Fair Routing for Overlapped Cooperative Heterogeneous Wireless Sensor Networks

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***Abstract*—In recent years, as WSNs (Wireless Sensor Networks) are diffused widely, multiple overlapping WSNs constructed on the same area become more common. In such a situation, their lifetime is expected to be extended by cooperative packet forwarding. Although some researchers have studied about cooperation in multiple WSNs, most of them do not consider the heterogeneity in characteristics of each WSN such as battery capacity, operation start time, the number of nodes, nodes locations, energy consumption, packet size and/or data transmission timing, and so on. In a heterogeneous environment, naive lifetime improvement with cooperation may not be fair. In this paper, we propose a fair cooperative routing method for heterogeneous overlapped WSNs. It introduces an energy-pool to maintain the total amount of energy consumption by cooperative forwarding. The energy pool plays a role of broker for fair cooperation. Finally, simulation results show the excellent performance of the proposed method.**

***Index Terms*—sensor network, cooperative routing, fairness, heterogeneous environment, load balancing**

I. INTRODUCTION

RECENTLY, wireless sensor networks (WSNs) have received much attention as a means for collecting and utilizing data from real world. The number of WSN applications has been increasing widely and the application range is expected to spread [1] [2].

A WSN is a network composed of a large number of sensor nodes with limited radio capabilities and one or a few sinks that collect data from sensor nodes. Generally, sensor nodes are powered by small batteries, hence, the energy consumption in operating a WSN should be as low as possible. Some methods for prolonging network lifetime are required in WSNs [1] [2] [3].

Although all sensor nodes generate an equal amount of data packets in a WSN, nodes around a sink have to relay more packets and tend to die earlier than other nodes because the energy consumption of sensor nodes is almost completely dominated by data communication rather than by sensing and processing. Hence, the whole network lifetime can be prolonged by balancing the communication load at heavily loaded nodes around a sink [4]. This issue is called the *energy hole problem* [5] [6] and is one of the most important issues for WSNs. There are numerous studies about load balancing for WSNs such as clustering [7].

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In addition, as WSNs are diffused widely, multiple overlapping WSNs constructed on the same area become more common. In such a situation, cooperation among the WSNs to prolong network lifetime has been studied [8] [9] [10]. Assuming that each sink of WSNs has a different location, the heavily loaded area is also different. In this case, cooperation of multiple WSNs may be able to improve the network lifetime of each WSN by load balancing all over the WSNs [11] [12] [13].

Note that even in a case where multiple WSNs are constructed at the same place, they operate their applications independently and they have heterogeneous characteristic features. However, most of the existing studies do not consider this issue. For instance, if battery capabilities of sensor nodes in each network are different, in order to cooperate in a profitable way, we need to consider some parameters, such as their energy consumption rate, not only their remaining battery. Otherwise, it is possible that certain WSNs prolong their lifetime but others shorten their lifetime. Since their applications are different, data sending interval and/or packet size may be also different. Hence, for fair cooperation, it is necessary to consider the total number of times that the node have forwarded a packet, instead of focusing on each packet forwarding only. Furthermore, operation start time, the number of nodes and/or sensing area of each network may be also different.

In this paper, we consider the heterogeneity of networks and propose a fair cooperative routing method, to avoid unfair improvement only on certain networks. We introduce one or a few *shared nodes* that can use multiple channels to relay data packets. Assuming that sinks and shared nodes can communicate with any WSNs here, different WSNs can use cooperative routing with each other since shared nodes allow sensor nodes to forward data from another WSN as the function of interchange points among respective WSN planes. When receiving a packet, a shared node selects the route to send the packet, according to proposed route selection methods. This cooperation prolongs the lifetime of each network equally as possible.

II. RELATED WORK

A. Traditional Approach for Longer Lifetime

Clustering [7] is one of the most famous methods because of its good scalability and the support for data aggregation. Data aggregation combines data packets from multiple sensor nodes into one data packet by eliminating redundant information.

This reduces the transmission load and the total amount of data. In clustering, the energy load is well balanced by dynamic election of cluster heads (CHs) [14]. By rotating the CH role among all sensor nodes, each node tends to expend the same amount of energy over time. Nevertheless, as with usual multihop forwarding, a CH around a sink tends to have higher traffic than other CHs. As a result, nodes around sinks die earlier than other nodes, even in clustered WSN [15].

In general, a single WSN has a single sink. The amount of traffic increases around the sink, therefore nodes around the sink tend to die earlier. This is called energy hole problem. Moreover, in a large-scale WSN with a large number of sensor nodes, the energy hole problem is more serious. Then, some researchers have proposed construction methods of multiple-sink networks [16] [17]. In a multiple-sink WSN, sensor nodes are divided into a few clusters. Sensor nodes within a cluster are connected with one sink, which belongs to that cluster. In contrast to a single-sink WSN, in which nodes around the sink have to relay data from almost all nodes, nodes around each sink relay smaller amount of data only from nodes that are in the same cluster. Therefore, the communication load of nodes around sinks can be reduced. However, there are some problems such as how to determine the optimal location of each sink and the optimal number of sinks.

