwon University

최적화된 가지치기 기법을 이용한 무선 센서 네트워크의 에너지 밸런싱을 위한 클러스터 라우팅 기법에 관한 연구

이동량[1], 민병원[2*]
[1]목원대학교 정보통신융합공학부 박사과정, [2]목원대학교 정보통신융합공학부 교수

Abstract The rapid development of wireless sensor network technology has garnered significant attention from researchers. In extensive distributed networks, these applications often rely on battery power. Given the limited energy capacity of batteries, effective energy management is crucial for improving network performance. Wireless sensor networks consist of numerous sensor nodes, where energy consumption is primarily driven by these nodes. In clustering protocols, certain nodes repeatedly serve as cluster heads, resulting in increased energy consumption compared to other nodes. This energy-balancing algorithm employs pruning techniques to evaluate and analyze a node's position, its frequency of acting as a cluster head, and its remaining energy. Additionally, it includes a dynamic adjustment mechanism for selecting the cluster head node. Experimental results demonstrate that this algorithm extends the operational duration of sensor nodes, thereby effectively prolonging the lifespan of the wireless sensor network.

Key Words : wireless sensor networks; pruning techniques; energy consumption; sensors; energy equalization

요 약 무선 센서 네트워크 기술의 빠른 발전은 연구자들로부터 많은 관심을 받고 있다. 광범위한 분산 네트워크에서 이러한 애플리케이션은 종종 배터리 전원을 의존한다. 배터리의 에너지 용량이 제한적이기 때문에 효과적인 에너지 관리가 네트워크 성능 향상에 매우 중요하다. 무선 센서 네트워크는 많은 센서 노드로 구성되며, 에너지 소비는 주로 이러한 노드들에 의해 발생한다. 클러스터링 프로토콜에서는 특정 노드가 반복적으로 클러스터 헤드 역할을 하게 되어 다른 노드에 비해 에너지 소비가 증가하게 된다. 이 에너지 균형 알고리즘은 가지치기 기법을 사용하여 노드의 위치, 클러스터 헤드로서의 빈도, 남은 에너지를 평가하고 분석한다. 또한, 클러스터 헤드 노드를 선택하기 위한 동적 조정 메커니즘을 포함하고 있다. 실험 결과, 이 알고리즘은 센서 노드의 작동 시간을 연장시켜 무선 센서 네트워크의 수명을 효과적으로 연장하는 것을 보여준다.

주제어 : 무선 센서 네트워크; 가지치기 기법; 에너지 소비; 센서; 에너지 균형 조정

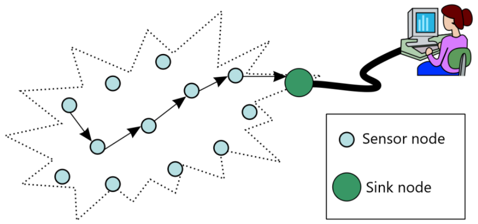
*교신저자 : 민병원(minfam@mokwon.ac.kr)
접수일 2024년 08월 19일 수정일 2024년 09월 10일 심사완료일 2024년 10월 08일

1. Introduction

1.1 Background of the Study

A wireless sensor network (WSN) is deployed in a specific monitoring area to sense numerous environmental parameters. The network consists of miniature, low-cost, resource-constrained sensor nodes that self-organize into a network. These nodes can process and store information, as well as communicate wirelessly. This emerging technology is crucial for information perception and data collection in the twenty-first century. Wireless sensor networks integrate sensor, semiconductor, microelectronic, computing, radio communication, and network technologies to create a novel type of network. A typical WSN includes a convergence node or base station (Sink), multiple sensor nodes, satellite communication links or Internet connections, sensing objects, and observers 〈Fig.1〉. The sensor node that senses and acquires information in the monitored environment is referred to as the Source. Unlike sensor nodes, the base station typically has sufficient energy, computational power, and storage resources, serving as a gateway between the sensor nodes and the observers.

Figure 1 illustrates an application scenario for deploying Wireless Sensor Networks (WSNs). In this scenario, numerous economical sensor nodes are strategically positioned to densely monitor data within a specific coverage area. These nodes perform tasks such as sensing, collecting, storing, and communicating data, which they then transmit to the base station to meet environmental monitoring objectives.



