Master's Thesis

Title

Proposal and Evaluation of an Information Sharing Method for All-to-All Communication in Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) consist of a large number of small nodes with sensing, computation, and wireless communication capabilities. Since it is wasteful and redundant to deploy multiple and independent application-oriented WSNs consisting of dedicated nodes and devices in the same region, a multi-purpose WSN has been attracting researchers in recent years. In a multi-purpose WSN, application or service-oriented networks are overlaid and they share physical nodes and devices. Each service network consists of nodes contributing to the application, e. g. nodes equipped with corresponding sensors or actuators and nodes which relay messages among them, and they exchange messages with each other to provide users with desired functions or services. Limiting message exchanges to nodes belonging to the same service network would help in saving energy and bandwidth to some extent. However, as the number of applications increases, concurrent multiple service networks dissipate energy and bandwidth. There have been many proposals for efficient information sharing in WSNs and they have advantages and disadvantages. Characteristics of information sharing methods differ from each other and their performance depends on several conditions such as the size of region and the node density. We conducted comprehensive evaluation of information sharing methods and found that a ring scheme was the most efficient among the six, whereas it had some disadvantages. Especially in a large scale network, the ratio of receiving node is lower, because each source node sends a data message in a short time and a node forwards a data message right after reception. On the contrary, none of methods could accomplish the perfect information sharing. In this thesis, we consider to improve a ring-based method to accomplish the perfect information sharing. Our proposal is based on a token-ring mechanism adopting multiple rings. It consists of three phases, i.e. area decomposition to decrease the size of ring for faster information sharing, ring construction for circular shape of ring, and scheduling for collision avoidance among tokens. Through simulation experiments, it is shown that it is shown that our method accomplishes the perfect and fast all-to-all information sharing.

Keywords

Wireless Sensor Network
All-to-All Communication
Information Sharing
Token Ring

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1 Introduction

Wireless sensor networks (WSNs) consist of a large number of small nodes with sensing, computation, and wireless communication capabilities. Because of easiness of deployment with the help of battery power supply a variety of applications are considered, ranging from factory automation, smart agriculture, home/office automation, surveillance, environmental monitoring, supply chain control, and security [1]. Since it is wasteful and redundant to deploy multiple and independent application-oriented WSNs consisting of dedicated nodes and devices in the same region, a multi-purpose WSN has been attracting researchers in recent years [2, 3]. In a multi-purpose WSN, application or service-oriented networks are overlaid and they share nodes and devices. Each service network consists of nodes contributing to the corresponding application, e.g. nodes equipped with corresponding sensors or actuators and nodes which relay messages among them. Participating nodes exchange messages with each other to provide users with desired functions or services. Limiting message exchanges among nodes belonging to the same service network would help in saving energy and bandwidth to some extent. However, as the number of applications increases, concurrent multiple service networks dissipate energy and bandwidth.

Additionally, in the case of event-driven systems such as a fire or intrusion detection system, the number and location of nodes which actively participate in event-driven actions would dynamically change depending on the condition of the event. For example, in a case of a smart fire detection system, a thermometer or a smoke detector first detects unusual condition, e.g. high temperature or smoke. The node sends a message to a home server to inform the possibility of fire. The home server then collects information from other thermometers and smoke detectors to confirm the occurrence of fire. If it surely is a fire, the home server sends a message to a node with an alarm to activate the fire alarm. It also needs to investigate whether people exist in a room or not by sending a request message to a node with a human detection sensor to ask for a report. When the home server gets information saying that there is none in the room, it then sends messages actuator nodes attached to doors and windows to close them. As can be seen, it takes time to take appropriate actions in such a scenario where a series of consequent control is required. One simple solution is for a home server to frequently collect information from all nodes regardless of the presence of an event. However, a home server becomes a single point of failure and it spoils the robustness and reliability of the fire detection system. Another solution is to adopt distributed decision making, where each node decides their actions without being ordered by a home server. Furthermore, if each node has up-to-date information about other nodes, it can considerably shorten the response time against an event. Sharing information also enhances the robustness of a system against message loss and node failures. However, for this purpose, we need an energy and bandwidth efficient mechanism for all-to-all communication.

There have been many proposals for efficient information sharing in WSNs [4] and they have advantages and disadvantages. For example, a flooding-based method is the most primitive method which is simple and easy to implement. However, their greedy information forwarding by broadcasting causes duplicated information reception, bandwidth starvation, and low delivery ratio, especially in a high-density network. A publish/subscribe-based method such as SPIN [5] was proposed to avoid redundant information transmission by introducing a handshaking procedure prior to information forwarding. A node having information to disseminate first checks whether any neighbor nodes have not received the information. Then it sends the information to neighbor nodes if it receives a request for information transmission. Such handshaking helps in reducing the number of information transmissions and receptions, but it would consume more energy and bandwidth and take longer time than a simple flooding method in disseminating new information.

As discussed above, characteristics of information sharing methods differ from each other and their performance depends on several conditions such as the size of region and the node density. Therefore, we need to carefully select a method fulfilling requirements of desired functions or services under the expected operational condition. Since the performance of methods is evaluated under a specific condition in preceding literatures and we cannot directly compare them, in reference [6], we conducted comprehensive evaluation of information sharing methods to clarify their comparative characteristics and the range of application. We first classified existing information sharing methods into six, i.e. flooding, gossiping, publish/subscribe, ring, tree, and cluster. Then we evaluated their model methods from viewpoints of the scalability by changing the size of observation region and the node density considering application to all-to-all communication. As a result, we found that a ring scheme was the most efficient among the six, whereas it had some disadvantages.

However, none of methods could accomplish the perfect information sharing. With perfect information sharing, each node can always perform optimal behavior appropriate for the situation, which can reduce the possibility of malfunction and improve the reliability of a system. In this thesis, we propose an information sharing method which can accomplish the perfect all-to-all information sharing based on the ring-based method. In a ring-based method, only one or two nodes receive information at a time. As such, it takes time proportional to the size of a ring. Furthermore, all nodes try to disseminate information at their own timing. It causes congestion and results in formation loss and delay. Therefore, in our method, the region is first divided into some areas and a ring is constructed within each of areas. Then, a ring is constructed from nodes in an area. Furthermore, to control the timing of message emission, we employ a mechanism of the token ring [7]. Actually, there is a proposal on a wireless token ring protocol and it is viable. In reference [8], the authors propose the Wireless Token Ring Protocol (WTRP). The WTRP is distributed medium access control protocol for ad-hoc networks. However, when we consider all-to-all information sharing using multiple rings, we further need to introduce mechanisms to exchange information among rings and to avoid collisions among tokens of neighboring rings.

