Multi-source and Multi-target Node Selection in Energy-efficient Fog Computing Model

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Multi-source and Multi-target Node Selection in Energy-efficient Fog Computing Model

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Abstract

In the fog computing model to realize the IoT, each fog node supports application processes to calculate output data on input data received from a fog node and sends the output data to another fog node. In our previous studies, types of the TBFC (Tree-Based Fog Computing) models are proposed to reduce the electric energy consumption and execution time of fog nodes and servers and to be tolerant of node faults. In the TBFC models, the tree structure of fog nodes is not changed even if some fog node is overloaded and underloaded. In this paper, we consider the DNFC (Dynamic Network-based Fog Computing) model. Here, there is one or more than one possible target fog node for each fog node and also one or more than one possible source node for each target node. A pair of a source node and target node which exchange data have to be selected. In this paper, we propose an MSMT (Multi-Source and Multi-Target node selection) protocol among multiple source and target nodes. Here, a pair of a source node and a target node are selected so that the total energy consumption of the nodes can be reduced. In the evaluation, we show the total energy consumption and total execution time by target nodes can be more reduced in the MSMT protocol.

Key words *: Internet of Things, Fog computing model, Energy-efficient*

I. Introduction

The IoT (Internet of Things) [1], [2] is composed of not only computers but also devices like sensors and actuators installed in various things [3]. The fog computing (FC) model is proposed to efficiently realize the IoT [4]. In order to not only increase the performance and reliability but also reduce the electric energy consumption of the IoT. The DNFC (Dynamic Network-based Fog Computing) model [5] is proposed to make the FC model more flexible. In a set of the source nodes and target nodes, a pair of source fog node f_i and a target fog node f_j which send output data and receives the data, respectively, are decided. So that the total energy to be consumed by the source and target nodes can be reduced. In this paper, we propose an MSMT (Multi-Source and Multi-Target node selection) protocol to make pairs of source and target fog nodes through the negotiation among source and target fog nodes. In the evaluation, we show the total energy consumption and total execution time of fog nodes in the MSMT protocol is smaller than the DNFCN [6] and random (RD) protocols.

In section II, we present the FC model. In section III, we discuss the computation and power consumption models of a fog node. In section IV, we propose the MSMT protocol in the DNFC model. In section V, we evaluate the MSMT protocol.

II. System Model

The fog computing (FC) model [4] to efficiently realize the IoT [3] is composed of fog nodes in addition to sensor and actuator devices and clouds of servers. Clouds are composed of servers like the cloud computing (CC) model. Various devices equipped with sensors and actuators are connected to edge fog nodes. A sensor node sends sensor data to an edge fog node. Each fog node f_i supports an application process $p(f_i)$ to calculate output data on input data from sensor nodes and other fog nodes. Then, the fog node f_i sends the output data to another fog node f_j which can calculate on the data. Fog nodes are interconnected with other fog nodes in types of networks including wireless networks. Fog nodes also move in networks as discussed in the MFC (Mobile FC) model [7].

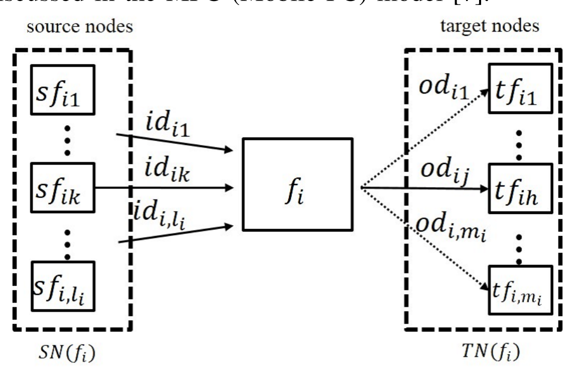

Fig. 1. Fog node model.

