Lightweight P2P-RPL for Efficient P2P Communication in 6TiSCH Networks

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***Abstract*—** With the emergence of various IoT applications, P2P functional support in the network is essential. RPL is a routing protocol for low-power loss wireless networks, but there is an inefficient aspect of P2P communication. Although P2P-RPL has been proposed to support P2P of RPL, it is inappropriate to apply it to 6TiSCH networks as it is due to excessive overhead. So, we propose Lightweight P2P-RPL and applied to 6TiSCH Networks. Lightweight P2P-RPL includes five techniques for reducing overhead, and the performance was measured using a 6TiSCH simulator. As a result of the simulation, there was no performance reduction despite providing P2P function.

Keywords—RPL, P2P, 6TiSCH, IEEE 802.15.4, TSCH, WSN

I. Introduction

RPL (Routing Protocol for Low-power Lossy Networks) [1] is an IPv6 routing protocol undergoing standardization in the IETF's ROLL working group. Through the construction of DODAG (Destination-Oriented DAG), ideal for applications that collect data from multiple sensor nodes to one root node. However, various applications are appearing in IoT networks, and support for P2P functions is essential. Since RPL causes unnecessary network consumption during P2P communication, P2P-RPL [2] for P2P application of RPL was presented. But, since P2P-RPL causes excessive broadcasting, there is an inadequate aspect to apply to the 6TiSCH [3] network as it is. We propose Lightweight P2P-RPL to support the efficient P2P communication capabilities of 6TiSCH networks. Lightweight P2P-RPL reduced the overhead generated by the network using five technologies The five technologies are P2P communication using autonomous cells, traffic-adaptive P2P-DRO waiting time, early decision using parent node for P2P-DRO transmission, direct transmission using neighbor node list, and P2P routing path length adaptive to network scale. The proposed network had been evaluated through a 6TiSCH simulator [4]. The performance evaluation was performed using two parameters. The first is performance evaluation by *scale_factor* and the second is performance evaluation by traffic. In the performance evaluation, network resource consumption was confirmed to check how much overhead was reduced, and an evaluation was also conducted to check network performance such as PDR and latency.

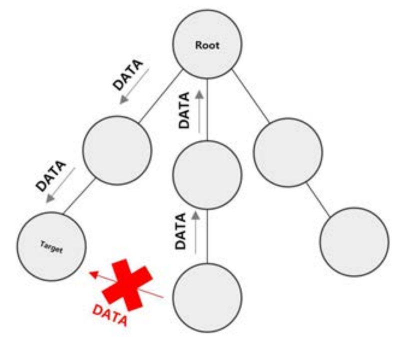

Fig 1. Routing path of P2P Packet

II. Background

A. RPL

The Internet Engineering Task Force (IETF) ROLL Working Group proposed IPv6 Routing Protocol Low power and Lossy Networks (RPL), a standard routing protocol for IPv6-based low-power wireless networks for forwarding data between multiple IoT devices. RPL enables packet routing between nodes through DODAG generation. In RPL, nodes in the network build DODAG using three control messages: DIO (DODAG Information Object), DAO (Destination Advertising Object) and DIS (DODAG Information Solicitation). The node receiving the DIO participates in the network and an upstream path is generated. Since the node participating in the network transmits a DAO to the root node, the root node may know the downward path of each node.

There are two types of RPLs, Storing Mode and Non-Storing Mode depending on the method of transmitting downward traffic. Nodes in Storing mode know the routing path to their child nodes. Therefore, in P2P communication, it is possible to directly route the target to the corresponding node

If the destination of the target is among the child nodes. However, in the case of Non-Storing mode RPL, all packets are transmitted through the root node because all nodes except the root node do not store any routing information. This process