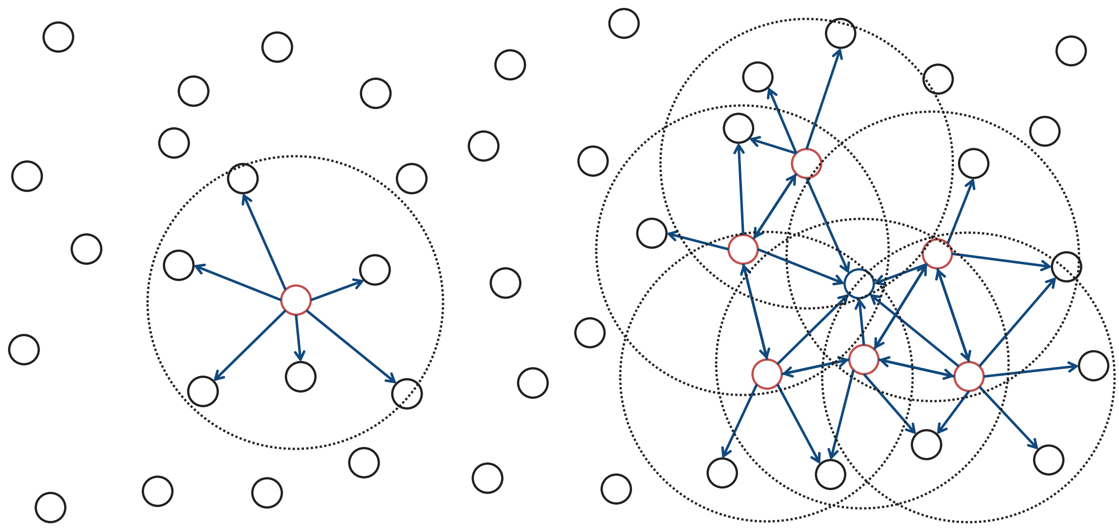
The remainder of this thesis is organized as follows. First, in section 2, we briefly describe six categories of information sharing methods. Next, in section 3, we present results of comparative evaluation of information sharing methods and discuss their characteristics. Third, in section 4, we propose an information sharing method for all-to-all communication based on region decomposition and a token-ring mechanism. Then, in section 5, we present results of simulation experiments. Finally, in section 6, we state concluding remarks and future work.

2 Related work

In this section, we group well-known information sharing methods mainly for all-to-one or one-to-all communication into six major categories and explain how they can be applied to all-to-all communication. Hereafter, information to be shared among nodes, e.g. sensing data in a case of WSN, is called *data*, a node which generates data is called *source node*, and a message carrying data is called *data message*. Moreover, a message other than a data message is called *control message*. We assume that a data message does not contain any control information.

Flooding-based Method

A flooding-based method is the most basic method. With a flooding-based method, a source node broadcasts a data message to all of its neighbor nodes (Fig. 1(a)). A neighbor node which receives the data message for the first time rebroadcasts the data message to all of its neighbor nodes. Otherwise, it silently discards the data message (Fig. 1(b)). By repeating the forwarding procedure, the data message is eventually received by all nodes in the network under ideal condition. To accomplish all-to-all communication, all nodes become source nodes and initiate flooding. In figure, we use solid line as broadcast communication and blue line as sending a data message.

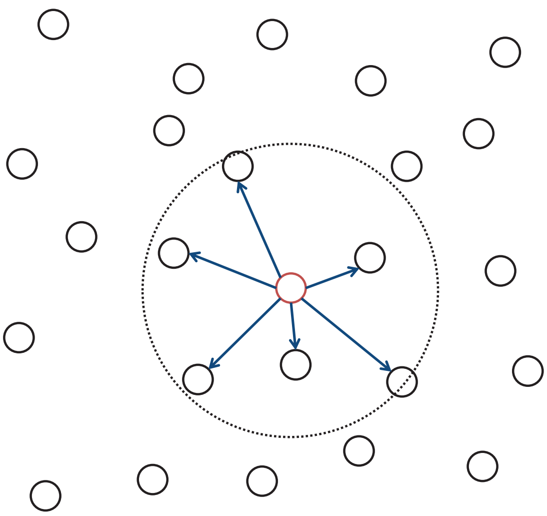


(a) Broadcast a data message (b) Rebradcast a data message

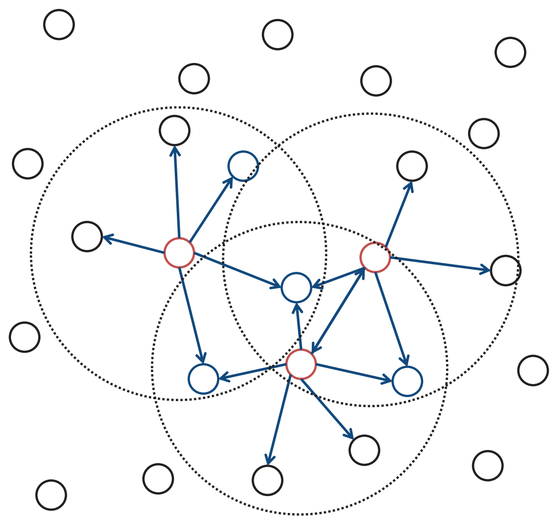
Figure 1: Flooding-based method

Gossiping-based Method [9–11]

A gossiping-based method is similar to a flooding-based method, but message fording is done in a stochastic manner. With a gossiping-based method, a source node broadcasts a data message to all of its neighbor nodes (Fig. 2(a)). A neighbor node which receives the data message for the first time broadcasts the data message with probability p $(0 < p < 1)$ to all of its neighbor nodes (Fig. 2(b)). Otherwise, it silently discards the data message. As far as the forwarding probability p is sufficiently large, whose critical value can be given by the percolation theory [12], the data reachability can stochastically be guaranteed. As in the flooding-based method, all nodes become source nodes and initiate data dissemination for all-to-all information sharing.



(a) Broadcast a data message

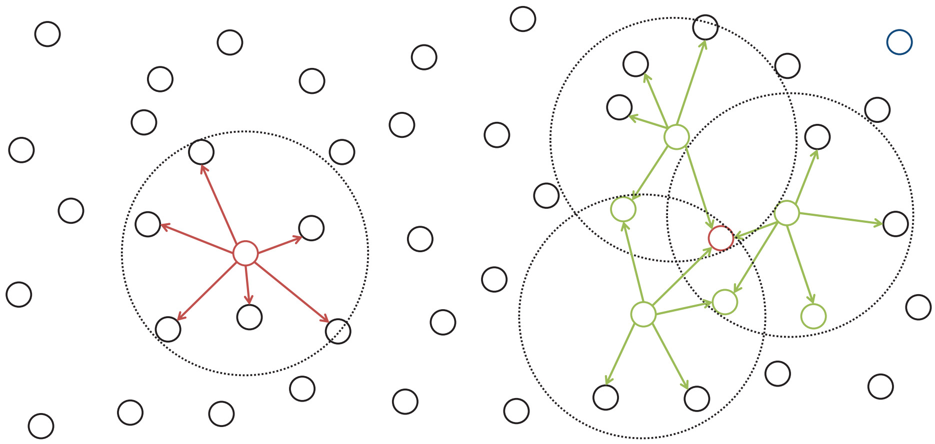


(b) Forward a data message with probability p

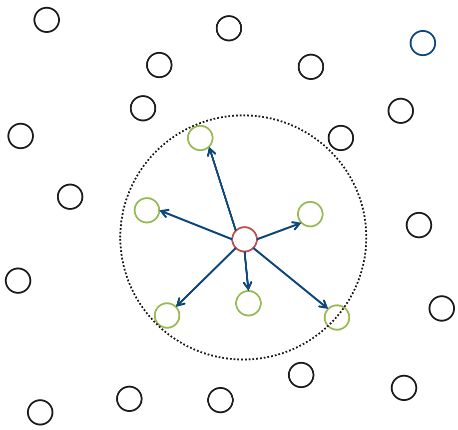
Figure 2: Gossiping-based method

Publish/Subscribe-based Method [5, 13]