〈Fig. 1〉 Architecture of wireless sensor network

As the basic units for sensing environmental parameters, numerous wireless sensor nodes are widely deployed in various unattended and dynamic environments, including sparsely populated hazardous areas. These nodes are used to sense environmental physical parameters. Despite their limited energy resources and the high likelihood of failure due to their miniature size, the dense deployment of nodes enables collaborative self-organization into a resilient network. This robustness, combined with their low cost, makes them applicable in military and national defense, healthcare, intelligent transportation, natural disaster early warning, radiation monitoring, biohabitat observation, precision agriculture, forestry, animal husbandry, fisheries, and complex field scheduling tasks. WSNs are widely used and bring significant convenience to residents, industrial and agricultural production, and scientific research, demonstrating their economic and practical value. They act as a bridge, closely linking the objective physical world with the virtual information world, and innovatively changing the interaction between humans and the natural environment.

With the in-depth study of the fundamental theories of wireless sensor networks and the application of novel technologies, data collection in application research has garnered significant attention from industrial experts, scholars, and research organizations. Functionally, wireless sensor networks can be divided into a foundation layer, a network layer, a data management and processing layer, and an application layer. When the base station transmits aggregated data to the monitoring center via Ethernet or satellite, this data is available for in-depth research by experts. The data management and processing layer is responsible for collecting, storing, querying, analyzing, and mining the sensed data, providing users with valuable information to aid in decision-making. Thus, data collection in the monitoring environment is a crucial driver for the widespread application of WSNs.

1.2 Significance of the study

A wireless sensor network comprises numerous small, inexpensive, battery-powered nodes typically used to monitor an area of interest and collect environmental data. In data collection applications, most sensor nodes rely on energy-constrained battery power. The specific, hazardous, and inaccessible deployment environments of these nodes, coupled with the human, material, and financial resources required for node replacement, make battery replacement challenging.

The unpredictability of sensor node energy consumption rates, the dynamics of residual energy, and the randomness of nodes joining or leaving the network emphasize the issues of energy constraints and uneven energy consumption in wireless sensor networks (WSNs). These factors render traditional fixed or predictable routing methods ineffective. Studies have shown that the primary challenge in WSN data collection applications is energy management.

Considering the actual application requirements of WSNs, the focus has shifted to extending network lifespan by addressing the cost and energy constraints of sensor nodes. This involves periodically collecting physical information from the monitoring environment and aligning practical applications with environmental data collection. The design of data collection algorithms must consider the size of the monitoring area, the diversity of monitoring tasks, and the specific types of monitoring content.

WSNs consist of numerous sensor nodes, and the energy consumption of these nodes is crucial to the overall network energy consumption. In cluster topology protocols, uneven load distribution can cause certain nodes to frequently act as cluster heads, leading to higher energy consumption compared to other nodes. To address this problem, this paper proposes an energy-balancing algorithm that uses a dynamic adjustment strategy to elect cluster head nodes. This strategy considers the node's position, the number of times it has served as a cluster head, and its residual energy through pruning techniques. Experimental results demonstrate that this algorithm can extend the operational time of individual sensor nodes and effectively enhance the lifespan of the entire wireless sensor network.

2. Current status of domestic and international research

In wireless sensor networks (WSNs), routing protocols are crucial for ensuring reliable data transmission between sensor nodes and aggregation nodes. With advances in science and technology, traditional protocols are becoming inadequate for the increasing variety of application scenarios. Consequently, researchers have developed numerous protocols tailored to specific application needs. Current routing protocols are mainly divided into two categories: planar and hierarchical.

Planar routing protocols were initially designed for small-scale WSNs, offering simple design solutions for networks with a limited number of nodes. However, they have limitations regarding network delay, scalability, and especially energy consumption. Typical planar routing protocols include Flooding[1], SPIN[2], and Directed Diffusion (DD)[3]. Flooding is simple to implement and broadcasts data to neighboring nodes, but it suffers from data redundancy. SPIN addresses this issue with a negotiation mechanism, though network performance can still be impacted. DD uses directed diffusion to address these limitations but is still constrained by energy consumption and scalability issues.