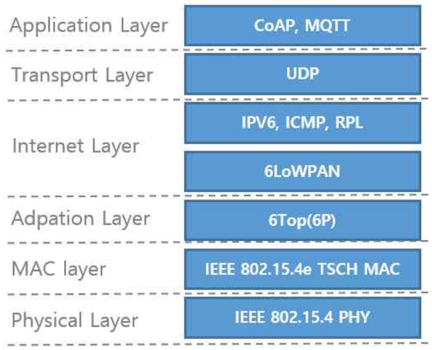

Fig 2. IETF 6TiSCH Netork Stack

causes unnecessary packet transmission and shortens the network life. In addition, excessive traffic is concentrated around the root node, causing bottlenecks. Bottlenecks can shorten the life of nodes around the root and cause packet drops due to packet queue overflow. "Fig. 1" shows the routing path through the root node, even though the P2P Initiating node can send packets to the destination node.

B. P2P-RPL

P2P-RPL is presented to improve the inefficiency of P2P communication of RPL. A node that initiates P2P communication broadcasts a P2P Mode DIO including a P2P RDO (Route Discovery Option) to generate a path with the target node. The nodes receiving the P2P Mode DIO create a temporary DAG and broadcast the P2P Mode DIO. The target node receiving the P2P Mode DIO sends a P2P-DRO (Discovery Reply Object) to the initiate node, and the initiate node receiving the P2P-DRO knows the routing path to the target node.

Network resource consumption can be excessive because P2P Mode DIO is broadcast to create a P2P path. And even if the P2P routing path is found, the existing routing path through the Root node may be a better path. Therefore, it is necessary to apply P2P-RPL appropriate to the network situation.

C. 6TiSCH Network

6TiSCH Working Group defined a network stack utilizing IEEE 802.15.4e TSCH [5] (Time slotted Channel Hopping). This is called the 6TiSCH Network, and the stack is "Fig. 2". TSCH MAC technology has high reliability and is used as an industrial wireless network. All nodes in the TSCH network are time synchronized through EB(Enhanced Beacon) reception and communicate within each time slot. A certain number of timeslots are called slot frames, which are repeated over and over again.

However, the IEEE 802.15.4e standard only presents TSCH operating mechanisms and does not present techniques such as link scheduling between nodes. Therefore, the 6TiSCH Working Group proposed a distributed scheduling algorithm, MSF [6] (Minimal Scheduling Function). If a link between nodes is required through MSF, a link can be created by assigning a time slot offset and a frequency channel offset pair

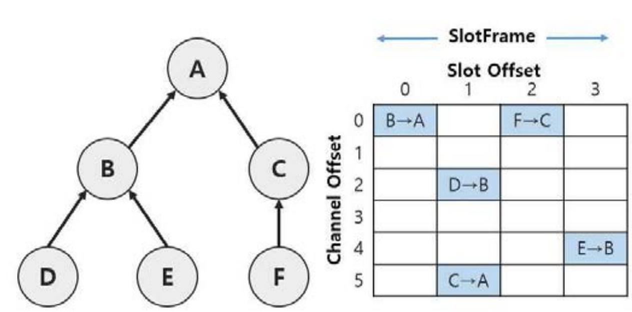

Fig 3. Example of TSCH Link Scheduling by Network Topology

(Cell). Negotiation between nodes is required for cell allocation, and 6P (6Top protocol) is used. "Fig. 3" is an example of a link scheduled according to a network topology.

However, autonomous cell allocation is possible without 6P transactions exchanging 6P packets for cell negotiation. In this article, node receives P2P packets through autonomous Rx cell allocated through hash calculation for EUI address of node. Conversely, when a node transmits a P2P packet, it allocates an autonomous Tx cell using the recipient's EUI address and transmits the packet.

In addition to the link scheduling technique, the 6TiSCH Network can support 6LoWPAN to support IPv6, RPL for routing in low power and lossy wireless networks, and Ipv6 to connect tens of billions of nodes.