B. Cooperation between Multiple WSNs

In existing studies, most researches assume that a single network is deployed by a single authority in the sensing area. However, as WSNs get utilized more widely, multiple WSNs tend to be deployed in the same area. For instance, in the UK, some different networks of cameras by different authorities such as police, highway patrol, and local city authorities are deployed on the same roads [18]. Recently, some researchers have proposed the cooperation method of multiple WSNs in such situations.

When multiple WSNs are constructed in close proximity, they can help each other by forwarding data so that all networks involved benefit from collaborative effort. In [11], the potential benefits of cooperation in multiple WSNs are investigated. The authors formulated the system model with objective function and a set of problem constraints. Then, a linear programming framework is used to solve the optimization problem. Since their goal is to investigate the maximum achievable sensor network lifetime with different multi-domain cooperation strategies, optimization objective is network lifetime, which is defined as the time when the first sensor node in a network exhausts its battery and dies. The authors also investigated the cooperation in multiple networks that are deployed slightly different location [12].

Some researchers have addressed the cooperation problem with using a game-theoretic framework [20] [21]. It is assumed that a WSN has a rational and selfish character and will only cooperate with another network if this association provides services that justify the cooperation.

Virtual Cooperation Bond (VCB) Protocol [20] is one of the game-theoretic approaches. It is a distributed protocol that makes different networks to cooperate, if and only if all the networks obtain some benefits by the cooperation. The authors formulated the cooperation problem among different WSNs as a cooperative game in game theory. In VCB protocol, the energy consumption of data communication is used as costs. When the cost gets higher, the payoff of a network gets lower. A sensor node and another node that belongs to another network forward a data packet coming from the other side, only if both networks can obtain the higher payoffs than no cooperation scenario. The simulation results showed that the VCB can save transmission energy between 20% and 30% in a certain environment.

C. Problematic Issues

As discussed above, we assume that multiple WSNs are deployed by different authorities in the same area. Those WSNs operate different applications independently, hence, they have heterogeneous characteristics, such as battery capacity, operation start time, the number of nodes, nodes locations, energy consumption, packet size and/or data transmission timing. However, most existing cooperation methods do not consider this heterogeneity. For instance, when batteries capacities on sensor nodes are quite different by a WSN, a cooperative routing method based on residual energy is not appropriate since a WSN which has the maximum battery capacity always forwards packets from other WSNs. As a result, although certain WSNs prolong their lifetime, the other WSNs may shorten their lifetime. In such a situation, fairness of cooperation is a highly important issue.

In this paper, we aim to improve all WSNs lifetime by fair cooperative routing in a heterogeneous environment, avoiding improving the lifetime of only certain WSNs.

III. PROPOSED METHOD

A. Assumed Environment

In this paper, we assume the following environment.

In a sensing field, m different WSNs are constructed, and different applications are operating on each WSN independently. Figure 1 shows an example where two WSNs are constructed. If heavy loaded nodes are in different places among the WSNs as indicated in the example, it is possible that data packets via heavy loaded nodes are forwarded by other nodes in another WSN. However, each network adopts different channel, hence sensor nodes are unable to communicate with a node belonging to another WSN. To overcome this limitation, q shared nodes, which are high-end nodes with multi-channel communication unit, are deployed in the area. Shared nodes and sinks are able to communicate with any nodes belonging to all WSNs.

Sensor nodes consume their energy only by communication, which is a reasonable assumption in sensor networks with simple sensors. Sinks and shared nodes have sufficiently large batteries or power supply. We define the WSNs' lifetime as the time when a first sensor node depletes its all battery energy.

For heterogeneity, the battery capacity of a sensor node, the number of nodes, nodes' locations, energy consumption by communication, packet size, data transmission timing and operation start time are different by each WSN. Note that the sensing area is the same in all WSNs since we aim at the cooperation in overlapped multiple networks.

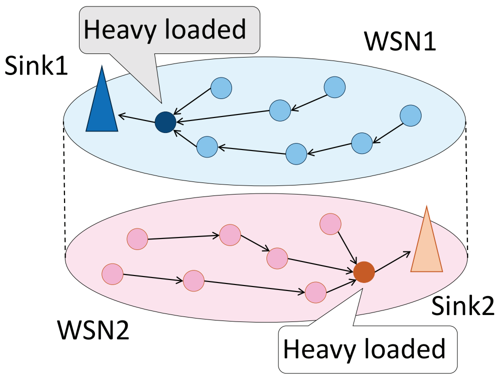

Fig. 1. Two WSNs deployed at the same area

B. System Model

In this subsection, we formulate the overlapped WSNs model for fair cooperation routing.

