International Journal of Hybrid Information Technology
Vol.2, No.1 (2022), pp.13-22
http://dx.doi.org/10.21742/ijhit.2653-309X.2022.2.1.02

A New Chain Formation Scheme for Wireless Sensor Networks

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Abstract

In recent years, Wireless Sensor Networks (WSNs) have rapidly developed as an indispensable part of the Internet of Things (IoT). Since sensor nodes operate by limited battery, they consume the unbalanced energy during the intra-communication in uneven WSNs. By this, the network performance is decreased. Therefore, it is necessary to research energy-efficient routing algorithms. The chain-based routing algorithm has many advantages such as energy-saving and a longer lifetime for WSNs but has disadvantages such as unbalanced energy consumption and intra-communication distance. In this paper, a chain formation scheme is studied to improve the energy-unbalanced routing in chain-based routing algorithms for WSNs. We compared and analyzed the performance of our study and existing algorithms (PEGASIS and Enhanced PEGASIS) via simulation results. We used the OMNET++ simulator for simulation experiments and measured simulation results such as network lifetime and average residual energy from a WSN with randomly distributed sensor nodes. In simulation results, our proposed scheme outperforms both PEGASIS and Enhanced PEGASIS in terms of network lifetime and average residual energy. These results mean to bring about the unbalanced energy consumption caused by the long-distance communication of some nodes in PEGASIS and Enhanced PEGASIS. In other words, in simulation results, the balanced energy consumption of our scheme has verified.

Keywords: *Chain formation, Energy-balanced routing, Internet of things (IoT), K-D-B-tree, Wireless sensor networks (WSN)*

1. Introduction

In recent years, wireless sensor networks (WSNs) have rapidly developed as an indispensable part of the Internet of Things (IoT) [1][2][3][4]. WSNs have features such as easy deployment, self-organization, lower cost, and fault tolerance. To sense and monitor in WSNs, interconnected intelligent sensors are used. The energy of sensor nodes is restricted due to the limited battery. The battery cannot replace in restricted environments. These reasons because unbalanced energy consumption during the intra-communication of uneven WSNs, and the energy of some sensors can rapidly exhaust [5]. The performance of the network such as connectivity, coverage, and life is affected by node death [6][7]. To prolong the network lifetime of WSNs in [8][9][10][11][12][13][14], chain-based improved

Article history:
Received (May 2, 2022), Review Result (June 5, 2022), Accepted (August 15, 2022)

algorithms have been proposed. The merit of chain-based routing algorithms can be checked as mentioned below [15][16]:

- -The chain-based routing algorithm consumes less energy than topologies based on the cluster.
- The distribution of the energy consumption is uniform.
- The low power consumption offers a longer network lifetime.
- The algorithm reduces the dynamic cluster formation overhead of cluster-based routing algorithms.

However, existing chain-based algorithms still have some drawbacks, such as unbalanced energy consumption and long-distance data transmission in intra-communication. To solve the above problems, we propose a new chain formation scheme. Our chain formation scheme consists of three phases (initial communication phase, chain formation phase, and data collection phase) and has the following signs for WSNs. First, we use chaining by the concept of the KDB-tree algorithm for data transmission in WSNs. Second, we overcome the energy unbalanced consumption and avoid long-distance data transmission in intra-communication. To compare the performance of our study with existing algorithms (PEGASIS and Enhanced PEGASIS), we measure the network lifetime and the average residual energy from the simulation experiment using the OMNET++ [17][18]. The remaining sections of this paper are structured as follows. Section 2 presents chain-based routing algorithms and the KDB-tree structure. Section 3 describes the proposed chain formation scheme in detail. In section 4, we analyze the performance of simulation results. Finally, section 5 concludes the study of this paper.