Both of the above methods adopt broadcasting in forwarding a data message. As such, there is a possibility that a node receives the same data message several times especially in a densely connected network. To avoid the redundant message reception, a publish/subscribe-based method introduces a handshaking procedure before data message transmission. When a source node has new data to share or a node receives new data, they first broadcast a small message, called meta-data, which contains the information about the data to send, so that neighbor nodes can judge whether they need to receive the data or not (Fig. 3(a)). If a neighbor node has not received the data, it sends a request message to the sender of the metadata (Fig. 3(b)). Then, the sender sends the data message to the requesting node (Fig. 3(c)). There are variants of publish/subscribe-base methods, which differ in the way that a node sends control and data messages, such as SPIN-PP and SPIN-EC [13]. We base our discussion on a method which adopts broadcasting in control and data message transmission. All-to-all communication can be accomplished by initiating data emission at all nodes. In figure, we use red line as sending a meta-data and green line as sending an request message.



(a) Broadcast a metadata (b) Replay a request message



(c) Broadcast a data message

Figure 3: Publish/Subscribe-based method

Ring-based Method [14, 15]

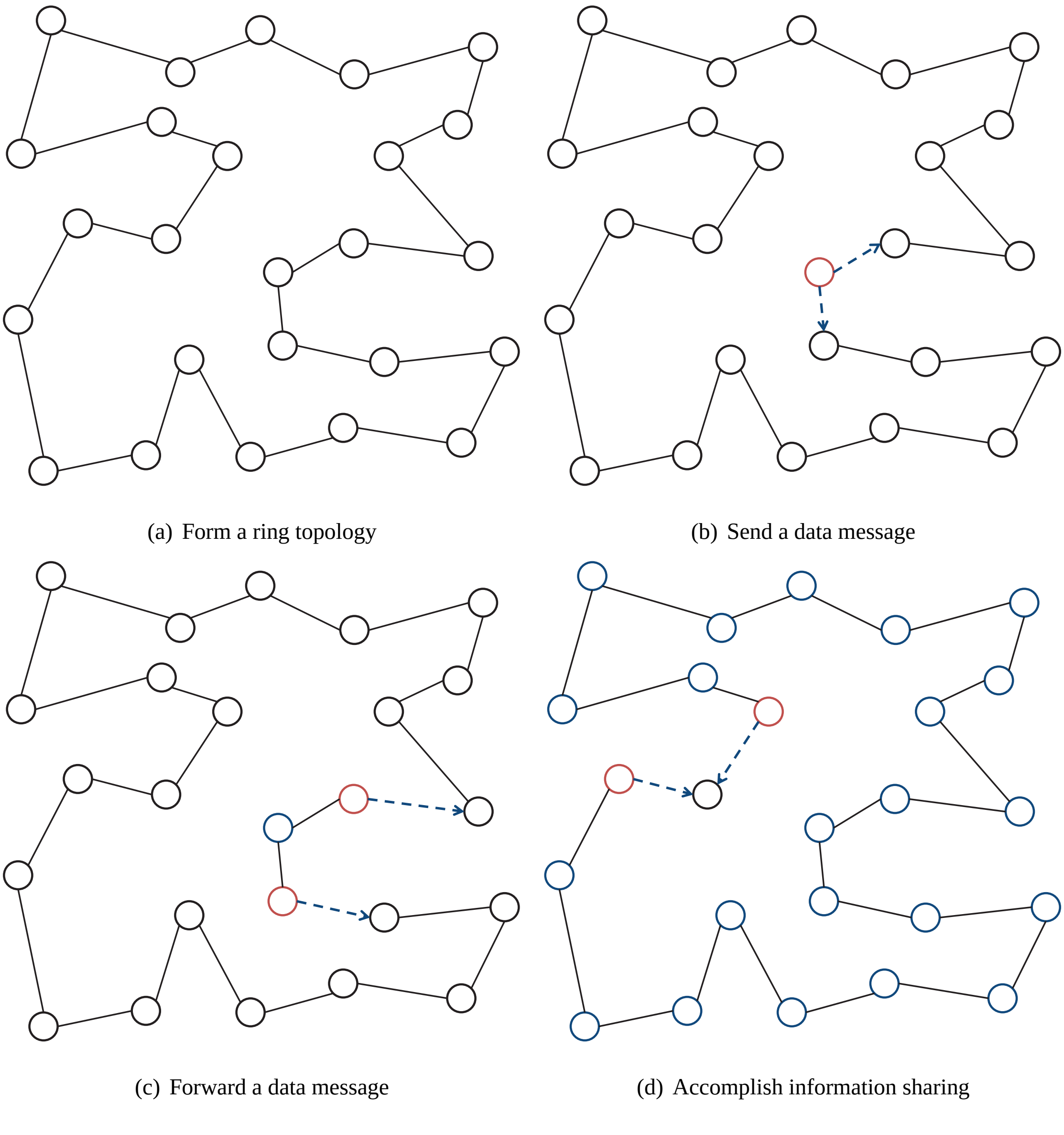
Differently from the above three methods, the following three methods rely on the topological structure of a network for efficient data sharing. With a ring-based method, all nodes in a network form a ring over the physical network topology (Fig. 4(a)). Independently of the actual number of physical neighbor nodes within the range of radio communication, each node has only two neighbors on a ring. First a source node sends a data message to two adjacent nodes in unicast communication (Fig. 4(b)). Next, a node receiving the data message forwards it to the neighbor node on the other side if it is the first reception (Fig. 4(c)). Two data messages traverse the ring both clockwise and counterclockwise respectively, and they eventually meet at the node locating at the opposite side of the source node on the ring. At this time, data sharing is considered finished (Fig. 4(d)). In the ring-based method, all nodes start sending its data message for all-to-all communication. In figure, we use dashed line as unicast communication.

Tree-based Method [16, 17]

With a tree-based method, a single tree topology which consists of all nodes in a network is constructed (Fig. 5(a)). A data message first goes up to a root of the tree and then it is distributed to all nodes. A source node first sends a data message to its parent node in the tree (Fig. 5(b)). If it is the first time that a parent node receives the data, it forwards the data message to its parent node (Fig. 5(c)). By repeating the process, the data message finally arrives at the root node. Then, the root node broadcasts the data message to all child nodes (Fig. 5(d)). They forward the data message by broadcasting if they have not done. Eventually, all leaf nodes located at the bottom of the tree receive the data message and data sharing is completed at this time. In the case of a tree-based method, not only superimposing one-to-all data sharing but data aggregation can be used to accomplish all-to-all communication.