In a sensing field, m different WSNs $N_1, \cdots, N_m$ are constructed, and each network N_i, $1 \leq i \leq m$, has a set of unique sensor nodes $N_i = \{n_{i1}, n_{i2}, ..., n_{i|N_i|}\}$ and the sink BS_i. q shared nodes $s_1, \ldots, s_q$ also exists in the area. All WSNs are able to use these shared nodes as relay node for packet forwarding.

For guaranteeing the lifetime improvement by the cooperation, we define *network lifetime* L_i, the estimated lifetime of N_i, is obtained by Eq. (1).

$$L_i = \min_{n_{ij} \in N_i} L_{ij} \qquad (1 \leq j \leq |N_i|). \tag{1}$$

L_{ij} is the estimated lifetime of the sensor node n_{ij} here. We call it *node lifetime*. In other words, the estimated lifetime of a WSN is a minimum estimated lifetime of its all sensor nodes. Each sensor node measures its own energy consumption during specific time τ and calculates L_{ij} by using it. Let e_{ijt} be the remaining energy of node n_{ij} at time t, then, energy consumption per unit time is described by

$$\frac{e_{ijt} - e_{ij(t+\tau)}}{\tau}, \tag{2}$$

and L_{ij} is represented by Eq. (3).

$$L_{ij} = e_{ij(t+\tau)} \cdot \frac{\tau}{e_{ijt} - e_{ij(t+\tau)}} \tag{3}$$

By exchanging L_{ij} periodically among neighboring nodes, each node updates L_i. In addition, *minimum lifetime* L_i^0, the estimated lifetime in the case of no cooperation, is calculated by each sensor node. Specifically, each WSN operates without any cooperation from time $t = 0$ to $t = 0 + \tau = \tau$, and after the duration, L_i^0 is calculated by Eq. (4).

$$L_i^0 = e_{ij\tau} \cdot \frac{\tau}{e_{ij0} - e_{ij\tau}} \tag{4}$$

L_i^0 is also exchanged and updated among sensor nodes. Specific updating procedure of L_i and L_i^0 is explained in Sect. 3.4.

A shared node s_k $(1 \leq k \leq q)$, has m routes R_{kl}^i to the sink BS_i via network N_l $(1 \leq l \leq m)$. Hence, s_k selects one of the m routes when s_k receives a data packet from network N_i. If $i \neq l$, N_i rents the energy resource from N_l.

Moreover, we define *route lifetime* $L_{R_{kl}^i}$ as the estimated lifetime of the route R_{kl}^i. The detailed definition is as follows.

$$L_{R_{kl}^i} = \min_{n_{lj} \in R_{kl}^i} L_{lj} \tag{5}$$

Eq. (5) means that $L_{R_{kl}^i}$ is the minimum lifetime among the nodes being contained in route R_{kl}^i.

C. Route Discovery

Each sensor node creates its routing table based on a routing protocol. In this paper, we used ad hoc on-demand distance vector (AODV) [19] as a routing protocol, because AODV was developed for wireless ad hoc networks and was adopted for some WSN protocols such as Zigbee [22] and ANT [23]. In route discovery, each sensor node discovers its routes not only to the sink in its WSN but also to all the other sinks in the different WSNs for opportunities to forward data packets from nodes in different WSNs to their sink. Therefore, the routing table of each sensor node has m routes corresponding to each sink in all WSNs.

A shared node discovers its route with a slightly different mechanism. A shared node creates m routes via m different WSNs to a sink. There are m sinks, in total, corresponding to m WSNs. Therefore, a shared node has $m \times m$ routes.

In AODV route discovery, each node chooses a route that has the minimum number of hops to the sink. However, the proposed method uses not the number of hops but a cost calculated by simple accumulation, so that more routes are established via shared nodes. This is because different WSNs can be used only via shared nodes as alternative routes. Specifically, we set 1 as the cost of going through a sensor node and we set $x(0 < x < 1)$ as the cost of going through a shared node. When each node discovers a route, it chooses a route that has the minimum cost calculated as the sum of traversing nodes. Another advantage of the proposed route discovery is that using shared nodes, which have sufficiently large batteries or power supply, is expected to reduce power consumption of other sensor nodes.

D. Obtaining Lifetime Information

For cooperation considering the fairness among multiple WSNs, shared node s_k maintains estimated lifetime information, *network lifetime* L_i, *minimum lifetime* L_i^0 and *route lifetime* $L_{R_{kl}^i}$. We explain how to obtain these information as follows.