Researchers have made various improvements to planar routing protocols. For example, Hu et al. enhanced the classical flooding protocol by reducing energy consumption through undirected broadcasting[4]. Jitender Grover et al. proposed a GAF improvement algorithm to reduce energy consumption during the discovery phase, extending network operation[5]. J. Wang developed a genetic algorithm-based improvement to optimize the rumor algorithm's path. However, as WSN deployments grow in scale, planar routing protocols struggle to manage large-scale information transmission[6].

Hierarchical routing protocols, in contrast, offer easier network management, good scalability, and efficient energy utilization, making them the mainstream choice in WSNs. These protocols use network clustering, where sensor nodes are divided into cluster heads (CH) and ordinary nodes. Ordinary nodes join nearby cluster heads, forming a two-tier "small network." Data is collected by ordinary nodes and sent to their cluster head, which then aggregates and transmits it to the base station (BS). Hierarchical routing protocols thus use intra-cluster and inter-cluster data transmission methods.

Typical hierarchical routing protocols include LEACH[7], TEEN[8], HEED[9], and DEEC[10]. LEACH, the most widely used, uses a random election of cluster heads to balance energy consumption. However, it has limitations, such as low-energy nodes being elected as cluster heads and imbalanced distances between cluster heads, which can accelerate energy consumption[11]. Various improvements have been proposed, such as the Minimum Energy Consumption (MEC) routing by Li et al. which does not account for nodes outside the minimum energy path, causing premature node death due to heavy data forwarding tasks[12]. Mohamad et al. introduced the EECS protocol, which forms non-uniform clusters to equalize energy consumption within the cluster[13]. Zhu et al. proposed the Self-Organizing Routing Protocol (SOR), which uses a payment strategy to motivate nodes to participate in data transmission, achieving a balance between energy efficiency and data effectiveness[14].

Despite these advancements, most protocols are developed under ideal conditions and do not account for specific application scenarios. They often assume reliable network transmission links and use large-scale fading models for estimating node transmission energy consumption without considering the impact of specific application conditions.

3. Energy equalization strategy based on pruning technique

Energy constraints in wireless sensor networks often limit their application areas. As discussed, energy savings can be achieved by putting nodes without data transmission into a dormant state. However, if all nodes are dormant, data cannot be transmitted in a timely manner. To address this, a clustering algorithm with a hierarchical topology is employed.

This algorithm selects certain nodes as backbone nodes, which are responsible for detecting, summarizing data, and transmitting data between non-backbone nodes. Non-backbone nodes can enter a dormant state when there is no data transmission, conserving energy. Meanwhile, the backbone nodes remain active, ensuring the timely transmission of data. This approach optimizes energy usage while maintaining network functionality.

3.1 Energy equalization mechanism in clustering protocols

In cluster algorithms, a fixed cluster head selection mechanism is often used, where certain nodes consistently act as cluster heads, resulting in higher energy consumption compared to other nodes. This can lead to abnormal energy consumption and network fragmentation, known as "hot spots."[15-17] Addressing this issue is crucial for energy efficiency and network stability in hierarchical networks[18].

This paper proposes a rotation mechanism for selecting cluster head nodes using pruning techniques in wireless sensor networks. This approach avoids fixed node selections, mitigating the creation of hot spots and preventing energy imbalances that could disrupt network operations[19-20]. Implementing a load balancing strategy further alleviates the hot spot phenomenon by distributing the workload among cluster nodes, thereby reducing the burden on cluster head nodes[21-23].

However, effective load balancing must consider several limitations[24-26]: First, frequent rotation of cluster head nodes increases energy consumption due to frequent transitions between dormant and active states. Second, the complexity of load balancing algorithms should be minimal to accommodate the limited computing and storage capacities of sensor nodes. Third, minimizing reliance on global information is essential, as hierarchical algorithms divide the network into clusters where global data management is impractical at the sensor node level.

3.2 Energy equalization mechanism based on pruning technique

Pruning technology, originating from tree cultivation, involves strategic branch management to optimize tree growth. By selectively removing dense, overgrown, and weak branches, trees can absorb nutrients more efficiently, improving ventilation and light permeability. This process enhances the overall energy utilization of the tree. The principles of pruning technology offer valuable insights for balanced energy allocation and efficient use in sensor networks.