Cluster-based Method [18–20]

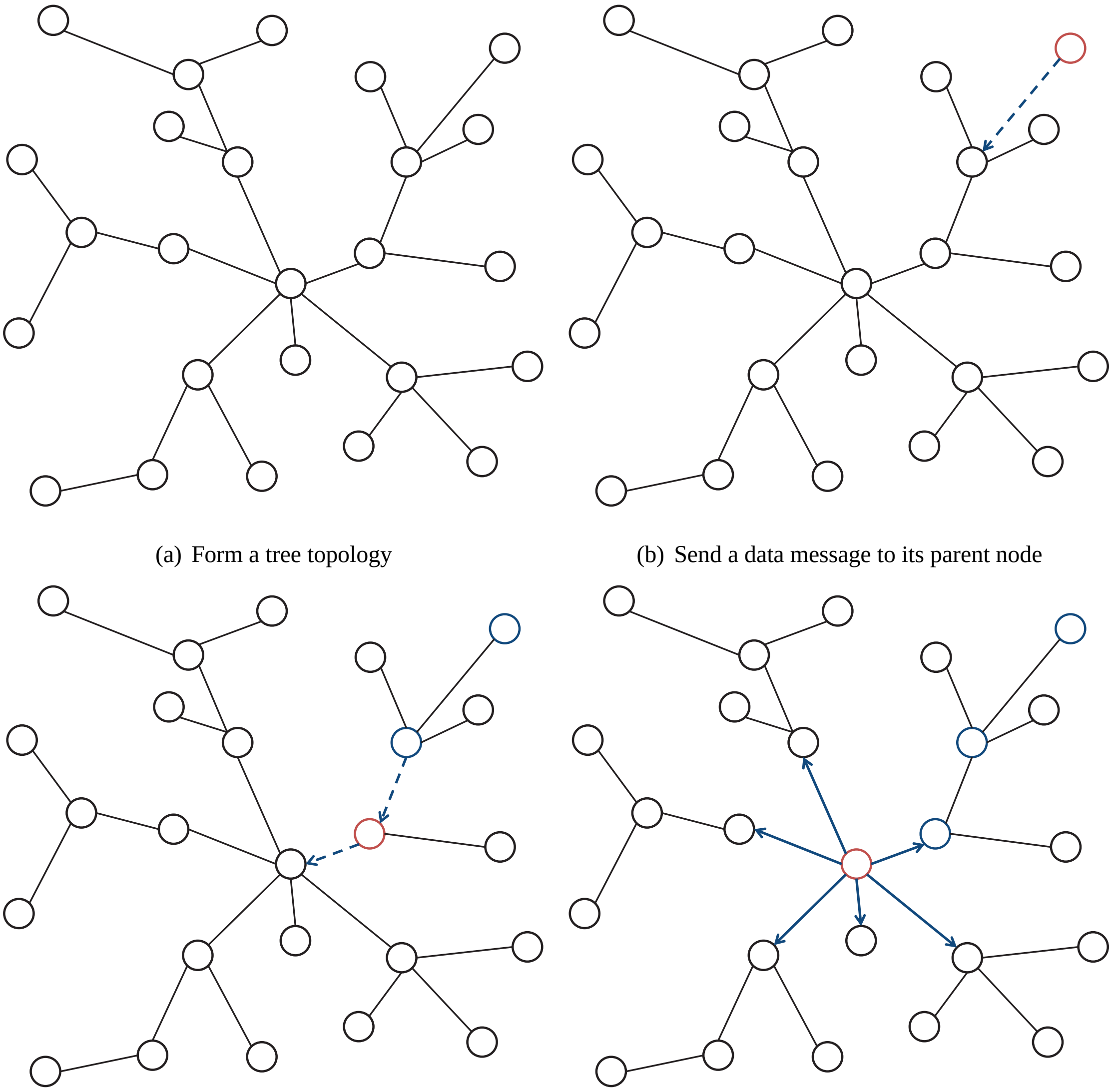
To save energy consumption in data dissemination and gathering, many researchers consider cluster-based methods are the most promising [21]. Nodes are grouped into clusters with a cluster-based method in accordance with their proximity and one node is appointed as a cluster head in each cluster (Fig. 6(a)). A cluster head is responsible for data dissemination and gathering within



(a) Form a ring topology (b) Send a data message

(c) Forward a data message (d) Accomplish information sharing

Figure 4: Ring-based method



(a) Form a tree topology

(b) Send a data message to its parent node

(c) arrive at the root node

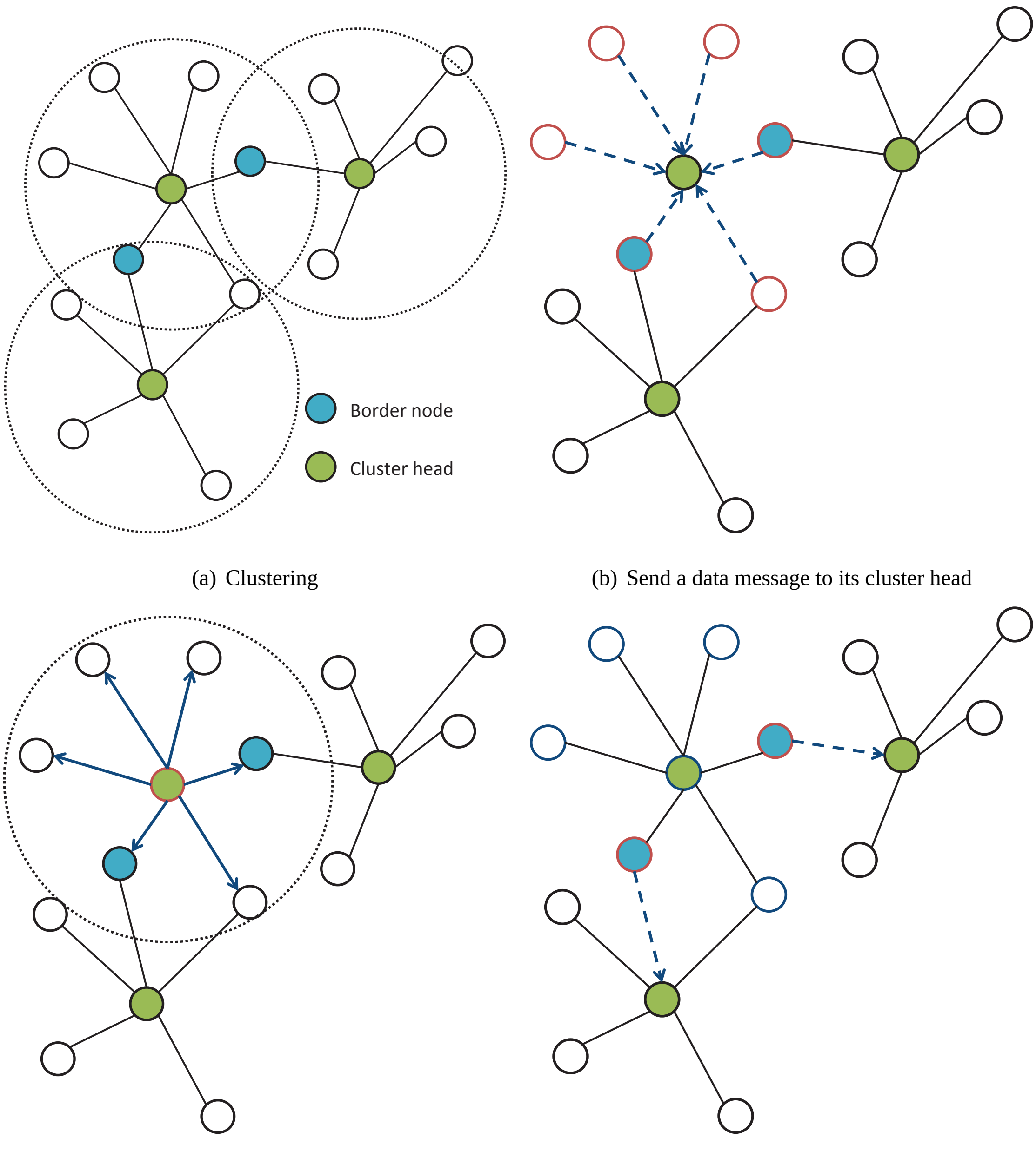
(d) Broadcast a data message

Figure 5: Tree-based method

its cluster and data exchange among clusters. The other nodes in the cluster are called cluster member. Although there are a variety of clustering methods proposed in literatures, in this paper we consider a method explained below as a typical and representative method.