At the time of transmitting a data packet, sensor node n_{ij} adds the values of its *network lifetime* L_i and *route lifetime* $L_{R_{kl}^i}$ to the MAC frame header of the packet. If the node does not have any information on *network lifetime* or *route lifetime* yet, for instance at the time immediately after creating or updating the route, its own *node lifetime* L_{ij} is added alternatively. Each node updates these information by overhearing data packets from other nodes. Specifically, when node n_{ij} overhears a data packet, it compares the value of the *network lifetime* in the data packet and L_i in its own information, and updates its own L_i to the smaller value between them. In addition, if the packet is from a node which is contained in R^i_{ji}, the route from n_{ij} to BS_i, it checks the value of *route lifetime* in the packet header, and updates its *route lifetime* by the smaller value as in the case of updating L_i. After that, the overhearing node discards the packet immediately if the destination of the packet is not itself. As we mentioned in Section 3.2, *network lifetime* for the time 0 to τ is represented as *minimum lifetime* L^0_i. To obtain this value, each node updates its *minimum lifetime* with the value of *network lifetime* on an overheard packet, from the time τ to 2τ. Figure 2 describes this mechanism to obtain lifetime information.

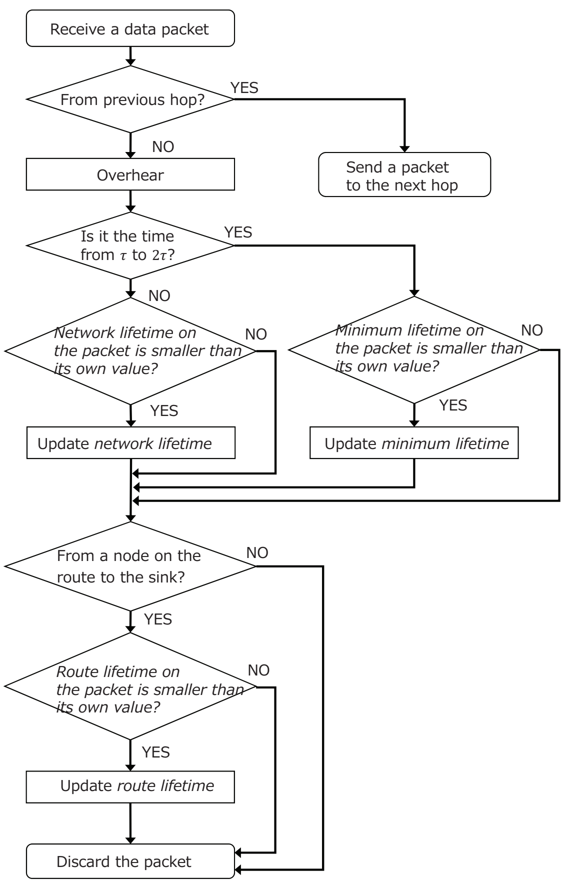

Fig. 2. Obtaining lifetime information

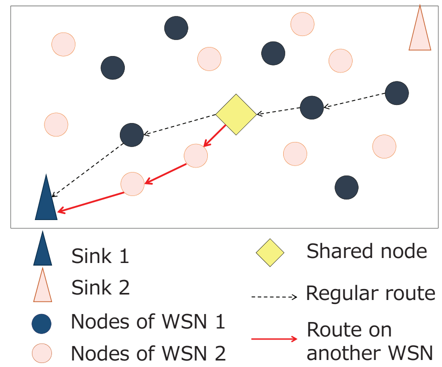

Fig. 3. Example of the cooperative routing with a shared node in two WSNs

E. Cooperative Data Forwarding

Since a sensor node has a single route toward the sink in its WSN, it forwards a data packet immediately to the next node on the route. On the other hand, a shared node s_k has m routes for the sink via m networks, therefore it can choose an appropriate route for data forwarding.

Since the lifetime of WSN depends on the lifetime of the energy-bottleneck nodes in the WSN, cooperative data packet forwarding via alternative nodes belonging to another WSN instead of the bottleneck nodes is expected to improve the lifetime of the WSN. An example is described in Figure 3. Here, the sensor nodes of WSN 2 between the shared node and sink 1 can forward data packets to sink 1 for WSN 1 as an alternative route on another WSN. However, if the alternative nodes are also bottleneck of their WSN, the lifetime of their WSN would be shortened. To avoid this result, a shared node is able to choose the alternative route only if the alternative nodes are not bottleneck. That is, the condition that packet forwarding from the shared node s_k to the sink BS_i in WSN i via route R^i_{kl} of WSN l is available can be formulated as follows.

$$L_{R^i_{kl}} > L^0_l \tag{6}$$

By this condition, lifetime reduction of each WSN by forwarding packets from other WSNs is avoided, and the improvement of WSNs lifetime is guaranteed.