III. LIGHTWEIGHT P2P-RPL

The 6TiSCH network constitutes a stable network with relatively few collisions. Excessive path generation attempts for P2P communication in a stable network may rather cause congestion in the network. Therefore, it is inappropriate to apply the existing P2P-RPL to the 6TiSCH network as it is. Therefore, this article presents five techniques that can reduce the overhead of P2P-RPL in a 6TiSCH network.

A. P2P communication using autonomous cells

P2P communication is generated as needed and is short-term compared to traffic collected as a root node. Thus, attempting to allocate additional cells for P2P communication in a 6TiSCH network not only generates additional traffic, but also increases the radio duty cycle due to cell allocation. Therefore, P2P communication is transmitted and received through an autonomous cell.

B. Traffic-adaptive P2P-DRO waiting time

Creating a P2P path for relatively little traffic is inefficient compared to the amount of network overhead generated. As an extreme example, one might attempt to create a P2P routing path to transmit one packet. To prevent such a case, the node that initiates P2P communication waits for P2P-DRO reception only for a time proportional to the amount of P2P traffic to be transmitted. At the end of the P2P-DRO waiting time, in the same manner as the existing P2P communication method of the RPL, P2P communication is performed through the root node.

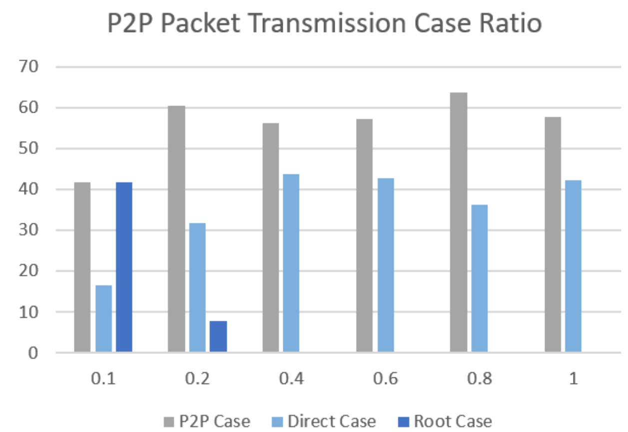

Fig 4. P2P Packet Transmission Case Ratio by scale_factor

C. Early decision using parent node for P2P-DRO transmission

The non-target node that receives the P2P Mode DIO sends the P2P-DRO to the initiate node without broadcasting the P2P Mode DIO if the target node is its parent node. This is because there is already a stable link with the parent node through 6p transaction, and additional P2P Mode DIO broadcasting can be prevented.

D. Direct transmission using neighbor node list

The case where the maximum gain may be obtained in the P2P communication is when the target node is in the neighbor list of the P2P initiate node. If there is a target node in its neighbor node list, it does not transmit P2P Mode DIO to create a P2P path, but directly transmits it to the node. When using this technique, when registering a neighbor in the neighbor node list, the technique of registering only neighbors that satisfy certain conditions, such as RSSI (Received Signal Strength Indicator) and ETX (Expected transmission count, must be concurrently used.

E. P2P routing path length adaptive to network scale

A P2P path that is too long for the scale of the network is highly unlikely to be an optimal path. The node that has received P2P Mode DIO does not retransmit DIO anymore if the path from the initiate node included in the P2P-DRO to the present is long compared to the overall network size. The network size is included in the transmission of the DIO of the Root node, and each node received can know the number of nodes participating in the entire network. (1) is a condition for transmitting a P2P Mode DIO, and the appropriate scale_factor will be tested through a simulator.

$$network\_scale \times scale\_factor > p2p\_routing\_path\_length \quad (1)$$

As a result of the five techniques presented above, the P2P packet is transmitted through the following three cases.