Key characteristics of pruning include:

1. Removal of Dense Branches: Trees require adequate light and carbon dioxide for growth. Selectively removing dense branches enhances ventilation and light penetration, promoting healthier tree development.
2. Pruning Overgrown Branches: Overly robust branches can divert nutrients from the trunk and fruit, impairing growth. Pruning these branches is essential to maintain nutrient balance and facilitate optimal growth.
3. Cutting Weak Branches: Weaker branches absorb fewer nutrients, impacting fruit quantity and quality. Removing these branches redirects nutrients to more productive areas, enhancing overall fruit development.

The deployment of nodes in wireless sensor networks (WSNs) is often irregular, resulting in dense distribution in detection areas. Similar to tree growth, unbalanced energy consumption among nodes can disrupt the entire network. Therefore, this paper applies the pruning mechanism to WSNs to address the "hot spot" problem.

In the LEACH protocol, a node that has served as a cluster head (CH) in the previous round is disqualified from serving as a CH in the current round. This paper proposes that each node has a set threshold value, becoming eligible as a CH only if it does not exceed this threshold.

Frequent rotation of CH nodes can lead to excessive energy consumption. Typically, only one node is selected as a CH per selection, necessitating constant execution of the CH selection algorithm and increasing energy costs, especially in clusters with many nodes. To mitigate this, the proposed dynamic CH allocation algorithm based on pruning technology employs a threshold-based CH selection mechanism. Multiple nodes can be selected as CHs within a cluster, and these nodes serve as CHs in a sequential order. This approach not only achieves dynamic CH selection but also effectively reduces the energy consumption associated with the CH selection algorithm.

The algorithm proposed in this paper considers three factors: the distance of the node to the base station, the node's remaining energy, and the frequency of the node serving as a cluster head. These three factors interact with each other. When the node's remaining energy and distance to the base station are high, the node's frequency of serving as a cluster head will increase. However, as the node continues to function as a cluster head, its energy will gradually deplete, reducing its frequency of serving as a cluster head. Therefore, a compromise among the three factors—distance to the base station, remaining energy, and frequency of serving as a cluster head—can be selected to achieve load balancing in the cluster.

The algorithm presented in this paper is divided into two phases: the cluster initialization phase and the cluster stabilization phase. The initialization phase primarily involves deploying sensor nodes. This phase is relatively simple and does not significantly impact energy consumption. Consequently, this paper assumes a stable, static wireless sensor network with no dynamic transformations between nodes. Nodes form clusters based on their physical proximity. For example, in a light sensor network, each node within a building unit can form a cluster, and the sensor's location determines its cluster membership. Once a node joins a cluster, it remains in that cluster. The stabilization phase includes information exchange, evaluation functions, and the selection of cluster head nodes. This is the primary focus of our discussion.

Once initialized, the node sends information to neighboring nodes. This information includes the node's ID, remaining energy, location, and distance relative to the base station, defined as (Fid, Ere, Cou, Dis). Here, Fid represents the node's ID, Ere the remaining energy, Cou the number of times it has served as a cluster node, and Dis the distance from the base station. The relative distance to the base station can be obtained using techniques such as GPS. In terms of energy consumption, the energy used for command computation is negligible compared to that used for message exchange. Therefore, the experimental data in this paper does not include the energy consumed by command computation.

The information sent to neighboring nodes during the initialization of the node is calculated using Formulas 1 to 3. Based on these calculations, it is determined whether a node can be used as the cluster head node.

$$T_i = \alpha \cdot Ere(i) - \beta \cdot Dis(i) - \gamma \cdot Cou(i) \tag{1.1}$$

The parameters α, β, and γ are weights, where Ere(i) represents the residual energy of nodei, Dis(i) is the distance from node i to the base station, and Cou(i) denotes the number of times node i has served as a cluster head.

$$P_i = \frac{T_i - Meat[T]}{T_i * Meat[T]} \tag{1.2}$$

Pi represents the dynamic threshold for the node, and Meat[T] is the average of the Ti values for all nodes within the cluster.A dynamic threshold (Meat[T]) for each node to serve as a cluster head can be obtained using Formula 2.

The state of the nodes varies in each round of cluster head selection, so Meat[T] also varies. Thus, the selection of the cluster head node is a dynamic process.

$$N_s(i) = \begin{cases} 1, P_i \geq 0 \\ 0, Other \end{cases} \tag{1.3}$$

Ns(i) is defined as the cluster head selection function for node i.