As explained in Section 3.3, a shared node has multiple routes to the sink, hence an algorithm to select an appropriate route is needed. We propose fair cooperative methods with two route selecting algorithms. The first one is named *Pool-based* selecting. We resemble the cooperative forwarding to debt of energy resource. Shared nodes maintain the *Energy Pool*, the total amount of energy consumption used by cooperative forwarding, continuously. When a node n_{lj} in N_l forwards a packet from another network N_u, the *Energy-Pool* of N_l is increased and that of N_u is decreased. By selecting a route based on the value of *Energy-Pool*, the cooperation with the fairness of energy consumption is achieved in a heterogeneous environment. In addition, this method is able to balance the energy consumption by cooperation even if each WSN starts to operate from different time.

When a shared node s_k receives a data packet, if it has multiple available routes to the sink, it compares the *Energy-Pool* P_l of each network N_l, and selects the route that has minimum P. Let R^i_{kv} denote the selected route from shared node s_k to sink BS_i via N_v. P_v, the *Energy-Pool* of the network N_v which the R^i_{kv} belongs to is increased, and P_i, the *Energy-Pool* of the network N_i which the source node belongs to is decreased. The amount of increase and decrease

ΔP is the energy consumption by packet forwarding from s_k to BS_i. It is obtained by Eq. (7).

$$\Delta P = h_{R^i_{kv}}(E_{rv} + E_{tv}) \tag{7}$$

$h_{R^i_{kv}}$ is the hop count on R^i_{kv}. E_{rv} and E_{tv} are reception and transmission energy cost per a packet on N_v, respectively. Figure 4 shows the flow chart on *Pool-based* route selection at the time when a shared node s_k receives a data packet from N_a.

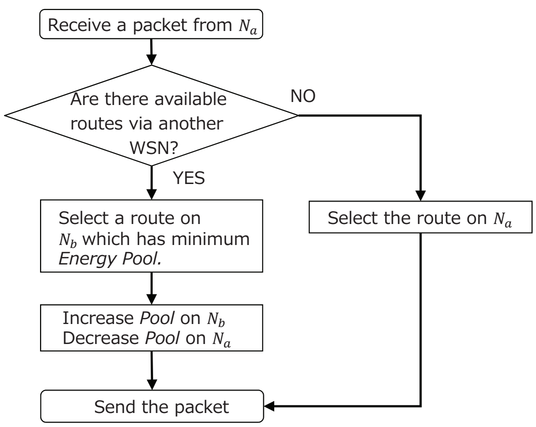

Fig. 4. *Pool-based* route selection

The other is named *Life-based* selecting, that selects the route with maximum *route lifetime*. In contrast to the *Energy-based* route selection that considers only remaining energy on the nodes, *Life-based* is focusing on the traffic loads by estimating the *route lifetime*. Therefore, it is expected that the heavy-loaded nodes balance their loads to other network nodes and it leads to a longer lifetime. Figure 5 shows the procedure of the *Life-based* route selection.

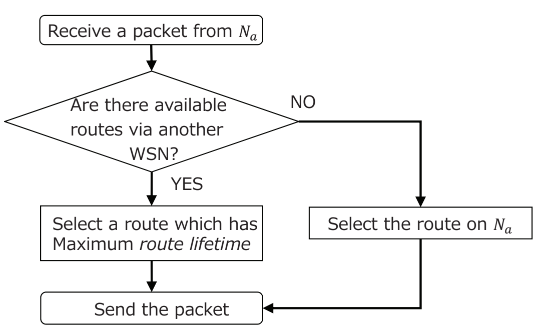

Fig. 5. *Life-based* route selection

IV. Performance Evaluation

A. Simulation Environment

We evaluated the performance of the proposed method with the network simulator QualNet 7.1 [24]. We observed the receiving rate, which is the rate of sensor nodes that send data packets to their sinks successfully. Therefore, we counted a node that cannot communicate with its sink as a dead node, in spite of its remaining battery. The maximum value of receiving rate is 1.

In this simulation model, we set the node configurations using datasheet and information provided by MEMSIC [25]. We simulated four WSNs, WSN 1, WSN 2, WSN 3 and WSN4 as follows. Each WSN had 49 nodes based on a random topology. The sensing field was a 490 m $\times$490 m square. The PHY model was IEEE802.11b and its data rate was 2 Mbps. The maximum range of radio transmission for each node was 150 m.

