# DIRECTED DIFFUSION APPLIED TO ACTUATOR NETWORK IN IOT

Shun Murata, Noriko Matsumoto and Norihiko Yoshida
*Department of Information and Computer Sciences, Saitama University*
*255 Shimo-Ohkubo, Saitama 338-8570, Japan*

**ABSTRACT**

By collecting and analyzing various data from things connected to the Internet, IoT can create new valuable information. Then, such obtained information is transmitted to an actuator, which can perform suitable operation to the situation and condition on the spot. However, there are only a few case studies focusing on how information obtained by data collection and analysis is given to each actuator. Therefore, in this research, we aim at achieving a network that distributes information according to requirements of actuators. To achieve this purpose, we considered applying Directed Diffusion, which is a Publish / Subscribe communication model. However, when the conventional Directed Diffusion is applied to the assumed environment of this research, there are issues that many interest and exploratory packets are generated, and that the data packet transfer route is frequently disconnected due to the movement of IoT devices. Therefore, we propose a method to connect the new data packet transfer route to the existing data packet transfer route used by another actuator. In this method, when there is a reinforced gradient corresponding to interest, transfer of interest packet is stopped, and exploratory packet is transferred from that node. In this case, since transfer of these packets is performed between the actuator and the intermediate node, the number of these transfers is suppressed. Further, it is possible to re-establish the data packet transfer route in a short time.

**KEYWORDS**

Internet of Things, Actuator Network, Directed Diffusion

## 1. INTRODUCTION

In recent years, the Internet of Things (IoT) which connects various things such as automobiles, household electrical appliances, medical equipment, industrial machinery etc. to the Internet attracts attention. By receiving the information obtained by data collection and analysis from the server / cloud, the actuator can achieve suitable operation according to the situation / condition. IoT consists of a sensor network and an actuator network. Currently, researches on sensor networks are actively conducted. However, there are very few cases of research focusing on how information obtained by data collection and analysis is given to each actuator.

In this research, we aim at designing an actuator network that distributes information according to the requirements of actuators. To achieve this purpose, we apply Directed Diffusion, which is a Publish / Subscribe communication model in a sensor network. However, when we apply the conventional Directed Diffusion to an actuator network, some issues must be addressed such that many interest packets and exploratory packets are generated, and that data packet transfer route is frequently disconnected due to movement of IoT devices. Therefore, in this research we propose a method to solve these issues.

This paper is organized as follows: Initially, we explain Internet of Things in Section 2, Directed Diffusion in Section 3. And we describe our proposed method in Section 4. In Section 5, we explain simulation of our proposed method. Subsequently, we evaluate our method through simulation experiment in Section 6. Finally, Section 7 contains some concluding remarks and future work.

ISBN: 978-989-8533-82-1 © 2018

## 2. INTERNET OF THINGS

Processing in IoT is as follows. First, an IoT device collects data using a sensor. The collected data is transmitted to the server / cloud using technologies such as a sensor network and accumulated. Next, in the server / cloud, the accumulated data is analyzed using statistical analysis and machine learning. Finally, the server / cloud gives the information obtained by analysis to the user or an IoT device. The user can improve the efficiency of business and real life. By utilizing the analysis result received from the server / cloud, the IoT device can perform suitable operation to the situation and condition on the spot (From now on, such an IoT device is called an actuator).

However, few studies focused on how information obtained by data collection and analysis is given to each actuator. To achieve optimum actuation, a mechanism is necessary so as to acquire information according to the situation and condition of the actuator. In addition, since it may be considered that the actuator must be controlled immediately, it is necessary to minimize the delay with information acquisition.

## 3. DIRECTED DIFFUSION

Directed Diffusion is a sensor network routing protocol based on the Publish / Subscribe communication model. A sink, which is a node requesting data, floods a packet indicating its interest, and conveys the interest of the sink to the nodes in the network. Sources, which are nodes possessing data, that matches the interest of the sink, transfer the data to the sink. In this way, the sink can acquire only the necessary data.

The purpose of this research is to realize a network that distributes information according to the requirements of actuators. Directed Diffusion is a protocol that allows receivers to receive only data that matches their interests. Therefore, it can be said that Directed Diffusion is a routing control method suitable for this research.