TABLE I. SIMULATION ENVIRONMENT

Features	Description
Num of slotframe	10000
Num of nodes	20
Slotframe Length	101 timeslot
Timeslot Length	10 ms
PDR mean	70 %
Packet Period	30 s
Transmissions per node pair	First simulation: 10 Second simulation: 1, 5, 10, 20, 40
scale_factor	First simulation: 0.1, 0.2, 0.4, 0.6, 0.8, 1 Second simulation: 0.2
RPL OF	OF0
Scheduling Function	MSF

- P2P Case: Create a P2P path and send packets to that path
- Direct Case: Directly send to the target node without creating a P2P path
- Root Case: Same as RPL, P2P communication via route

IV. SIMULATION ENVIRONMENT

All simulations were performed using the 6TiSCH network simulator. The 6TiSCH network simulator is implemented in Python and includes a 6TiSCH network stack. All simulation results were measured during the time that 10000 slot frames were repeated, and 20 nodes including the root node were randomly arranged in a square space with a side length of 3 km. Initiate node and a target node are randomly selected among 19 nodes excluding the root node, and P2P communication is performed as much as a set amount of traffic. After the communication of one pair of nodes is finished, another random one node pair is selected. That is, two pairs do not perform P2P communication at one time. The detailed simulation environment is shown in Table I.

V. PERFORMANCE

A. Performance Evaluation by scale_factor (First simulation)

According to scale_factor, the performance of 6TiSCH Networks to which Lightweight P2P-RPL is applied was confirmed.

- P2P Packet Transmission Case Ratio: "Fig 4" shows the ratio of P2P cases, Direct case, and Root Case according to *scale_factor* among all packet transmission cases. As the *scale_factor* increases, the number of P2P cases increases, the Root Case decreases, and no single case has been created since 0.4. If a longer P2P path was possible, the initiate node could have successfully received P2P-DRO and created a P2P path. The Direct

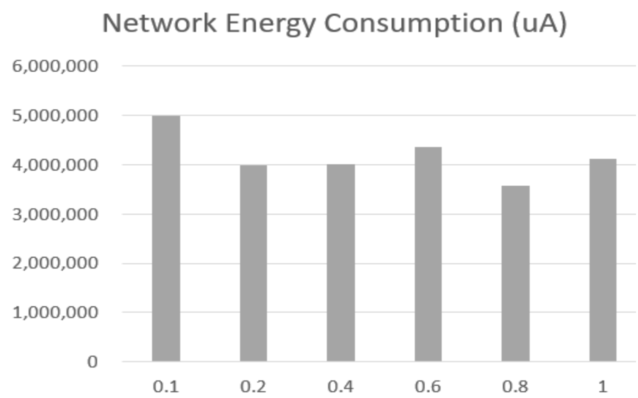

Fig 5. Network Energy Consumption by scale_factor

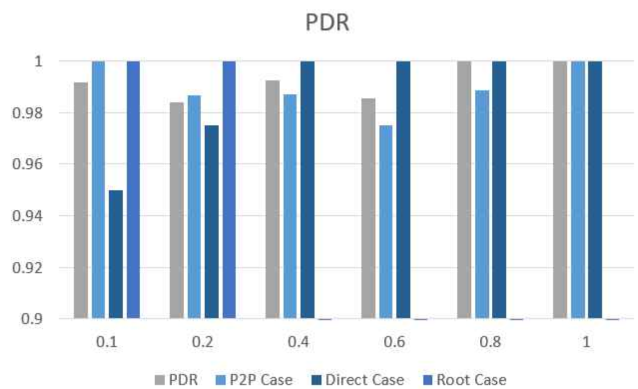

Fig 6. PDR by scale_factor

case is a case in which the target node is transmitted when it is in the neighbor list of the initiate node, and each case shows a different result.

- Network Energy Consumption: "Fig 5" shows network energy consumption according to scale_factor. Energy consumption shows the highest consumption at 0.1. This is because it transmits P2P Mode DIO, but excessively limits the length of the P2P routing path relative to the size of the network. The initiate node and its surrounding nodes transmit many P2P Mode DIOs, but the path cannot be found during the P2P-DRO waiting time, causing Root Case again, which consumes a lot of energy. In all other cases, similar energy consumption is shown.