The method consists of two phases. First in the clustering phase, a certain number of nodes in a network elect themselves as cluster heads by, for example, an algorithm used in LEACH [18], and broadcast an advertisement message. Other node receiving the advertisement message becomes a cluster member of the sender. A node which receives two or more advertisement messages is called border node. It becomes a cluster member of a cluster head with the highest signal strength and participates in inter-cluster message transmission in the data transmission phase. Then, a cluster member sends a join message to the cluster head.

Once clusters are organized, next in the data transmission phase, a cluster member, i.e. a source node, sends a data message to its cluster head (Fig. 6(b)). Next, a cluster head broadcasts a data message, which contains both of data received from cluster members and its own data, to all cluster members (Fig. 6(c)). A border node in the cluster then forwards the data message to the other cluster heads from which it received advertisement messages (Fig. 6(d)). When there are two or more border nodes in a cluster, one of them is appointed as a forwarder by a cluster head. If it is the first time that a neighbor cluster head receives the data message, it aggregates all data it has and broadcasts an aggregated data message to cluster members. Consequently, data is shared among all nodes in the network.



(a) Clustering

(b) Send a data message to its cluster head

(c) Broadcast a data message to its cluster members

(d) Send a data message to another cluster heads

Figure 6: Cluster-based method

Table 1: Comparison of information sharing methods

	Flooding	Gossiping	Pub/Sub	Ring	Tree	Cluster
Narrow area	△	△	△	○	◎	×
Wide area	△	△	△	×	×	×
Low density	○	○	○	△	◎	×
High density	×	×	×	△	△	×

3 Comparative evaluation of information sharing methods

In ref [6], we conduct comprehensive evaluation of information sharing methods to clarify their comparative characteristics and the range of application. As performance measures we used the ratio of receiving nodes and the ratio of active time to evaluate the efficiency of information sharing. Table 1 shows the pros and cons of each information sharing method.

In the case of changing the number of nodes, a tree-based method accomplishes the highest ratio of receiving nodes in the small number of nodes, but the performance drastically deteriorates with the increase in the number of nodes. The reason is that there occur collisions among data messages going up toward the root node and those going down toward leaf nodes. Although a node discards data messages received after the waiting time to avoid such collisions, the waiting time becomes insufficient for a tree of high height. A ring-based method also suffers from the increase in the number of nodes. Since a node forwards a data message right after reception, it experiences more collisions than a tree-based method and gives up transmission for backoff counter limitation. A reason why a cluster-based method results in the lowest performance is in inter-cluster message transmission. Message broadcasting from a border node to neighbor cluster heads and from a cluster head to border nodes often collide with each other. As a result, data are only shared among nodes belonging to the same cluster.

Differently from the topology-dependent methods, we can observe the increase in the ratio of receiving nodes with flooding-based, gossiping-based, and publish/subscribe-based methods. The reason is that they adopt broadcasting in data message forwarding. Broadcasting does not negotiate channel usage by RTS/CTS with neighbor nodes, confirm reception of data message, or MAC-layer retransmission as unicasting does. As such, the ratio of receiving nodes is lower than the tree-based method and the ring-based method for cases with the small number of nodes.

In the case of changing the node density, a tree-based method accomplished the highest ratio of receiving nodes independently from the node density. It is because the tree height remains the same against density changes, while the higher tree causes performance deterioration. A ring-based method achieves the slightly higher ratio of receiving nodes among the remaining methods for unicast-based message forwarding. The other methods suffer very much from the increase in the node density. Broadcasting is apparently an ineffective mean of message transmission in a dense network.

As a result, we revealed that a tree-based method well fits to the small observation region regardless of the node density and a flooding-based method can achieve the higher ratio of receiving nodes in the large observation region. However, none of methods could accomplish the perfect information sharing. A tree-based method achieves the high performance in particular cases. However, the ratio of receiving node rapidly decreases as the size of region increases, although it is not shown here. The performance of a flooding-based method is lower in the high density network. In a ring-based method, since each source node sends a data message in a short period of time and a node forwards a data message right after reception, it gives up transmission for backoff counter limitation. However, because most of data messages without backoff counter limitation are shared by all nodes, the ratio of receiving node is constant in wide area. If a ring-based method can avoid giving up transmission for backoff counter limitation, the ratio of receiving nodes becomes highest in all methods. Therefore, we propose an information sharing method based on a ring-based method in section 4.

4 Information sharing method using multiple rings

4.1 Overview

Our previous study in [6] showed that a ring-based method has the most stable performance. Therefore, we further improve the ring-based method and propose a new ring-based information sharing method in this thesis. Our method consists of three algorithms, which are area decomposition, ring construction, and scheduling. In a ring-based method, a time taken in an information sharing process becomes longer becomes larger in respect to the increasing number of nodes in the ring. It suggests that we can reduce the time for information sharing by dividing the monitoring region into some areas and constructing a ring for each area. Regarding the ring construction, we need to design a ring which the power consumption becomes smaller in a WSN. Therefore, we set the objective function to the sum of the squares of distance. Another problem is the limitation of unicast communication which allows only a single node in the same communication range to transmit at a time due to the RTS/CTS mechanism. Therefore, we need to consider a scheduling algorithm that can avoid collision both within a ring and between rings.

In this thesis, we use a combination of centralized and distributed control. On one hand, we assume that there is a centralized server that can exactly location information of all nodes that are immobile. Based on the obtained information, it performs area decomposition and ring construction and notifies the results to all nodes. In the future, we will relax this assumption. On the other hand, message transmission is handled by each node in a distributed manner. We describe area decomposition in section 4.2, ring construction in section 4.3, and scheduling in section 4.4.

4.2 Area decomposition

In a ring-based information sharing scheme, it is known that the information sharing time is roughly proportional to the number of nodes participating in a ring. Area decomposition, which reduces the number of nodes belonging to a ring can decrease information sharing time per ring and in total. Moreover, for the sake of easier scheduling to avoid collision among rings, the decomposed areas should have roughly equal number of nodes. In order to do so, we use k-means clustering algorithm which divides the area in a way that each cluster has an equal number of nodes [22].