### 3.1 Routing

Routing control of Directed Diffusion is performed in the following four steps.

1) Interest propagation (Figure 1)

The sink floods the interest packet indicating its interest in the network. The node which received the interest packet stores the interest and the information called the gradient corresponding to the interest. The gradient has information on the node that transferred the interest packet and the validity period. Eventually the interest packet reaches the source.

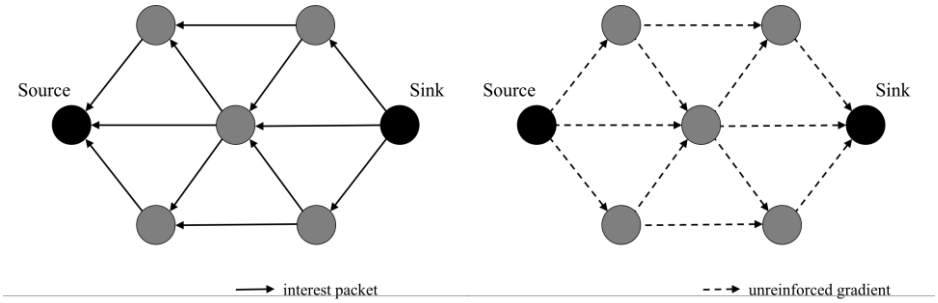


Figure 1. Interest Propagation

2) Search for transfer route (Figure 2)

The source generates an exploratory packet to search the data packet transfer route. The generated exploratory packet is repeatedly transferred to the node set to the gradient and reaches the sink.

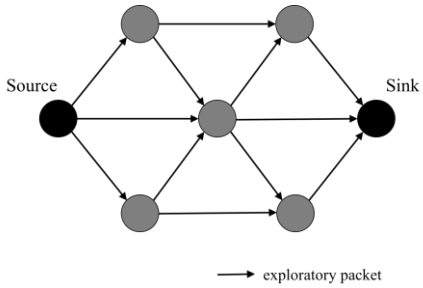


Figure 2. Search for Transfer Route

3) Establishment of transfer route (Figure 3)

The sink that received the exploratory packet generates a reinforce packet to determine the data packet transfer route (generally the route from which the exploratory packet was first sent). The reinforce packet is transferred in the direction opposite to the route forwarded by the exploratory packet and reaches the source. The node that received the reinforce packet causes the gradient used for transferring the exploratory packet to be established as a data packet transfer route (reinforcement of the gradient).

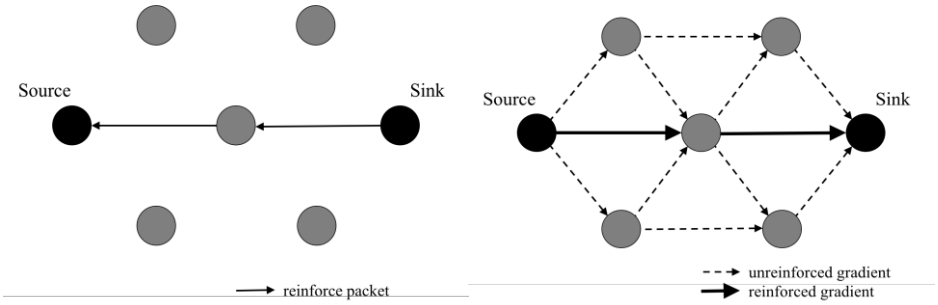


Figure 3. Establishment of Transfer Route

4) Data transmission

The data packet generated by the source repeats transfer along the reinforced gradients and reaches the sink.

The data packet transfer route may be disconnected due to a topology change caused by failure or movement of the node. For this reason, to optimize the data packet transfer route, the sink periodically transmits an interest packet.

## 3.2 Applicability to this Research

Directed Diffusion can distribute information to the node that needs it. By applying it to the assumed environment in this research, it is possible to achieve information distribution as requested by the actuator. In addition, the number of data packet can be reduced.

Presently there are efficient protocols for IoT, like MQTT, CoAP, etc. MQTT [MQTT] aims at a lightweight protocol of Publish /Subscribe type, but needs a central broker. Directed Diffusion achieves the function of the broker in a distributed manner. CoAP [Shelby, 2014] aims at a lightweight protocol on UDP as an alternative to HTTP. It is different from the purpose of this research. For example, it would be possible to implement the results of this research on CoAP.