When selecting cluster head nodes, first determine each node's value. A node can be a cluster head only if its value is 1; if its value is 0, it cannot be a candidate. In each round of cluster head selection, there can be one or more cluster head nodes, determined by the node's value. If multiple nodes have a value of 1, they will take turns acting as cluster head nodes based on their Ti values.

Formulas 2 and 3 ensure that at least one node's value is equal to 1, preventing round-robin issues. Adjusting the dynamic threshold value ensures at least one cluster head node, guaranteeing information transmission to the base station. In each selection round, subtract the energy consumed by the previous cluster head node and increase its Cou value by 1, then recalculate using the above formulas.

The pseudocode for the specific implementation of the algorithm is as follows:

```
BEGIN
    // Node initialization
    Initialize Node

    // Calculate the Ere, Dis, and Cou for each node
    Calculate Ere, Dis, and Cou for each node

    // Calculate Ti for each node
    Calculate Ti for each node

    // Calculate Meat[T]
    Calculate Meat[T]

    // Calculate Pi for each node
    Calculate Pi for each node

    // Calculate Ns(i) for each node
    FOR each node i DO
        Calculate Ns(i)
        IF Pi >= 0 THEN
            Ns(i) = 1
            // Add to cluster head election queue
            Add node i to the cluster head election queue
        ENDIF
    ENDFOR

    // If the queue length is greater than 1, sort by Ti in descending
order
    IF Length of cluster head election queue > 1 THEN
        Sort the queue by Ti in descending order
    ENDIF

    // At the end of each round, subtract the consumed energy from
each node and increment Cou
    AT the end of each round DO
        Subtract consumed energy from each node
        Increase Cou by 1
    ENDDO
END
```

4. Experiment and result analysis

4.1 Purpose of the experiment and experimental environment

In the simulation experiments presented in this paper, there are 601 nodes, including one base station node and 600 common sensor nodes. These nodes are randomly and uniformly distributed in a 200 × 200 m² field. The communication radius of the nodes is dynamically adjustable. The base station node is located at (0, 0). The energy consumption during the simulation is negligible. The 600 sensor nodes are divided into 50 clusters, each containing 12 nodes.

The pruning strategy with different values of α,β,γ is applied to 50 networks with various topologies. The collected data is used to analyze the pruning strategy and the cluster head algorithm across these networks. The remaining initialization conditions are shown in ⟨Table 1⟩.

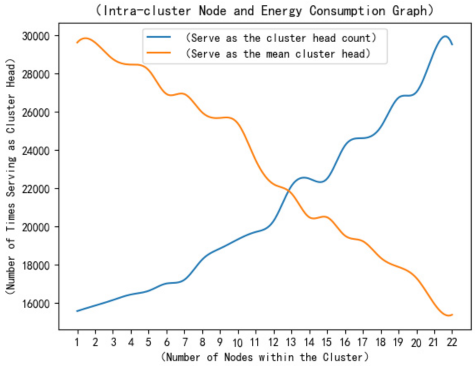
⟨Table 1⟩ Simulation initialization conditions

name	initialization value	Eelec	Eamp	Hello.	Load
starting value	3J	50nJ/bit	100pJ/bit/m2	512bit	1024bit

Where J represents the energy unit Joule, nJ is $1/10^9$J, and pJ is $1/10^{12}$J. The significance of each field name is as follows: e_elec (energy consumption per byte), e_amp (energy consumption per square byte), Hello (information sent by the sensor to neighboring nodes), and Load (information initialized by the node).

4.2 Experimental results and analysis

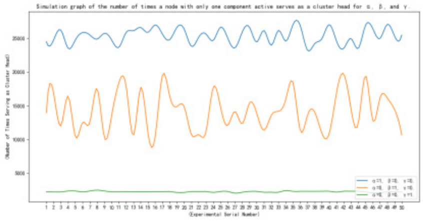
In this experiment, we established 50 clusters, each comprising 12 nodes. The selection of 12 nodes per cluster is intentional, balancing the trade-off between energy consumption for cluster head selection and the frequency of each node serving as a cluster head. As cluster size increases, the energy expended on selecting a cluster head rises, while the frequency of each node serving as a cluster head decreases, and vice versa. Therefore, determining the optimal cluster size is crucial for achieving energy equalization. Simulation analysis reveals that optimal energy consumption occurs when the cluster size is set to 12 or 13, as depicted in ⟨Fig.2⟩.