2. Related works

2.1. Chain-based routing algorithms

Sensor nodes are randomly distributed in the network field and then the chain is organized using the greedy algorithm [8]. Each sensor fuses its data and its neighbor. The fused data is transmitted to a leader node along the chain. A leader node transmits the fused data to the BS. The token-passing mechanism is used to gather data. Multiple levels and chains are used. At each level, a chain is formed by using the greedy algorithm [9]. A leader node is selected at each level. The leader node receives the data from the lower level and then sends the data toward a higher level. At the higher level, the leader node sends the collected data to the sink. Jung et al. proposed the concentric clustering scheme based on multiple chains [10]. The signal strength from the BS decides the level of sensors. A head node in the different levels sends its location information to the upper and lower levels. Finally, at the lowest level, a head node sends the gathered data to the BS. One or two heads are selected at each level. In the levels with two heads, the collected data is sent to the lower level with one head, and then the head sends data to the next level cluster with two heads [11]. The data are sent to the BS along heads as diamond-shaped structures. Since the leader node transmits the aggregated data to the BS for each round, the failure of a leader node leads to data loss [8]. The data loss problem is addressed [12]. The leader's neighbor, which is selected based on the residual energy, sends the fused data to the BS. The network field is split into sub-areas of equal size [13]. In each sub-area, the chain structure is organized. The chain in each sub-area is connected using bridge nodes. Wang et al. adopted the multi-hop transmission for conserving energy [14]. Optimal communication and hop counts were used for decreasing the times of data forwarding times and achieving optimal energy consumption.

2.2. The KDB-tree structure

The KDB-tree that will solve the issue of retrieving multi-key records through range queries was firstly introduced in 1981 [19]. The KDB tree consists of the region and point pages. The region and point pages contain the region and page ID and point and location pairs, respectively.

(1) Region pages

- Region pages have a binary KD tree and a limited size.
- In the regional pages, the elements in entries store data pointers and sub-spaces descriptions pairs.

(2) Point pages

- Point pages are index records consisting of the point and location pairs.
- Since the location gives the location of the database record, they are the actual data or reference to them.

The properties of the KDB-tree are followed, and the example of the KDB-tree algorithm is shown in [Figure 1].

- If each page is considered a node, in a region page, each page ID becomes a node pointer and then the graph structure of the tree with the root ID is made.
- The path length from the root page for all leaf pages is the same.
- On the page, the regions are disjoint.
- The union of the root page that a region page is $domain_0$ x $domain_1$ x ... x $domain_{k-1}$.
- The union of the regions in a region page that is the child page referred to by the child ID is a region.
- If the child page is a point page, then all the points on the page must be in the region.

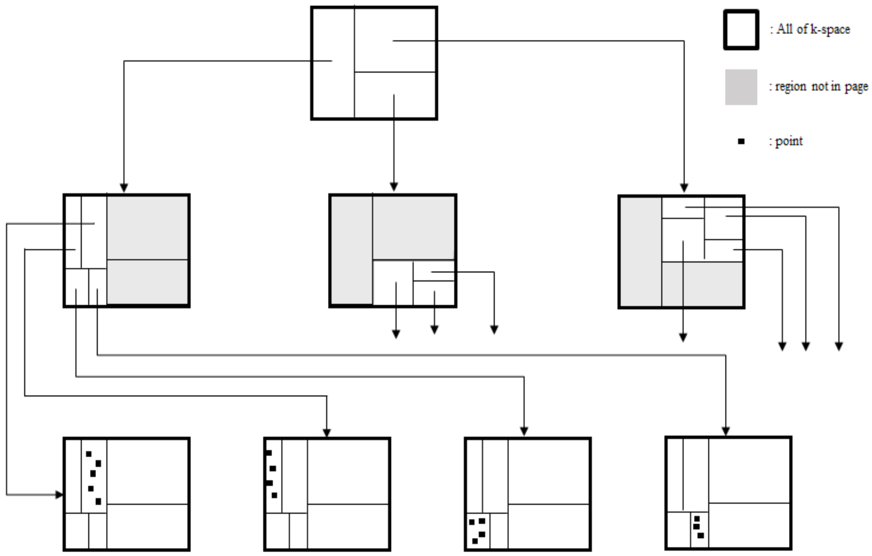

Figure 1. Example 2-D-B-tree

3. Proposed scheme

Our proposed scheme consists of an initial communication phase, chain formation phase, and data collection phase. In the initial communication phase, sensor nodes send their location information to a sink, and then the chain formation phase will be started. The proposed scheme uses the centralized method to form the chain-based network structure. In the chain formation phase, the chain-based structure using the concept of the KDB-tree algorithm and the in-order traversal algorithm is organized. After the chain formation phase is finished, the data collection phase enters, and the tasks of gathering and transmitting data are carried out in this phase. [Figure 2] shows the workflow between a sink and sensors in our study.