As described above, Directed Diffusion is suitable for this research. However, If the conventional Directed Diffusion is directly applied to the assumed environment of this research, the following issues occur.

1) Mass occurrence of interest and exploratory packets

In general, Directed Diffusion is used in sensor networks, and the number of requesting nodes is not so large. In this research, it is assumed that the server / cloud distributes various data to many actuators. Therefore, the number of requesting nodes is larger than the environment assumed by Directed Diffusion in

the past, enormous number of interest and exploratory packets are generated. As a result, the network bandwidth is compressed, and there is a fear that a delay occurs in obtaining the data packet.

2) Disconnection of data packet transfer route due to movement of IoT devices

There is an environment in which IoT devices move like cars and drones. In this case, the topology changes due to the movement of the IoT device, and the data packet transfer route is frequently disconnected.

# 4. PROPOSED METHOD

As mentioned in Chapter 3, when applying conventional Directed Diffusion to information distribution of actuators as it is, two issues occur. In this section, we propose a method that improves Directed Diffusion to solve these issues. From this chapter onwards, a request node in the assumed environment of this research is called a target.

The proposed method establishes an data packet transfer route by connecting a new data packet transfer route to an existing data packet transfer route used by another target. For example, a target floods an interest packet to establish a new data packet transfer route. If there is a reinforced gradient corresponding to the interest at an intermediate node that received the interest packet, the transfer of the interest packet is stopped, and the exploratory packet is transferred from the node. In this case, transfer of interest and exploratory packet is not performed between the target and the source but between the target and the intermediate node. As a result, these transfer count can be reduced. This can deal with the issue that a lot of interest and exploratory packets are generated, prevents compression of bandwidth of the network.

In the assumed environment of this research, many actuators keep interest and establish the data packet transfer route corresponding to their interest. Therefore, when the actuator newly establishes the data packet transfer route, there is a high possibility that the data packet transfer route corresponding to the same interest already exists, and the route control method of the proposed method can be used.

In addition, when a target moves and a data packet transfer route requested by itself is disconnected, there is a situation that the target transfers the interest packet again to re-establish the transfer route. In the case of the proposed method, transfer of interest and exploratory packets is performed between the target and an intermediate node with a reinforced gradient corresponding to interest of the target. As a result, it is possible to re-establish the data packet transfer route in a shorter time than the conventional Directed Diffusion.

## 4.1 Routing

Routing control of the proposed method is performed in the following four steps. Figure 4 shows the initial gradient before routing control which is described below. The data packet path of the lower target already exists.

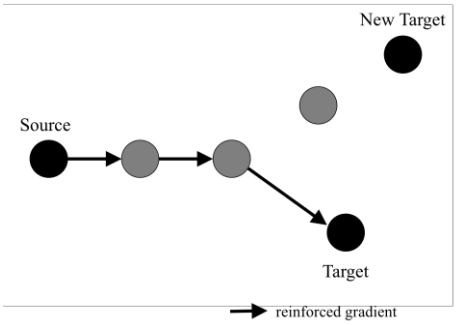


Figure 4. Initial Gradient

1) Interest propagation (Figure 5)

The target transfers the interest packet to neighboring nodes. The node that receives the interest packet stores the interest and the corresponding gradient. Thereafter, the node transfers the interest packet to the neighboring node. However, if there is a reinforced gradient corresponding to the interest at that node, since

there is a data packet transfer route between the node and the source, the transfer of the interest packet is stopped, and the exploratory packet is transferred from the node.

When the interest packet arrives at the source, the source generates an exploratory packet, like the conventional Directed Diffusion.