Each sink was located at each corner of the field. A shared node was placed at the center of the field. Each node sent 512 bytes data packets asynchronously at intervals of 10 seconds. We assumed that sinks and shared nodes had a sufficiently large battery, and that their battery capacities were unlimited. We set x, the cost of using a shared node, to 0.5. To give opportunities for cooperative forwarding to sensor nodes fairly, all nodes deleted their route entries and discovered new routes at intervals of 720 minutes.

We evaluated two proposed method, *Pool-based* and *Life-based*. For comparison, we simulated an environment where four WSNs were operated independently without any cooperation. In addition, *Energy-based* method was also evaluated as a conventional method. It just focuses on prolonging total lifetime but ignores the fairness among WSNs.

B. Simulation Results

1) Scenario 1: heterogeneous battery capacity: As a basic evaluation for heterogeneity, sensor nodes have different battery capacity by a WSN. WSN 1 has the largest capacity and WSN 4 has the lowest. We set the battery capacity of a node in WSN 1 to 1, and the capacity ratio is represented as; $WSN1 : WSN2 : WSN3 : WSN4 = 1 : 0.75 : 0.625 : 0.5$. Note that each node does NOT need to know the initial capacity of nodes in other WSNs. All each node has to know is its own initial capacity for operating the proposed method properly.

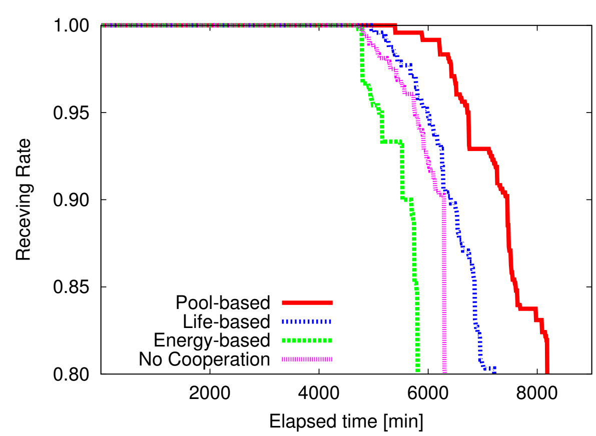

Fig. 6. Receiving rate on WSN 1

Figures 6-9 show the receiving rate as a function of elapsed time for each WSN. They are averaged over 10 trials. We