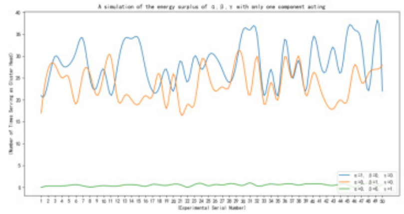
〈Fig. 2〉 Cluster nodes and energy consumption map

In this paper, 12 nodes are selected as a cluster, a total of 50 clusters, in the experimental simulation by analyzing the differentα,β,γ ratios in different network deployments in the context of each time to act as a cluster head node is determined, so the more the number of nodes acting as a cluster head node the more it can show that the network's lifetime will be longer.

The values of α,β,γEre indicate the energy surplus of the node, Cou, the number of cluster nodes, and Dis, the distance from the base station in the cluster head node selection, respectively. Energy is the most important factor in the whole wireless sensor network, soα occupies more weight thanβ,γ. In the experiment the value ofα,β,γ is allowed to be 1 and the other two are 0 in sequence and the simulation results are shown in 〈Fig.3〉.



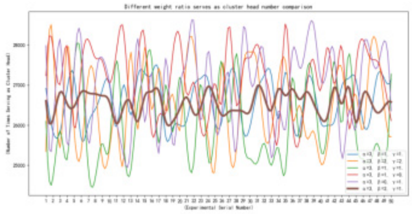
〈Fig. 3〉 α,β,γNumber of times nodes act as cluster head simulation graph for which only one component plays a role



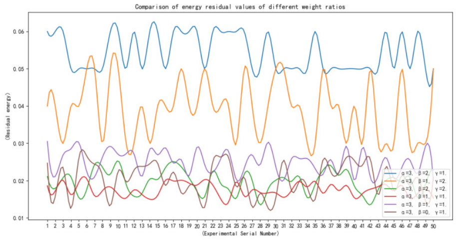
〈Fig. 4〉 α,β,γ only one component is effective in the remaining energy simulation diagram

As shown in Figures 3 and 4, the experimental results for components α,β,γ were obtained by setting one component to a value of 1 and the other two to 0. When considering only one component, load balancing based solely on the energy component outperforms the other two components. This is because the energy of the nodes in the wireless sensor network is the fundamental factor in determining the network's service life. Thus, the energy factor serves as the dominant factor in the load balancing mechanism.

The simulation of energy residual value and number of times a node acts as a cluster head for different weight ratios is shown in 〈Fig. 5〉.



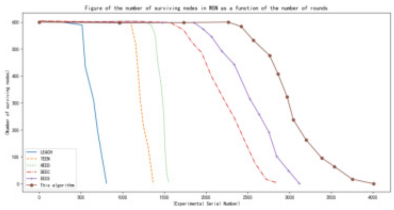
〈Fig. 5〉 Comparison of the number of times different weight ratios act as cluster heads



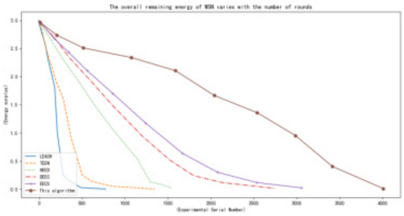
〈Fig. 6〉 Comparison of energy residual values for different weight ratios

From the simulation images in ⟨Fig.5⟩and ⟨Fig.6⟩ it can be seen that in terms of the distribution of the number of times of acting as a cluster head node and the remaining energy in the way of different weight ratios, the number of cluster head nodes is distributed more uniformly and the remaining energy is also the most in the case of a 3:2:1 weight ratio betweenα,β,γ , which means that the remaining energy is the first thing to be taken into account when considering the load balancing, and at the same time the weights of geographic location and the number of times of acting as a cluster head have to be balanced as well.

From the simulation images in Figures 7 and 8, it can be observed that in terms of the distribution of the number of times acting as a cluster head node and the remaining energy under different weight ratios, the number of cluster head nodes is more uniformly distributed, and the remaining energy is highest with a 3:2:1 weight ratio between α,β,γ. This indicates that remaining energy should be prioritized when considering load balancing. Additionally, the weights of geographic location and the frequency of acting as a cluster head must also be balanced.