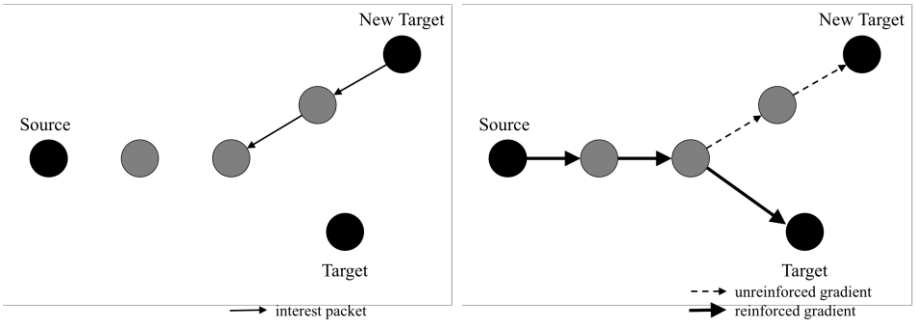


Figure 5. Interest Propagation

2) Search for transfer route (Figure 6)

The exploratory packet is repeatedly transferred to the node set to the gradient. Finally, the exploratory packet reaches the target.

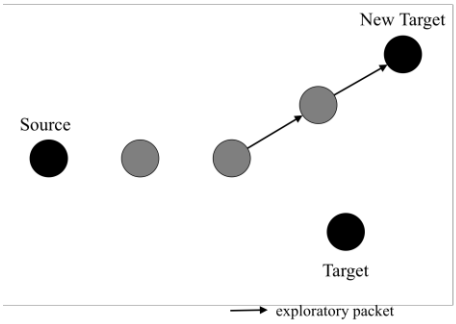


Figure 6. Search for transfer route

3) Establishment of transfer route (Figure 7)

The target that received the exploratory packet generates a reinforce packet. The reinforce packet is transferred in the direction opposite to the route forwarded by the exploratory packet and reaches the source. The node that received the reinforce packet causes the gradient used for transferring the exploratory packet to be established as a data packet transfer route (reinforcement of the gradient).

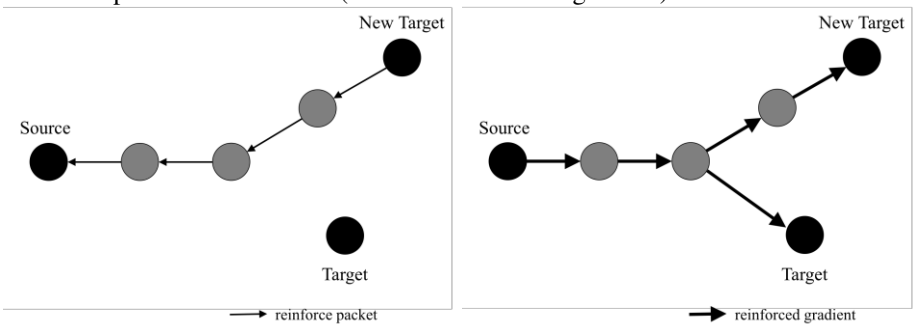


Figure 7. Establish of Transfer Route

4) Data transmission

Like the conventional Directed Diffusion, the source transfers the data packet in multi-hop according to the reinforced gradient. Finally, the data packet reaches each target.

# 5. SIMULATION

Experiments using a simulator were conducted to confirm the effectiveness of the proposed method.

We created a simulator using the java language. In this simulator, one server / cloud and a number of IoT devices are generated, and the server / cloud distributes various data to actuators. The simulator uses three routing control methods of flooding, Directed Diffusion, and proposed method. The parameters of the simulator were set based on empirical rules.

## 5.1 Simulation Process

The basic flow of the simulator is performed in the following five steps (one cycle).

1) Each node searches for a communicable node.
2) Each actuator generates interest with a certain probability (Interest is deleted after a certain period elapses).
3) The server / cloud generates each data packet corresponding to the interest with a certain probability.
4) Each node processes packets in the reception queue.
5) Each node sends packets in the transmit queue.

## 5.2 Node

It is generated in the field of size 1000 × 1000 horizontal using the distance on the simulator. However, it is not generated at a position where no communicable node exists. All nodes do not move from initial position.

**Server / Could:** The node (Source) that is the source of the data. One is generated in the center of the field.

**IoT device:** IoT devices are classified into the following two types.

**- Actuator:** The node (Target) that requested the data.

**- Other:** A node that relays packets.

Table 1. Environment of the Simulator

| Parameter | Value |
|---|---|
| Environment time | 5000 cycles |
| Number of Server / Cloud | 1 node |
| Number of IoT devices | 100 nodes |
| Number of interest types / corresponding data packet | 10 types |
| Probability of generation of each data packet | 20 % per cycle |
| Probability of generation of Actuator's interest | 0.4 % per cycle |
| Validity period of Actuator's interest | 500 cycles |
| Validity period of data packet | 10~50 cycles |
| Validity period of other packet | 50 cycles |

# 6. EVALUATION

We conducted an experiment using the simulator described in Chapter 5, examined changes in the performance of each method when the ratio of the actuators in all the IoT devices is increased. In the experiment, the number of transfers of each packet, the acquisition probability and acquisition time of data packet were measured. The average of the data obtained by ten simulations was taken as the measured value.