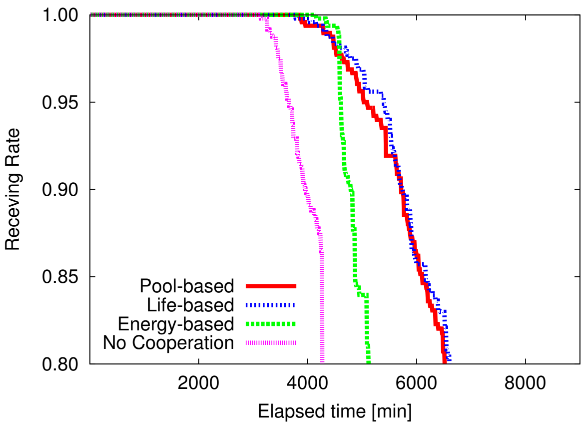

Fig. 7. Receiving rate on WSN 2

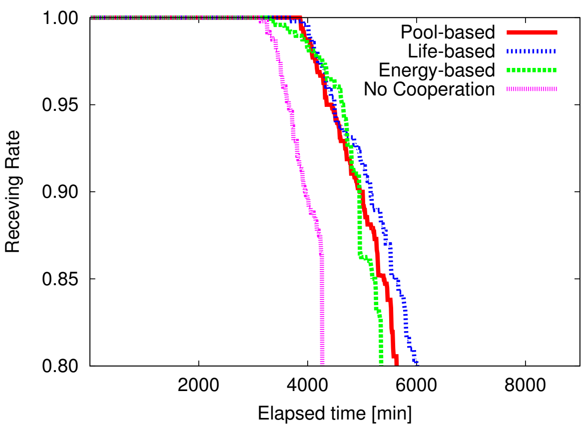

Fig. 8. Receiving rate on WSN 3

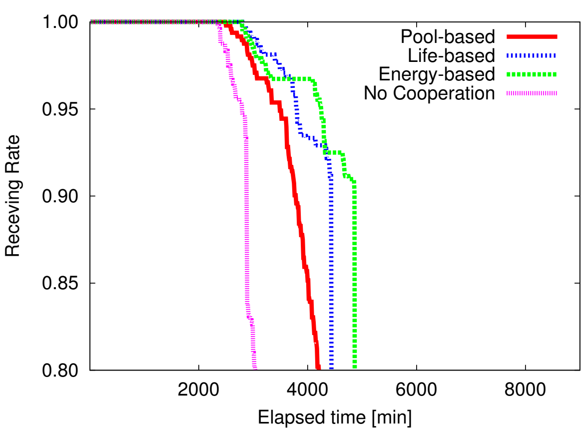

Fig. 9. Receiving rate on WSN 4

can see that *Pool-based* and *Life-based* cooperation extend the lifetime of $WSN1$ in Fig. 6. Especially, *Pool-based* achieved dramatic improvement. On the other hand, *Energy-based* cooperation degraded the lifetime of $WSN1$, since $WSN1$ has larger battery capacity than any other WSNs. On *Energy-based*, a shared node always selects the route that has the maximum residual energy. Therefore, in this scenario, the route via $WSN1$ forwarded a lot of packets from other WSNs and $WSN1$ consumed much more energy than any other WSNs. As a result, the lifetime of $WSN1$ was shortened. To the contrary, on *Pool-based*, the route via each WSN forwarded the almost same amount of data packets. Hence, $WSN1$ was also able to improve its lifetime. On *Life-based*, since a shared node compares the estimated lifetime of the routes, the heavy-loaded nodes tend to be avoided even if they belongs to $WSN1$. In Figs. 7, 8 and 9, we can see both the proposed method and conventional method improved network lifetime.

For evaluation, we define the $\alpha - lifetime$ as the time when the receiving rate has fallen below α on a WSN. We also define life improving ratio, which is represented by $\alpha - lifetime$ on the method divided by $\alpha - lifetime$ in no cooperation scenario.

Figure 10 shows the average life improving ratio in 4 WSNs for each method as a function of α. All methods extended the network lifetime by cooperative forwardings. In most of other range than α close to 1, specifically, *Life-based* and *Pool-based* achieved greater benefits than *Energy-based*.

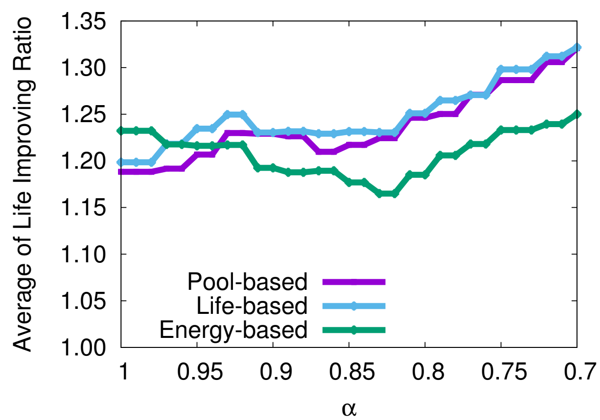

Fig. 10. Average of life improving ratio in 4 WSNs (scenario 1)

Since the networks have different battery capacities, the lifetime of them without cooperation are also different. Even if the total amount of extended lifetime is equal, the life improving ratio may take a larger value with smaller battery capacity. Hence, for confirmation, we present the total amount of extended lifetime in 4 WSNs in Figure 11. We can see slightly different behavior from Figure 10. *Pool-based* method achieved the maximum improvement in all range, since it cooperated more aggressively than *Life-based* method.

In addition, Figure 12 shows the variance of life improving ratio in 4 WSNs for each method. Obviously, the variance on *Pool-based* is remarkably small. This result implies *Pool-based* method achieved fair cooperation in a heterogeneous environment. The energy-pool successfully plays a role of broker for cooperation.

2) Scenario 2: heterogeneous data transmission: We evaluated the 4 WSNs that send data packets in different timing. In this scenario, WSN1, WSN2, WSN3 and WSN4 send a

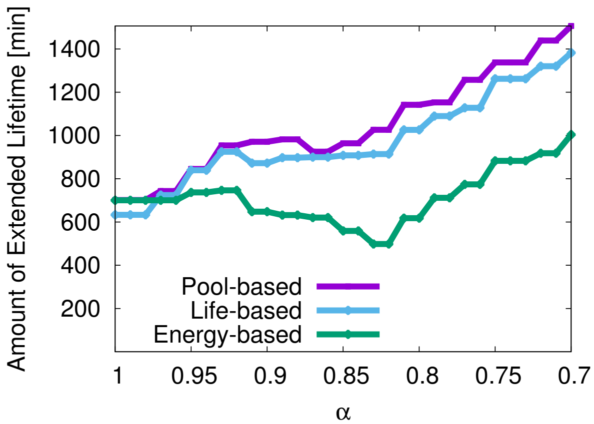

Fig. 11. Total amount of extended lifetime in 4 WSNs (scenario 1)