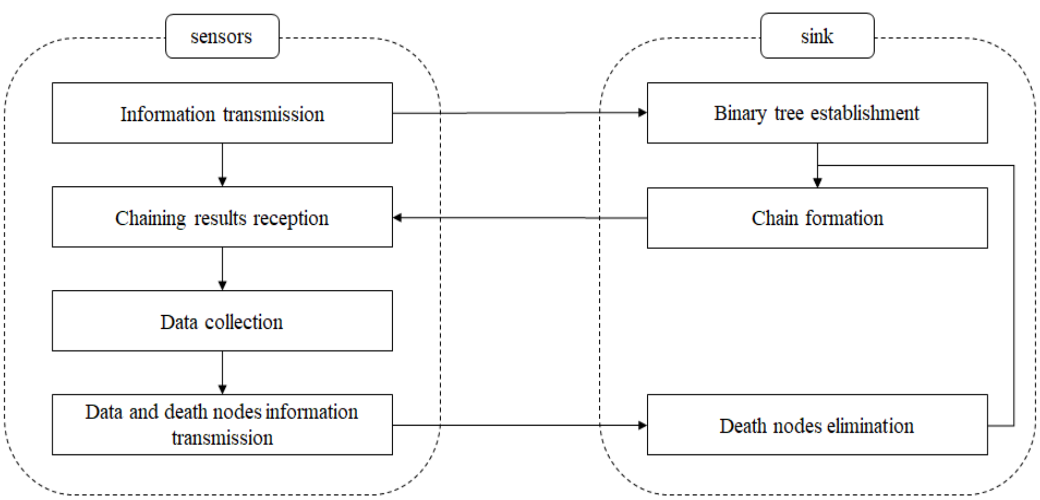

Figure 2. Workflow

3.1. Initial communication phase

When sensor nodes are randomly distributed in the sensing region, the initial communication phase begins. In this phase, the chain-based structure has not been established. Each sensor can get its location by GPS signal and then transmits its location information to a sink. The sink obtains its location information from all sensors. After the information transmission is finished, the algorithm enters the chain formation phase.

3.2. Chain formation phase

In this phase, all sensors are organized into a single chain. Firstly, the set of sensors in the sensing region is made into the binary tree using the concept of the KDB-tree algorithm. The KDB-tree algorithm sorts the location coordinates of sensor nodes. Figure 3 explains to divide the sensing region with 2-dimension by the concept of the KDB-tree algorithm from even and odd overall sensors. In a 2-dimension region, the region is split into two sets such as L1 and R1 or L2 and R2 based on the half of sensors of the overall number as shown in [Figure 3]. When sensor nodes are even, the root is decided within the left division region, as shown on the left side (a) even nodes in [Figure 3]. Until all sensors become the binary tree's node, the process shown so far is performed iteratively in both of the x- or y-dimension. The final chaining result is formed using the in-order traversal of a binary tree. In the proposed scheme, the result of chaining, which is calculated in the sink, is broadcasted to each sensor. When all sensors receive chaining results, the chain-based network structure is constructed.