- PDR (Packet Delivery Ratio): "Fig 6" shows the total transmission PDR according to *scale_factor* and PDR according to each transmission case. In the case of the entire packet PDR, each case does not show much difference, and in the case of 0.4, 0.6, 0.8, and 1, it can be seen that PDR is not expressed because Root case does not exist. However, compared to Root Case recording PDR 1 at 0.1 and 0.2, it can be seen that PDRs are distributed in various ways in P2P Case and Direct Case. It can be confirmed that communication using autonomous cells is unstable compared to Root

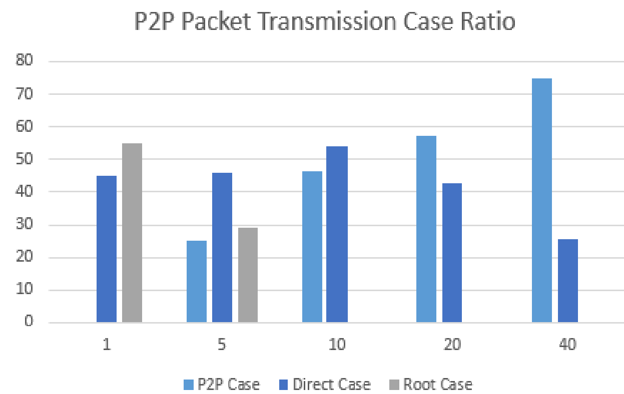

Fig 7. P2P Packet Transmission Case Ratio by traffic

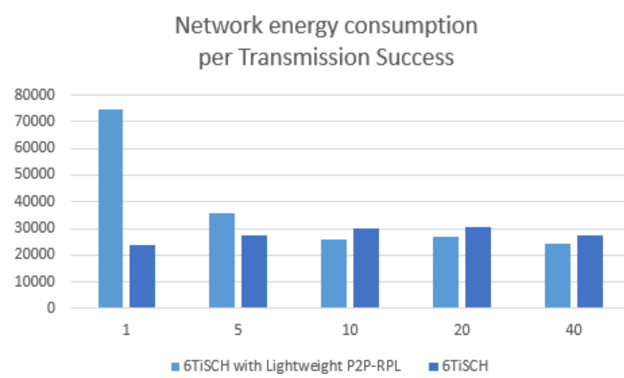

Fig 8. Energy Consumption per Transmission Success by traffic

case, which created a link by selecting the optimal parent considering ETX by applying OF0.

B. *Performance Evaluation by Traffic* (*Second simulation*)

6TiSCH Networks with Lightweight P2P-RPL and 6TiSCH networks are compared according to traffic. After the node pair is selected, the simulation is performed while changing the number of transmissions to 1, 5, 10, 20, and 40.

- P2P Packet Transmission Case Ratio: "Fig 7" shows P2P Packet Transmission Case Ratio according to Traffic. In the case 1, it can be confirmed that there is no P2P case. This is because the P2P-DRO waiting time proportional to the traffic is too short, so the P2P-DRO could not be received and thus the P2P route could not be created. As the P2P-DRO waiting time increases depending on traffic, about 74% of packets were transmitted through the P2P Case in case 40.

- Network energy consumption per Transmission Success: "Fig 8" shows P2P Network energy consumption per Transmission Success according to Traffic. Since the number of packet transmission attempts of the two networks is different, comparison was conducted with the energy used per successful transmission. Most of them show similar results, but in the case 1, the energy consumption of lightweight P2P-RPL was extremely high. It is the same as the cause of

Fig 9. PDR by traffic

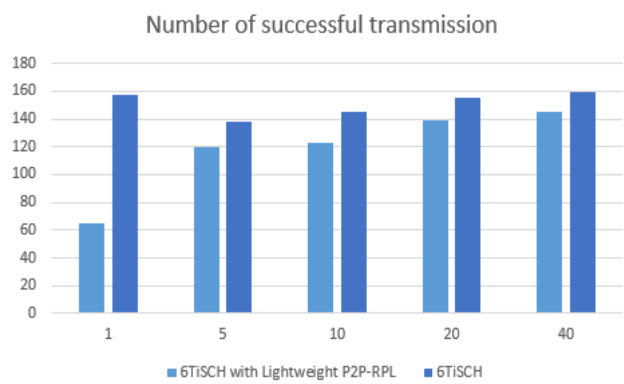

Fig 10. Number of successful transmission by traffic

the P2P Packet Transmission Case Ratio experiment result.