In the k-means clustering algorithm, nodes are divided into k clusters based on their location with a constraint that each node belongs to only one of k clusters. Initially, each node $x_i(i = 1, ..., n)$ is allocated randomly to one of k clusters. Then, the gravity center of each cluster $V_j(j = 1, ..., k)$ and the distance between each node x_i and the gravity center of each cluster V_j are calculated. Subsequently, each node x_i is reallocated to a cluster with the nearest gravity center. The recalculation and reallocation process are repeated until the center gravities of all clusters do not change. At that time, the area decomposition process is completed (Fig 11). However, the k-means clustering does not guarantee the connectivity of nodes in a cluster and the connectivity of clusters. In order to communicate with any nodes, the connectivity between any clusters is required. In the following steps, the connectivity between any clusters is constructed. First, we find the node x_1, which is in a module except for "cluster 1 ' ' and the closest to the gravity center V_1 in the cluster 1. Second, we give the node x_1 the role of relaying token between the two clusters and scheduling transmission timing of nodes in cluster 1. Third, we find nodes which are corresponding to nodes x_1 in each cluster in the network. Finally, we conducts above steps for other clusters which are not cluster 1 (Fig. 7(c)).

4.3 Ring construction

In this section we describe how to construct a single ring topology using connection relationship between nodes in each divided area. This problem can be generalized as the Traveling Salesman Problem (TSP). There are many proposed heuristic algorithms for solving TSP, such as, genetic algorithm, simulated annealing, Tabu search, etc [23].

In this thesis, we construct a ring topology using a genetic algorithm based on following steps. First, one random initial solution is generated. Next, 1000 solution candidates are created by rearranging three connections of the initial solution. Then, the initial solution is replaced by a solution candidate which has the lowest objective function. Then, solution candidates are created from the solution which replaces the initial one and evaluate the objective function. In this case, a smaller value of the objective function means a better solution. The process is repeated until the current solution has the lowest value of the objective function against 1000 candidates. In our method, we define the objective function as the square sum of the Euclidean distance between nodes 8.

4.4 Scheduling

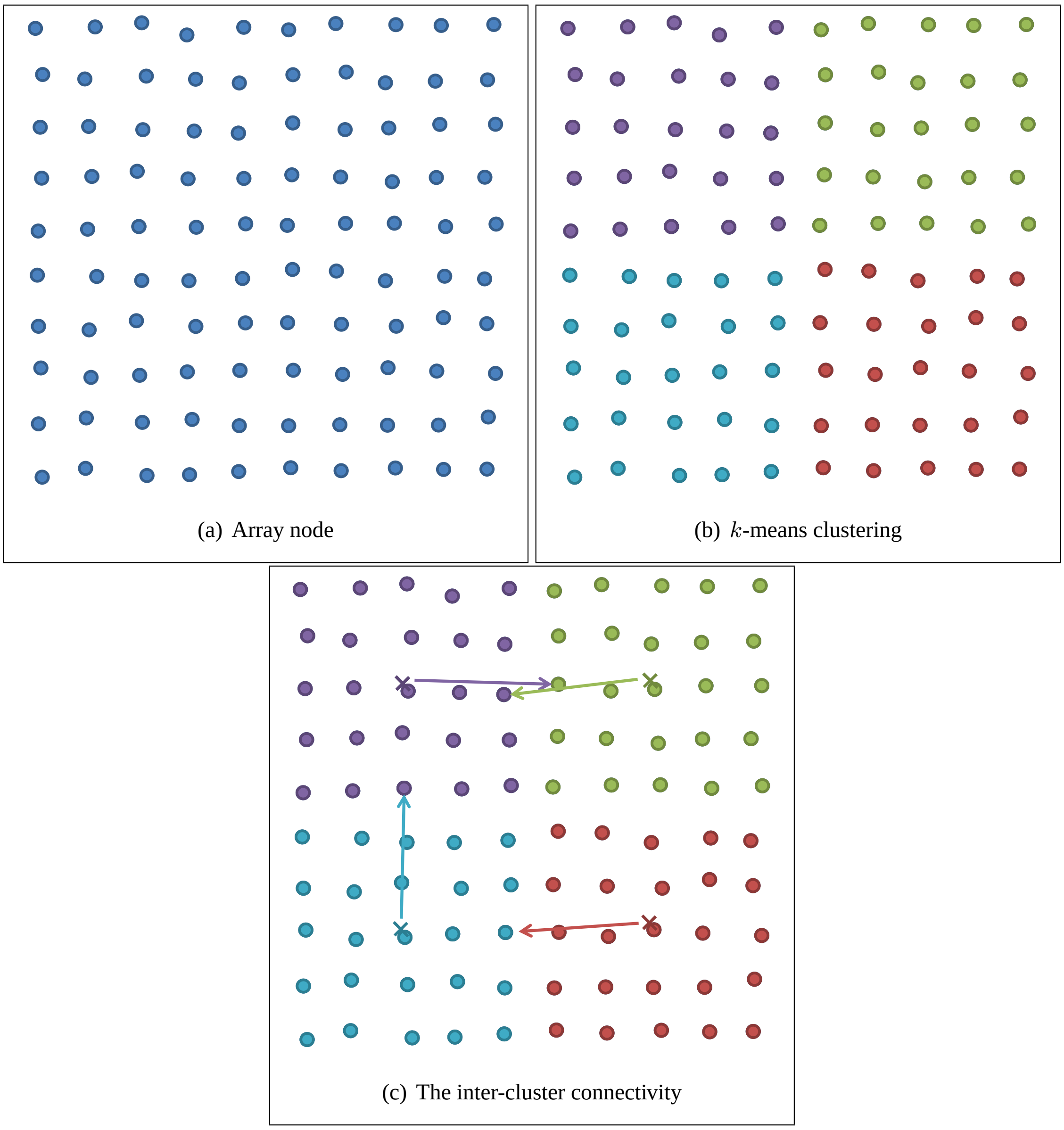
As the basis of scheduling, we adopt a general token-ring mechanism. A token moves along a ring. When a node has information to send, it first needs to catch an empty token. Next it attaches information to the empty token and sends it to a next node on a ring by unicasting. Then, nodes on a ring receive the token with information. Finally, the token comes back to the originating node. At that time, the node considers that information is successfully shared among nodes on a ring. It empties the token and releases it on a ring. It is a simple and reliable mechanism. However, in a case of multiple rings, there is possibility of loss of token due to collision among rings and transmission failure for backoff counter expiration.

To avoid collision of tokens, we adopt DESYNC [24] which is the information collection method having a de-synchronization mechanism to distribute timing of message emission among nodes. Here, we assume that there are ring i, which has token p_i, and ring j, which has token p_j. Ring i is connected to ring j at node n_i. Node n_i originally belongs to a cluster j of ring j, but it is made to join cluster i of ring i for inter-ring connectivity in the area decomposition phase. Node n_i is specifically called *coordination node* which controls de-synchronization of token by shifting emission of token p_i. A coordination node n_i has a timer. The phase of the timer is denoted as ϕ_i which is the elapsed time for transmitting token p_i. When coordination node n_i transmits token p_i, it records $T = \phi_i$ and its phase $\phi_i = 0$. When coordination node n_i receives token p_j before emission a token p_i, it records phase difference $\phi_i^{prev} = T - \phi_i$. When coordination node n_i receives token p_j after emission a token p_i, it records phase difference $\phi_i^{next} = \phi_i$. Then it calculates the shift based on the following equation.

$$\phi_i^{change} = \alpha\phi_i + \alpha\frac{\phi_i^{prev} + \phi_i^{next}}{2} \quad (1)$$

α is a parameter which determines the speed of converge to a steady state. We use $\alpha = 0.95$. If ϕ_i^{change} is larger than 0, the coordination node n_i defers transmission of token p_i for ϕ_i^{change} after receiving it (Fig. 9). As a result, a coordination node can receive each token at equal interval.