The result of the experiment is shown in Figure 8 ~ 10.

The left side of Figure 8 shows the number of transfers of all packets including interest, exploratory, reinforce and data packets, and the right side shows the number of data packet transfers. In the proposed method and the method using Directed Diffusion, the number of transfers of all packets is smaller than that of flooding. It is because these methods suppress the number of data packet transfers. It can be said to that information distribution according to the actuator's request is achieved in these methods.

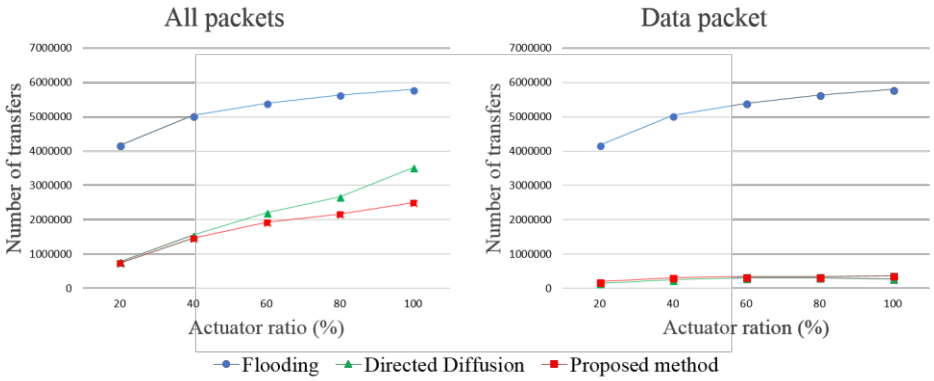


Figure 8. Number of Transfers of All Packets (Left) and Data Packet (Right)

The left side of Figure 9 shows the number of interest packet transfers and the right side shows the number of exploratory packet transfers. In Directed Diffusion, the higher the ratio of the actuators (the requesting nodes), the greater the number of transfer of interest and exploratory packets increases rapidly. In contrast, the proposed method can suppress transfers of interest and exploratory packets, the rate of increase in the number of transfers is low.

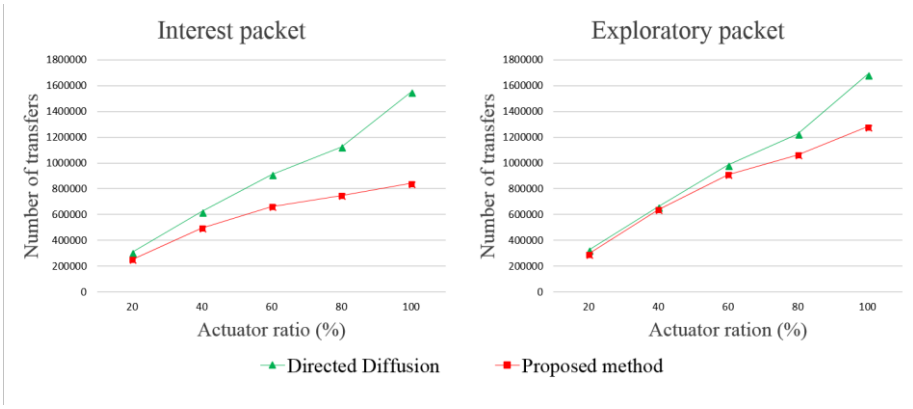


Figure 9. Number of Transfers of Interest Packet (Left) and Exploratory Packet (Right)

The left side of Figure 10 shows the acquisition probability of data packet and the right side shows the acquisition time of data packet. In Directed Diffusion, performance of acquisition probability and acquisition time greatly deteriorated due to rapid increase in interest and exploratory packets. On the other hand, in the proposed method, performance deterioration of acquisition probability and acquisition time was not seen much due to suppression of interest and exploratory packets.