- PDR (Packet Delivery Ratio): "Fig 9" shows PDR according to Traffic. The PDR according to the traffic showed that both networks exceeded 0.94. Lightweight P2P-RPL shows a characteristic low figure at case 40, In this case, about 74% of packets are transmitted through the P2P case, and the transmission in the autonomous cell is unstable.

- Number of successful transmission: "Fig 10" shows Number of successful transmission according to Traffic. In all cases except once, the transmission success of the basic 6TiSCH has a large number of times, because the basic 6TiSCH does not spend time finding the path. In the case of one time, all P2P-DRO waiting time is waited, and since there has never been a case of receiving P2P-DRO, the cycle of selecting a new node pair itself becomes longer. As a result, the number of transmissions itself is reduced.

- Latency: "Fig 11" shows Latency according to Traffic. Except for case 40, latency is similar for both networks. In the case of case 40, lightweight P2P-RPL shows a high delay time because there are many P2P cases.

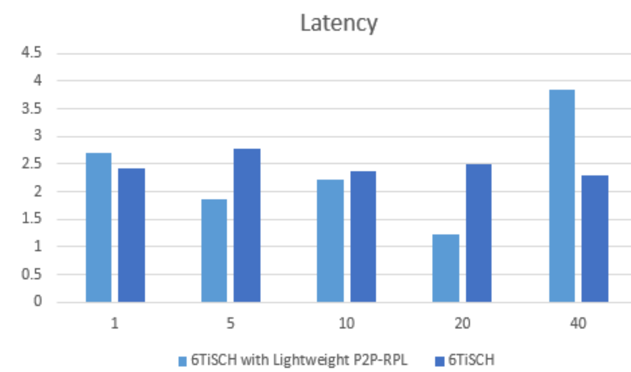

Fig 11. Latency by traffic

VI. CONCLUSION

P2P functionality is essential for supporting various applications. In this article, a Lightweight P2P-RPL is applied to the 6TiSCH network. Through the *scale_factor* change simulation, it has been confirmed that the *scale_factor* has a lot of influence on the packet transmission case. In particular, the Root Case decreased when the *scale_factor* was 0.1 or 0.2, and no Root Case occurred in 0.4, 0.6, 0.8, and 1. And it was confirmed that a lot of energy consumption occurred at 0.1. Other case energy consumption was similar, so it was confirmed that the network performance did not have a significant impact unless the *scale_factor* was too low. In the case of PDR, there is no significant change according to the value of the *scale_factor*, but it can be seen that the Root Case has a higher PDR than P2P Case. That is, the network configuration using OF0 enables reliable network construction. And in the second traffic experiment, the proposed network showed similar results for PDR compared to the 6TiSCH network, but it was confirmed that the performance was poor when a path was created to attempt a single P2P transmission. Similarly, Number of successful transmissions and Network energy consumption per Transmission Success also showed poor performance in the case of transmitting a single packet. However, in the remaining cases, 5, 10, 20, and 40, there was no significant performance difference from the 6TiSCH network. In particular, in terms of excessive network energy consumption, which has been pointed out as a disadvantage of P2P-RPL, there have been cases where it shows less energy consumption compared to 6TiSCH networks. Although it supports P2P function, it is very meaningful to show similar results in terms of network performance. Through additional experiments, we will find parameters that affect the decision to create a P2P path and conduct a study to make a decision to create a P2P path through reinforcement learning.

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