Next, we describe how to detect the loss of a token. A node has one unique integer, called node identifier, such as MAC address. A token also has one integer, called token identifier. A management node is autonomously selected in each ring by the following algorithm. When a node generates a token, the token identifier is set at the node identifier. When a node receives the token with smaller token identifier than its node identifier, the token identifier is changed to its node identifier. Then, the node forwards the token. When a node receives the token with the same token identifier with its own, the node becomes a management node. A management node stores the interval to receive a token. If a management node does not receive a token for quadruple of token interval after emission of the last token, it considers that the token is lost and sends a new token. A management node, which receives a token within the half of token interval after emission of a token, it considers that the token is duplicated and discards it.



(a) Array node

(b) k-means clustering

(c) The inter-cluster connectivity

Figure 7: Area decomposition

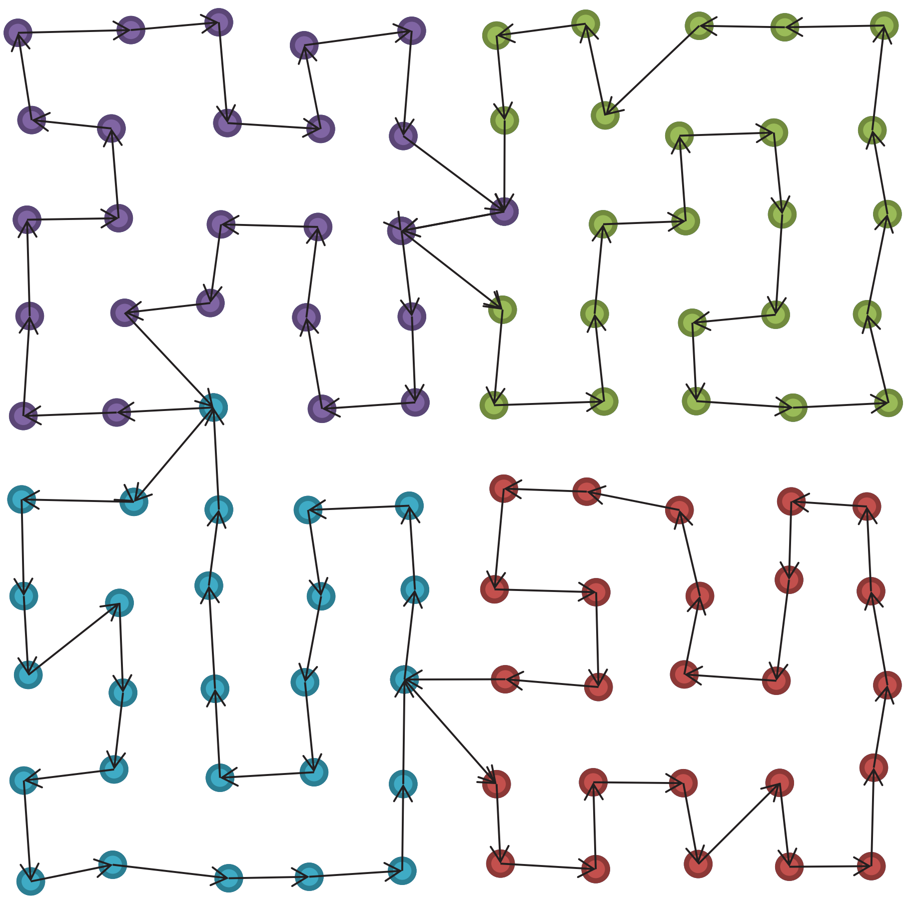


Figure 8: The ring construction

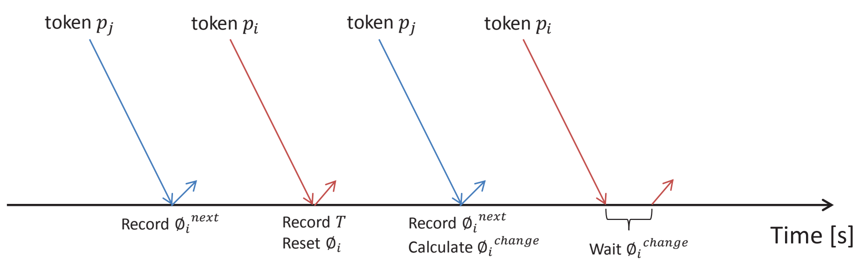


Figure 9: DESYNC algorithm

5 Performance evaluation

5.1 Evaluation setting

In the experiments, we call an area of 40 [m] $\times$ 40 [m] "block". One node is placed at a random location of each block. The observation region is constituted by arranging 10 $\times$ 10 blocks i.e. 100 nodes in the region of 400 [m] $\times$ 400 [m]. The node density is 0.000625 [node/m^2]. Nodes communicate with each other by the IEEE 802.11 MAC protocol with RTS/CTS. The communication range is set at 100 [m] and transmission speed is 1[Mbps]. We use ns-2.34 [25].

Performance of information sharing methods heavily depends on the way that data are generated at nodes. If all nodes begin sending a data message at the same time, information sharing suffers from collisions and congestions and all-to-all communication easily fails. In this paper we consider asynchronous data generation, which is more realistic than the synchronous data generation. With the asynchronous data generation model, each node generates new data at random time from 0 to 1 [s] of simulation time. In our method, a random node begins to send token in each ring when the simulation starts. The size of token is set at 1 [Kbyte].

To evaluate performance of information sharing methods in all-to-all communication, we use the ratio of receiving nodes and the time for information sharing. e first define $R(t, i, j)$ by Eq. (2). It represents whether node j has received data generated by node i by time t [s].

$$R(t, i, j) = \begin{cases} 1, & \text{if i} \neq \text{j and received} \\ 0, & \text{if } i = j \text{ or unreceived} \end{cases} \tag{2}$$

Furthermore, we define $T(i)$, which is time for dissemination of data generated by node i to be completed. Then, the ratio of receiving nodes is derived as follows.

$$D = \frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{j=1}^{n} R(T(i), i, j) \tag{3}$$

where n is the number of nodes in a network.