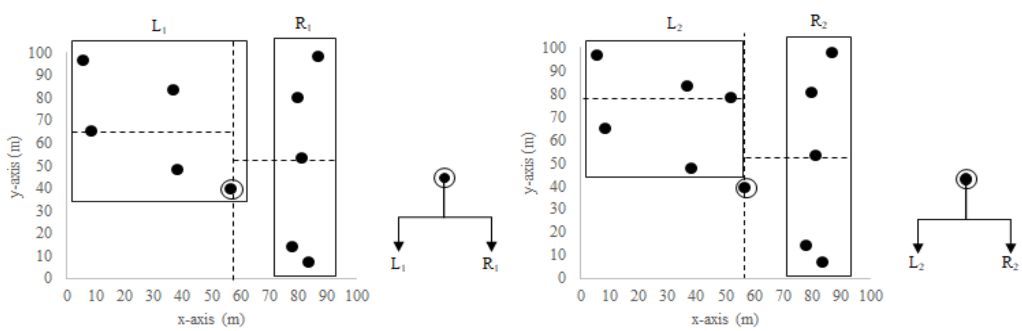

Figure 3. Splitting sensor nodes

3.3. Data collection phase

To collect data in the *r*th round, a leader node is elected by *R mod N* (*R*: round, *N*: number of sensors). The leader node uses the token-passing mechanism and takes turns transmitting the aggregated data to a sink. The small token does not affect simulation results. In each round, a sensor node transmits its data, which is aggregated, and the information of death nodes toward a leader node. Each sensor performs the data aggregation. The sink calculates the chain-based network structure for the next round via the information of death sensors and then broadcasts. The chain formation phase is repeated to start the next round. In our scheme, because sensor nodes are made into a binary tree using the concept of KDB-tree and then the chain-based network structure is calculated by the in-order traversal algorithm, sensor nodes can communicate with their near neighbors for collecting data. Therefore, our scheme can solve the intra-communication overhead of long-distance data transmission and the unbalanced energy consumption.

3.4. Research method

To analyze and evaluate the performance of our study, the simulation experiments are carried out until the first sensor dies using the OMNET++ simulator. The performances of our scheme are analyzed and compared with the existing PEGASIS and Enhanced PEGASIS in terms of network lifetime and average residual energy. When a sink receives data from a leader node, the total number of rounds means the network lifetime is added. The average residual energy means the average energy values of alive nodes.

For the simulation, assumptions and conditions are defined as follows:

- Sensor nodes are randomly distributed in the sensing field. They are homogeneous.
- Each sensor is aware of its stationary location via GPS signals.
- Sensor nodes can transmit their data to a sink and adjust their radio range.
- There are restrictions on their energy, and they cannot be recharged.

4. Simulation results

4.1. Simulation parameters

The radio model, which is defined in [Table 1] is the same as PEGASIS and Enhanced PEGASIS. In Table 1, in the transmitting formula, $E_{TX}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^2$, the total transmitting energy, $E_{TX}(k, d)$ is computed E_{elec}, which is the amount of energy consumption of the electronic circuit for transmitting or receiving the signal, *k-bit* packet, ϵ_{amp}, which the energy consumption of amplifiers, and d, which is the communication distance. The communication distance d considers d^2 energy transmission loss. The Receiving formula is computed E_{elec} and *k-bit* packet. In [Table 2], the parameters (number of sensor nodes, coordinate of a sink, sensing region, transmitter or receiver circuitry, transmitter amplifier, energy used for data aggregation, the initial energy of each node, packet size) are listed for the simulation.

Table 1. Radio model

Radio Model	Formulas
Transmitting	$E_{TX}(k, d) = E_{elec} * k + \epsilon_{amp} * k * d^2$
Receiving	$E_{RX}(k) = E_{elec} * k$

Table 2. Parameters

Parameter	Value
Number of Sensor Nodes	50, 100, 150, 200
Coordinate of a Sink	(50, 300)
Sensing Region	100 ×100 m2
Transmitter or Receiver Circuitry	50 nJ/bit
Transmitter Amplifier	100 pJ/bit/m2
Energy Used for Data Aggregation	5 nJ/bit/message
Initial Energy of Each Node	1 J
Packet Size	2000 bit

4.2. Analysis of network lifetime

In [Figure 4], the number of sensor nodes and the result of network lifetime are represented in X-axis and Y-axis coordinates, respectively. As [Figure 4] shows, in case the number of sensors is 50, the lifetime performance of our scheme is 1211. It shows about 3 to 6 times more efficient performance results compared to PEGASIS and Enhanced PEGASIS. Until the first sensor died, these results were measured. The results would lead to different results according to parameters, and the measurement time.