III. Computation and Power Consumption Models

Let F be a set of fog nodes $f_1, \ldots, f_n$ $(n \geq 1)$ in a system. Let CR_i show the computation rate of a fog node f_i to a root node f, i.e. server. Let CR be the computation rate of the root node f. We assume the computation rate CR to be one. $TP_i(x)$ shows the execution time [sec] of a fog node f_i to calculate output data OD_i on input data ID_i of size x. That is, it takes $TP_i(x)$ [sec] to perform a process $p(f_i)$. The execution time $TP_i(x)$ is $ct_i \cdot C_i(x)$ where ct_i is $1/CR_i$. In this paper, $C_i(x)$ is assumed to be x or x^2. $C_i(x)$ stands for the computation complexity of a process $p(f_i)$ of a node f_i. The execution time $TI_{ik}(x)$ and $TO_{ik}(x)$ [sec] of a fog node f_i $(\in F)$ to receive and send data of size x from a source node sf_{ik} and to a target node tf_{ik} ($\in F$), respectively, are proportional to the data size x, i.e. $TI_{ik}(x) = rc_i + rt_i \cdot x$ and $TO_{ik}(x) = sc_i + st_i \cdot x$. Here, rc_i, rt_i, sc_i, and st_i are constants for f_i.

The total execution time $TT_i(x)$ [sec] of a fog node f_i for input data ID_i of size x is given as follows:

$$TT_i(x) = TI_i(x) + TC_i(x) + \delta_i \cdot TO_i(or_i \cdot x). \quad (1)$$

Here, $\delta_i = 0$ if the fog node f_i is a root node, otherwise $\delta_i = 1$.

We discuss the energy consumption model of a fog node. Let $EI_i(x)$, $EC_i(x)$, and $EO_i(x)$ show electric energy [J] consumed by a fog node f_i to receive, calculate on, and send data of size x, respectively. First,we discuss the electric energy $EC_i(x)$ to be consumed by a fog node f_i to calculate output data od_i on input data ID_i of size x $(= |ID_i|)$. In this paper, we assume each fog node f_i follows the SPC (Simple Power Consumption) model [1], [8], [2]. A fog node f_i consumes the maximum power $maxE_i$ [W] to do the calculation on input data ID_i.

A fog node f_i consumes electric power PI_i and PO_i [W] to receive and send data where $PI_i = re_i \cdot maxE_i$ and $PO_i = se_i \cdot maxE_i$, respectively, where $re_i \leq 1$ and $se_i \leq 1$. It takes time $TI_i(x)$ and $TO_i(x)$ to receive and send data of size x from $l_i (\geq 1)$ source nodes sf_{i1}, ..., sf_{i,l_i} and to $m_i (\geq 1)$ target nodes tf_{i1}, ..., tf_{i,m_i}. EI_i and EO_i are the energy consumption of a fog node f_i to receive and send data of size x. $EC_i(x)$ is energy consumption to calculate to data size x. Finally, a fog node f_i consumes energy EE_i to receive and calculate output data on input data and to send output data to target nodes is given as follows:

$$\begin{aligned} EE_i(x) &= EI_i(x) + EC_R(x) + \delta_i \cdot EO_i(or_i \cdot x) \\ &= (re_i \cdot TI_i(x) + TC_i(x) + \delta_i \cdot se_i \cdot TO_i(or_i \cdot x)) \\ &\cdot \; maxE_i \\ &= ((re_i \cdot (l_i \cdot rc_i + rt_i \cdot x)) + ct_i \cdot C_i(x) \\ &+ \; \delta_i \cdot se_i \cdot (m_i \cdot sc_i + st_i \cdot or_i \cdot x)) \cdot maxE_i. \quad (2) \end{aligned}$$

IV. MSMT (Multi-Source and Multi-Target selection) Protocol

A. DNFC model

A fog node f_i supports an application process by which output data is calculated on a collection of input data received from other source nodes. Then the output data is delivered to another target fog node f_j. Here, the fog node f_j is a target node of the fog node f_i. The node f_i is in turn a source node of the target node f_j.

Suppose a pair of fog nodes f_i and f_j are in the communication range of the fog node f_i. Let $TAN(f_i)$ and $SAN(f_i)$ be a set of target and source nodes with witch f_i can communicate.