⟨Fig. 7⟩ Survival Node Count of WSN Changing with Round Number Graph



⟨Fig. 8⟩ WSN Total Remaining Energy Changing with Round Number Chart

The role of the clustering-based pruning algorithm in reducing network energy consumption is then verified. To ensure the network runs for its entire life cycle, the experiment assumes that the collected temperature and humidity data follow a Gaussian distribution, and simulation data is used for the experiment. Fig.7 illustrate the changes in the number of remaining nodes and the overall energy of the network over the number of rounds during the operation of the wireless sensor network with the pruning algorithm.

Simulation results show that the overall energy consumption of the wireless sensor network using the pruning algorithm is reduced, indicating that the clustering algorithm with the pruning strategy effectively extends the network's lifetime, particularly in terms of the number of times nodes serve as cluster heads. Compared to the average distribution, the number of times nodes can serve as cluster heads is increased by more than two-fold. Furthermore, the remaining energy in the network accounts for only a minimal fraction compared to the average distribution method for cluster head qualification. These results demonstrate that the pruning algorithm effectively extends the network's service life and reduces energy consumption. Therefore, wireless sensor networks based on pruning technology can effectively save energy and significantly extend network service life.

5. Conclusion and outlook

This paper proposes an innovative energy-balancing algorithm to address the energy management issues in wireless sensor networks, particularly the excessive energy consumption of cluster head nodes caused by load imbalance under the split cluster topology protocol. The algorithm employs pruning techniques to evaluate three key factors: node position, frequency of serving as cluster head, and residual energy. It adopts a dynamic adjustment mechanism to elect the cluster head node. Experimental results validate the algorithm's effectiveness, showing a significant increase in sensor node usage time, thereby extending the network's overall life cycle. This energy-balancing strategy optimizes the network's energy distribution while also enhancing its stability and reliability.

Future research can deepen and expand the algorithms in several directions. First, test the algorithms in diverse real-world environments to verify their universality and robustness, and adjust and optimize them for different application scenarios to meet specific performance requirements. Second, explore the possibility of combining the algorithms with other energy-saving technologies, such as data compression, sleep scheduling mechanisms, and low-power communication protocols, to further improve the network's energy efficiency. Third, consider the security of the algorithms to ensure data protection and resistance to potential threats while saving energy. Finally, conduct cross-layer design research to achieve fine-grained and comprehensive energy management, considering all layers from the physical to the application layer. These comprehensive research efforts are expected to advance wireless sensor network technology towards greater efficiency, reliability, and security, providing robust technical support for a wide range of practical applications.

REFERENCES

[1] Z. Ren, Z. Zhou, "Optimization of low overhead topology maintenance algorithm of link state routing protocol," Computer Engineering, Vol. 47, No. 9, pp. 120-127, 2021.

[2] Y. Su, X. Gao, "Research on the improvement of SPINS Protocol in WSN," Computer and Digital Engineering, Vol. 46, No. 4, pp. 793-796, 2018.

[3] W. Huang, "Research and improvement of WSN directional diffusion Routing Protocol," Nanjing University of Posts and Telecommunications, 2021.

[4] H. S. Hu, Y. J. Han, "Trust-based secure and energy-efficient routing protocol for wireless sensor networks," IEEE Access, Vol. 10, pp99, 2022.

[5] J. Grover, M. Sharma, "Optimized GAF in wireless sensor network," Proceedings of IEEE, 2014.

[6] J. Wang, "Research on several types of remote state estimation problems in wireless sensor networks," University of Science and Technology of China, 2021.

[7] S. Qi, X. Xue, "Improvement of Cluster routing protocol in wireless sensor networks based on LEACH," Electronic Technology and Software Engineering, Vol. 2022, No. 13, pp. 53-55, 2022.

[8] B. Che, G. Guo, "Research on Transmission Efficiency and Security of Wireless Sensor Network Protocol TEEN," Journal of Chongqing University of Science and Technology, Vol. 20, No. 1, pp. 75-79, 2018.

[9] X. Liu, J. Yang, "Research on Clustering routing protocols in wireless sensor networks," Wireless Interconnection Section Technology, Vol. 17, No. 6, pp. 87-92, 2019.

[10] Prashanth, G. S. , and P. Manjunatha . "Cluster based energy efficient routing protocol for heterogeneous wireless sensor networks." Concurrency and computation: practice and experience 35.21(2023):e7693.1-e7693.17.