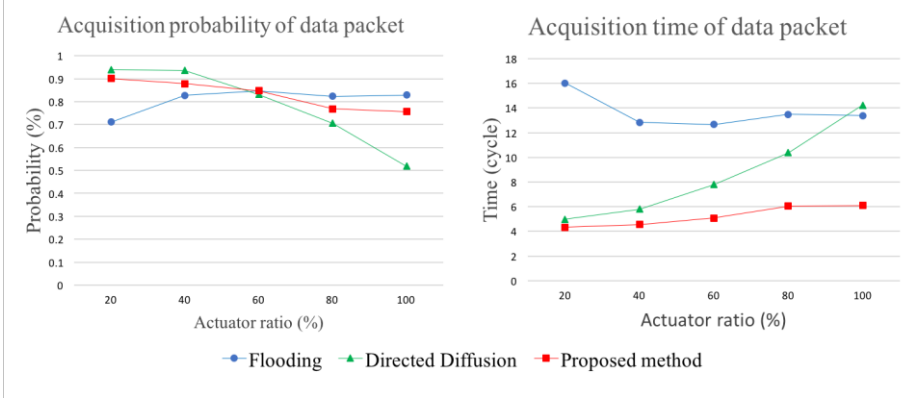


Figure 10. Acquisition Probability (Left) and Acquisition Time (Right) of Data Packet

The proposed method suppresses the number of times data packets are transferred, and it can be said that information distribution according to the requirements of the actuator is achieved. In addition, even when the ratio of the actuator as the requesting node increases, the number of transfers of interest and exploratory packets can be suppressed. Since the proposed method showed high performance under the condition that there are many actuators, it can be said that the proposed method is suitable for the information distribution to actuators.

# 7. CONCLUSION

The technology of data analysis in IoT is developing day by day, and it is getting feasible to perform advanced analysis in a short time. As a result, the importance of distributing information to actuators is increasing.

In this research, we aimed to achieve a network that distributes information according to the requirements of actuators. To achieve this purpose, we applied Directed Diffusion, which is usually used for sensor network, to actuator network. And we proposed an improved method of Directed Diffusion.

We verified the effectiveness of the proposed method by implementing the assumed environment of this research in the simulator and comparing it with the method applying flooding and Directed Diffusion. As a result, by the proposed method, the number of times of transfer of interest packet and exploratory packet was suppressed, and the acquisition probability and acquisition time of data packet were high. Also, since the number of times of transfer of data packet is small, it can be confirmed that the data packet is forwarded to the actuator that needs it, and information distribution according to the actuator's request, which is the object of this research, was achieved.

Future tasks are listed below.

1) Disconnection of data packet transfer route by movement of IoT devices

In the proposed method, we focused on the situation that the actuator moves and the data packet transfer route requested by itself is disconnected. However, we do not consider the situation that the data packet transfer route is disconnected by moving the other IoT device on the transfer route. It is necessary to devise a method to deal with this.

2) Investigation of various parameters to be set in the simulator

In this experiment, parameter values of the simulator were set based on empirical rules. In recent years, various IoT devices have been born, and the environment of IoT has diversified. It is necessary to investigate various parameters in detail, experiment under various circumstances, and confirm whether the proposed method is effective.

# REFERENCES

Botta A. et al, 2016. Integration of Cloud computing and Internet of Things: A survey. *Future Generation Computer Systems*, Vol. 56, pp. 684-700.

MQTT: http://mqtt.org [viewed Aug. 2018]

Shelby Z. et al, 2014. The Constrained Application Protocol (CoAP) IETF Internet Draft. No.7252.

Intanagonwiwat C. et al, 2000. Directed Diffusion: A scalable and Robust Communication Paradigm for Sensor Networks. *Proc. MobiCOM'00,* Boston, U.S.A., pp. 56-57.

Casey K. et al, 2008. RTDD: A Real-Time Communication Protocol for Directed Diffusion. *Proc. 2008 IEEE Wireless Communications and Networking Conference*. Las Vegas, U.S.A., pp. 2852-2857

Rawat U. et al, 2012. Directed Diffusion: Features, Current Developments, Issues and Analysis. *Int. J. of Computer Applications*, Vol.49, No. 12, pp. 31-35.