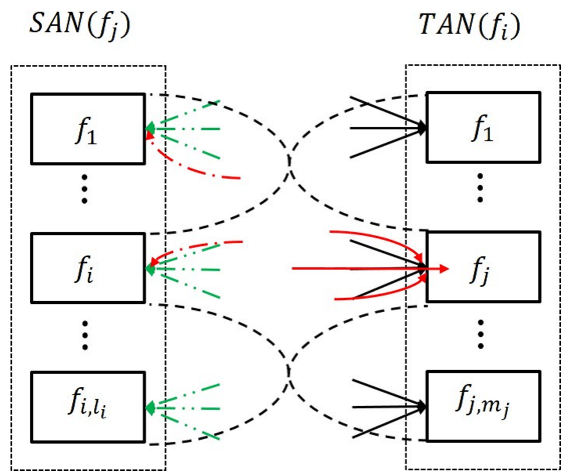

Fig. 2. Source and target nodes.

B. Negotiation protocol

A pair of a source fog node f_i in $SAN(f_j)$ and a target fog node f_j in $TAN(f_i)$ are selected to communicate with each other in an MSMT protocol as follows:

1) A source fog node f_i sends a processing request $Q_i(x_i)$ to every target fog node f_j with the size x_i of he output data od_i.
2) The target fog node f_j obtains the expected energy consumption and sends a confirmation $C_j(E_{ij})$ to every source fog node.
3) If the source fog node f_i receives confirmations from target fog nodes, a source fog node f_i selects a target fog node f_{ij} in the set TN where the expected energy consumption is smallest.
4) f_i sends a $DO_{ij}(x_i)$ message to the target fog node f_{ij} and a NO message to the other.
5) If the target fog node f_j receives the $DO_{ji}(x_i)$ message from the source fog node f_{ji}, sends an OK message to the source fog node f_{ji}.
6) On receipt of the OK message from the target fog node f_{ij}, the source fog node f_i sends the output data od_i to the target fog node f_{ij}.

V. Evaluation

In the evaluation, we consider l source fog nodes and m target fog nodes and $l = m$. The size x_i of output data od_i of each source fog node sf_i and the size X_j of input data id_j of each target fog node tf_j are randomly taken out of $1, 2, ..., 10$[MB].

We consider a random (RD) protocol and the DNFCN protocol [6] in addition to the MSMT protocol. In the RD protocol, each source fog node sf_i randomly selects a target fog node tf_j in the set TAN. In the DNFCN protocol, each target fog node tf_j receives data from only one source fog node.

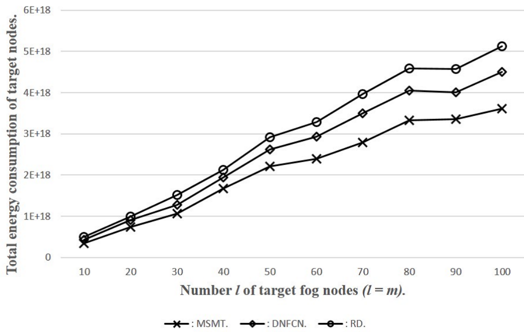

Fig. 3. Energy consumption of target nodes.

As shown in Figure 3, the total energy consumption of l target fog nodes is smaller in the MSMT protocol than the DNFCN and RD protocols. The total energy consumption of target fog nodes in the MSMT protocol is smaller than the DNFCN and RD protocols.

VI. Concluding Remarks

In the DNFC (Dynamic Network-based Fog Computing) model [6], each source fog node dynamically selects a target fog node, each time the source fog nodes send output data. In order to more reduce the total energy consumption of fog nodes, we proposed the MSMT protocol to do the negotiation among source and target fog nodes to select pairs of a target fog node and a source fog node which exchange data with each other in this paper. In the evaluation, we showed the total energy consumption and the total execution time of target fog nodes can be reduced in the MSMT protocol compared with the random (RD) and DNFCN protocols.

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