[11] Faisal, Muhammad , and G. Husnain . "Blockchain Based Multi-hop Routing and Cost-Effective Decentralized Storage System for Wireless Sensor Networks." Wireless Personal Communications 131.4(2023):3009-3025.

[12] Hosein, et al., "Solving Target Coverage Problem Using Cover Sets in Wireless Sensor Networks Based on Learning Automata," Wireless Personal Communications: An International Journal, Vol. 76, No. 1, pp. 1-15, 2014.

[13] W. Li, B. Y. Tu, B. Jia, et al., "An energy-based dynamic AODV routing protocol in wireless Ad Hoc networks," CMC-Computers Materials & Continua, Vol. 63, No. 1, pp. 353-368, 2020.

[14] M. H. Anisi, G. Abdul-Salaam, A. H. Abdullah, "A survey of wireless sensor network approaches and their energy consumption for monitoring farm fields in precision agriculture," Precision Agriculture, Vol. 16, No. 2, pp. 216-238, 2015.

[15] M. M. Mohamad, M. T. Kheirabadi, "Energy efficient opportunistic routing algorithm for underwater sensor network: a review," Proceedings of the 2nd ICSITech, pp. 41-46, IEEE, 2016.

[16] L. Zhu, C. Fan, H. Wu, et al., "Coverage optimization strategy for WSN based on energy-awareness," International Journal of Computers Communications & Control, Vol. 11, No. 6, pp. 877-888, 2016.

[17] C. Hu, "Research on secure cluster routing algorithm for wireless sensor networks based on genetic algorithm," Journal of Nanjing Engineering College: Natural Science Edition, Vol. 20, No. 3, pp. 28-32, 2022.

[18] Selvi, M. , et al. "Energy and Security Aware Hybrid Optimal Cluster-based Routing in Wireless Sensor Network." Wireless Personal Communications 137.3(2024):1395-1422.

[19] J. Wang, Y. Liu, H. Cui, et al., "A WSN cluster routing method based on weighted optimization tree," CN201910028071.5, 2023.

[20] H. Zhang, "Cluster routing based on Dijkstra's algorithm in wireless sensor networks," Fire and Command and Control, Vol. 2022, No. 2, pp. 101-109, 2022.

[21] T. Bao, J. Gao, Y. Wang, et al., "Research on energy optimization method of wireless sensor network based on dynamic cuckoo algorithm," Automation and Instrumentation, Vol. 2022, No. 9, pp. XXX-XXX, 2022.

[22] Tiwari, Keshav Kumar , and S. Singh . "Energy-optimized cluster head selection based on enhanced remora optimization algorithm in underwater wireless sensor network."International journal of communication systems 36.15(2023):e5560.1-e5560.19.

[23] Y. Bao, Z. Wang, "Energy-efficient residency routing algorithm for wireless sensor networks based on mobile Sink," Journal of Central South University for Nationalities: Natural Science Edition, Vol. 41, No. 6, pp. 734-739, 2022.

[24] L. Zhu, X. Chen, "Analysis of an improved algorithm for cluster routing protocol for wireless sensor networks," Integrated Circuit Applications, Vol. 40, No. 3, pp. 11-13, 2023.

[25] H. Wu, "Research and implementation of high-precision node localization algorithm for wireless sensor networks," Shandong University, 2021.

[26] L. Shi, "Research on routing protocols for efficient and reliable transmission in hydroacoustic sensing networks," Guilin University of Electronic Science and Technology, 2021.

이 동 량(Li Dongliang) [정회원]

- September 1998- July 2002, Henan Normal University, Bachelor's Degree in Computer Science Education.
- September 2006- July 2009 Graduated with a Master's degree in Computer Application Technology from China University of Geosciences.
- March 2022- Present, has been pursuing Ph.D. in Intelligent Fusion in IT at Mokwon University, Daejeon, Korea (Student)

〈관심분야〉
Sensor Networks, Data Processing

민 병 원(Byung-Won Min) [정회원]

- He received M.S. degree in computer software from Chungang University, Seoul, Korea in 2005.
- He received Ph.D. degree in the dept. of Information and Communication Engineering, Mokwon University, Daejeon, Korea, in 2010.
- He is currently a professor of Mokwon University since 2010.

〈관심분야〉
digital communication systems, Big Data