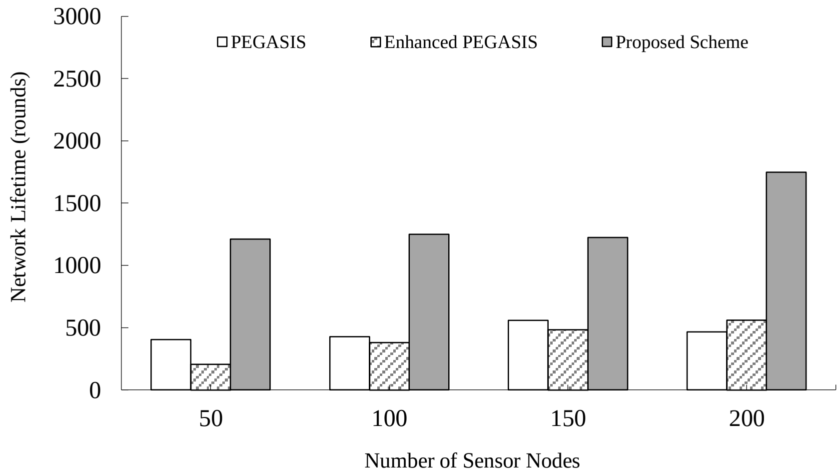

Figure 4. Network lifetime between different algorithms

4.3. Analysis of average residual energy

[Figure 5] illustrates the average residual energy when the first sensor node dies. In Figure 5, the number of sensor nodes and the average residual energy is represented in X-axis and Y-axis coordinates, respectively. In simulation results, PEGASIS and Enhanced PEGASIS consumed less than the energy consumption of our scheme. This result means the unbalancing energy usage caused by the long-distance communication of some sensors in PEGASIS and Enhanced PEGASIS. These results need to tie it into the previous '4.2. Analysis of the network lifetime'. Overall, our scheme achieved a more balanced energy consumption of sensor nodes.

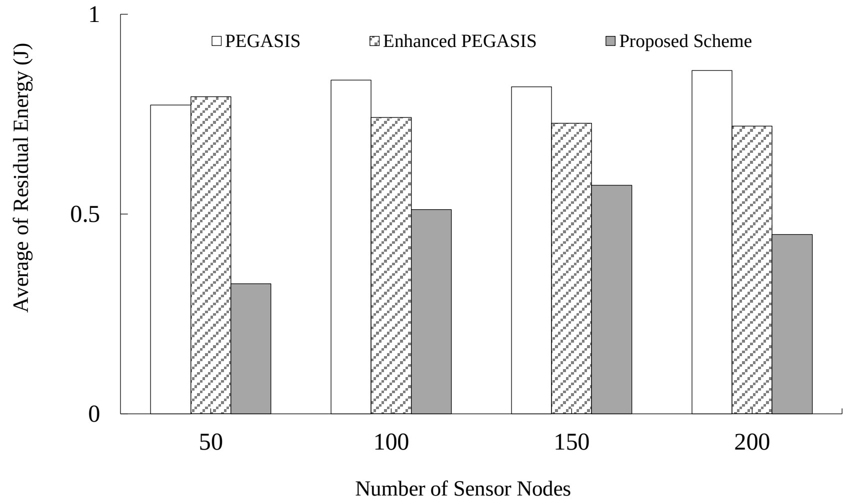

Figure 5. Average residual energy between different algorithms

5. Conclusion

In WSNs, in which sensor nodes are randomly distributed, energy is rapidly exhausted due to the unbalanced energy consumption and then the network performance is decreased, hence the routing algorithm for balanced energy consumption has been one of the important issues. In this paper, a chain formation scheme is presented, which can balance energy consumption. The proposed scheme consists of an initial communication phase, chain formation phase, and data collection phase. An initial communication phase exchanges the information between each sensor and a sink. In the chain formation phase, the concept of the KDB-tree algorithm calculates a k-dimensional binary tree and then the binary tree is organized into a chain using an in-order traversal algorithm. Finally, the gathering and transmitting of data are conducted in the data collection phase. In our proposed scheme, the simulation results for the network lifetime have shown about 3 to 6 times more efficient performance results compared to PEGASIS and Enhanced PEGASIS. In the comparative analysis of the average residual energy, our scheme has been verified more effective in terms of the unbalanced energy consumption caused by the intra-long-distance communication between sensors than PEGASIS and Enhanced PEGASIS. Because the main contribution of our study is to divide the sensing region, adjacent sensors can be grouped for data transmission. Sensor nodes can avoid long-distance data transmission in intra-communication. However, the problem of unbalanced energy consumption in WSNs is not disappearing. Since energy consumption is still one of the important issues in WSNs, our future research plan will focus on improving chaining performances for balancing energy consumption.

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