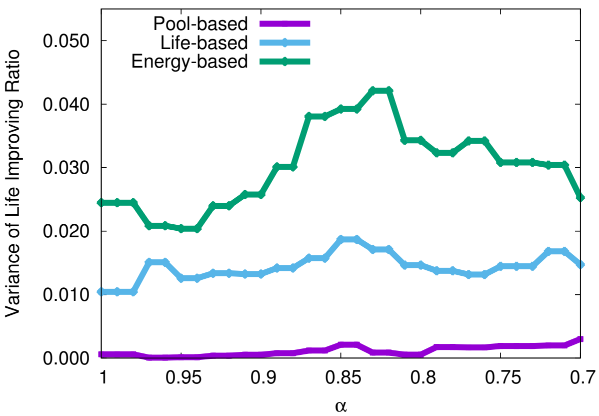

Fig. 12. Variance of life improving ratio in 4 WSNs (scenario 1)

data packet every 10 minutes, every 7.5 minutes, every 6.25 minutes and every 5 minutes, respectively. These values were not special. In this scenario, we intended to evaluate how the proposed method works in a case where each WSN collects data in deferent timings. In other words, a WSN with larger interval consumes its battery more slowly and may have to forward more packets from other WSNs unfairly. Other parameters are the same as scenario 1 except that all sensor nodes in any WSNs have the equal battery capacity.

We do not present any graphs for the life improve ratio in scenario 2 since the results are very similar to scenario 1. We observed that the proposed methods extended lifetime of all WSNs fairly. Due to the non-uniform traffic modeling, particular areas may get congested temporarily. But, the assumed packet generation interval is long enough, so that collisions can be avoided by CSMA/CA manner.

3) Scenario 3: heterogeneous operation start time: In this scenario, each WSN starts its operation at different time. WSN1, WSN2, WSN3 and WSN4 start to work at 0, 1000, 2000 and 3000 minutes, respectively. Other parameters are the same as scenarios 1 and 2, with the same battery capacity and the same data sending interval.

Figure 13 shows the averaged lifetime improving ratio over 4 WSNs in scenario 3. *Pool-based* cooperation achieved the maximum lifetime improvement.

Moreover, in Figure 14, we can see that the proposed methods obtained quite smaller variance than the conventional method also in scenario 3. Note that the variance of *Pool-based* cooperation is slightly larger than in scenario 1, since a network that started operating at earlier time has more opportunities to cooperate than others. We can see this fact in Figure 14.

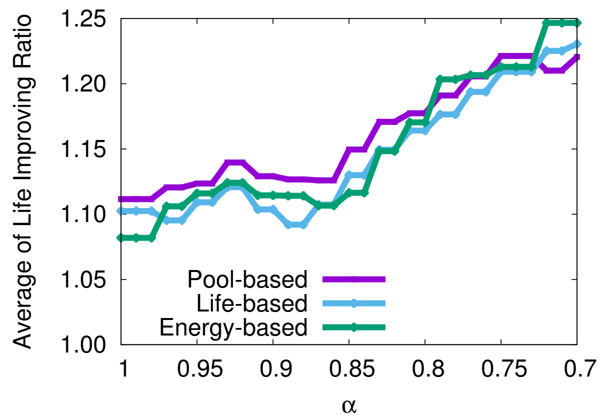

Fig. 13. Average of lifetime improving ratio in 4 WSNs (scenario 3)

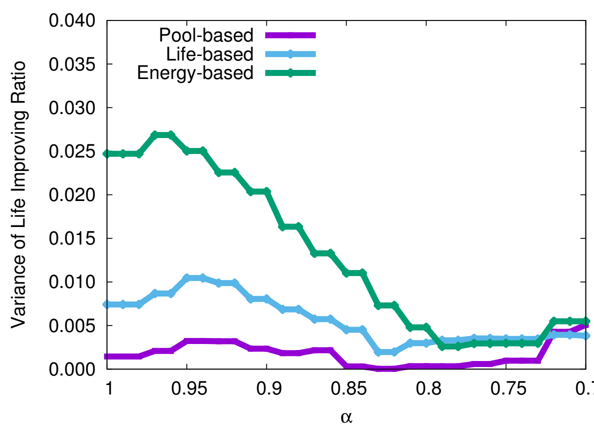

Fig. 14. Variance of lifetime improving ratio in 4 WSNs (scenario 3)

V. CONCLUSIONS

In this paper, we focused on heterogeneous overlapped sensor networks that were constructed at the same area. In such a situation, it is expected that the lifetime of all networks should be extended by cooperation in multiple networks. However, since the existing methods do not consider the heterogeneity in each network, fairness in terms of lifetime improvement is required. We proposed a fair cooperative routing method with shared nodes, with the aim to achieve fair lifetime improvement in heterogeneous overlapped sensor networks.

Simulation results showed that the proposed method extended the network lifetime. In particular, *Pool-based* cooperation achieved quite small variance of lifetime improvement, that is, it provided quite fair cooperation.

As a future work, we try to implement the proposed method on an experimental system and evaluate its feasibility.

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