5.2 Simulation results

In this section, we show results of simulation experiments. We compare the ring-based method defined in Section refrelated, the token ring-based method with area decomposition, the token ring-based method additionally with retransmission of lost token, and finally the method with all additional mechanisms. In our method, we divide all nodes into 4 areas. In Fig. 10, the horizontal axis is the simulation time and the vertical axis is the ratio of receiving nodes. This result shows the result of a simulation by a topology. In the ring-based method which nodes send a data messages without token, information sharing takes long and the ratio of receiving nodes is smaller than 0.5. The method only with the area decomposition does not accomplish the perfect information sharing, because of loss of token, where as the speed of information sharing becomes faster for collision avoidance with token rotation. By introducing a mechanism of detection of token loss and retransmission, the perfect all-to-all information sharing can be accomplished. Furthermore, scheduling helps in accelerating information sharing very much. A reason that the speed of information sharing is slower than the method without scheduling at the beginning is that coordination nodes suspend emission of token for de-synchronization.

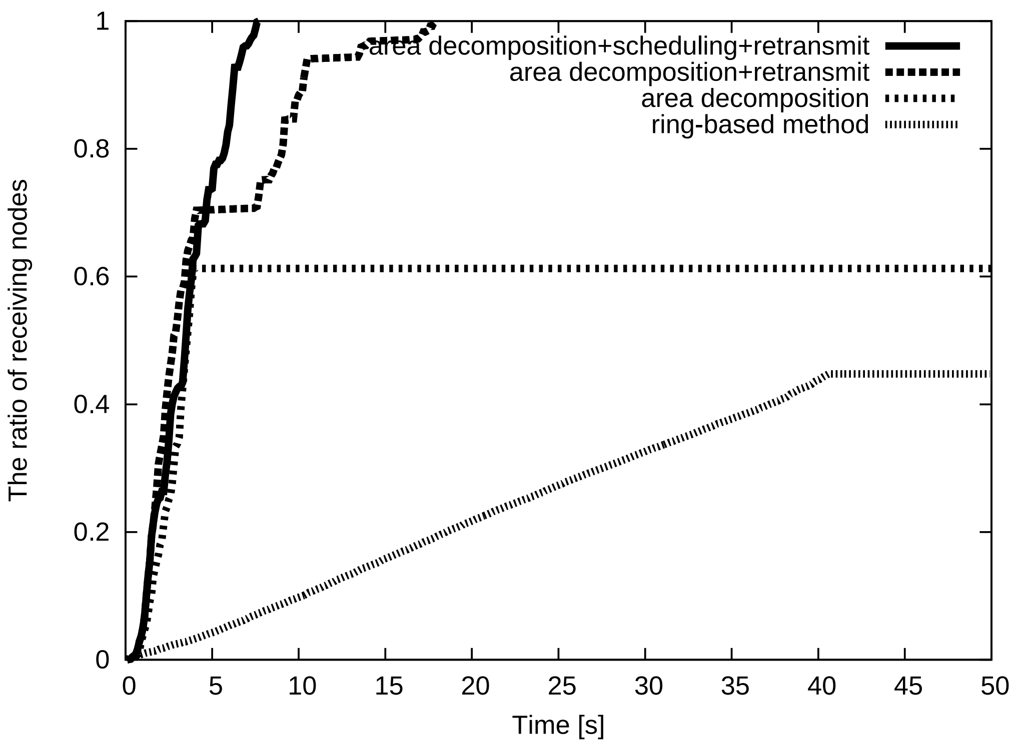


Figure 10: Comparison among methods regarding ratio of receiving nodes

In Fig. 11, the horizontal axis is the number of areas and the vertical axis is the time for information sharing. As the number of areas increases, time required for information sharing increases. It is because the number of rings becomes larger and there occur more collisions among rings. Tokens are often lost and it delays information sharing for timeout. Furthermore, coordination nodes often need to defer emission of token to avoid simultaneous emission of tokens of multiple neighboring rings. When the monitored region is divided into the smaller number of areas, the ring construction phase takes long and requires much computation.

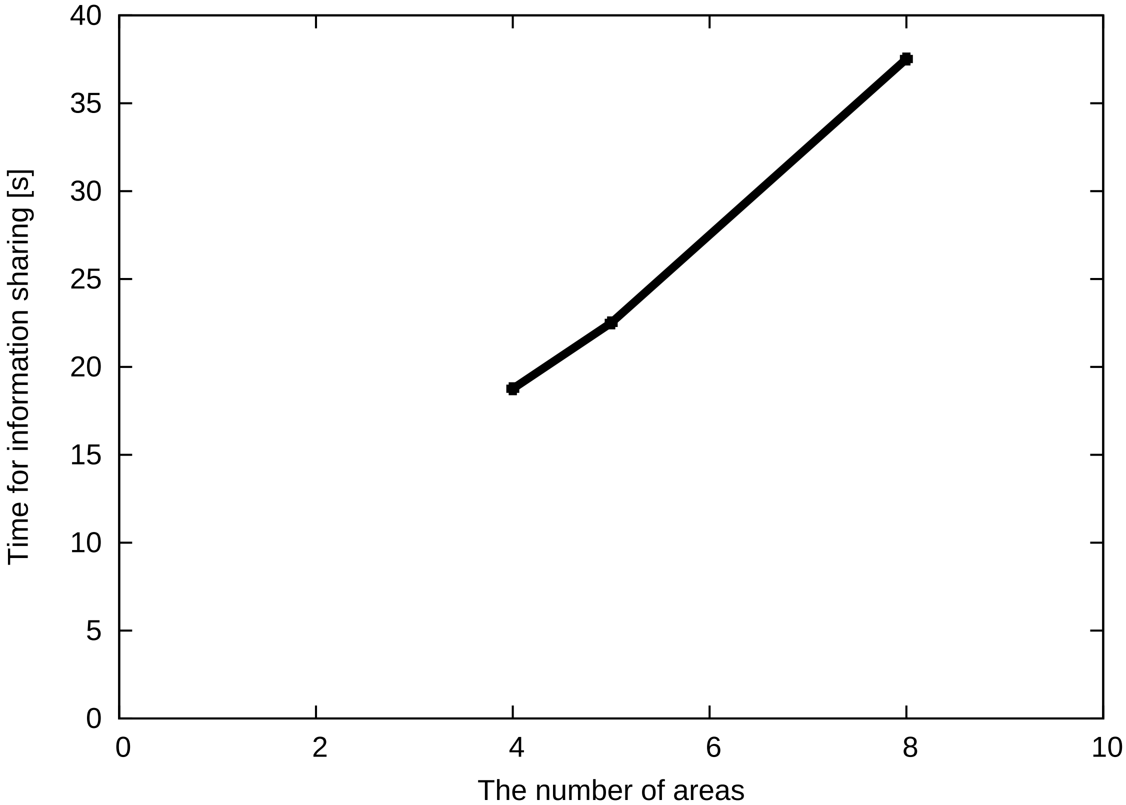


Figure 11: Influence of number of areas

6 Conclusion

In this thesis, we proposed an information sharing method for all-to-all communication in a multi-purpose WSN. Our proposal has three phases of area decomposition, ring construction, and scheduling, which further includes retransmission of lost token and de-synchronization. Through simulation experiments, we revealed that our method accomplished the perfect information sharing, where the ratio of receiving node is improved by using detection of loss of token and retransmission, and reduced the time for information sharing using scheduling algorithm. As future work, we plan to evaluate our proposal under a variety of scenarios of different region size and node density for different control setting, i.e. the number of areas. It involves comparison with WTRP. We further consider to introduce multiple tokens for faster information sharing in a large ring while it would cause collisions.

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