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Efficiently Probability and Topic-based Data Transmission Protocol

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Abstract

In the fog computing (FC) models, a fog node supports not only routing functions but also application processes. By the application processes, output data is calculated on input data from sensors and other fog nodes and sent to target fog nodes which can calculate on the output data. In this thesis, we consider the MPSFC (Mobile topic-based PS (publish/subscribe) FC) model where mobile fog nodes communicate with one another by publishing and subscribing messages of data in wireless networks. Subscription topics of a fog node denote input data on which the fog node can calculate. Publication topics of a message show data carried by the message. In the TBDT (Topic-Based Data Transmission) protocol proposed in our previous studies, a fog node only publishes a message of the output data to a target fog node in the communication range. Here, while a fewer number of messages are transmitted, the delivery ratio of messages is smaller than the epidemic routing protocol. In this thesis, we newly propose a PTBDT (Probability and TBDT) protocol in order to increase the delivery ratio. If another node is found in the communication range, a fog node forwards messages to the node. Even if the node is not a target node, the node receives the mesage with some probability. In the evaluation, we show the delivery ratio and exchanged messages in the PTBDT protocol.

Key words *: IoT, Mobile fog computing (MFC) model, Probability and topic-based data transmission (PTBDT) protocol, Mobile topic-based publish/subscribe fog computing (MPSFC) model*

I. Introduction

Fog computing (FC) models [1] to efficiently realize the IoT are composed of fog nodes in addition to server clouds and sensor and actuator devices. A fog node supports application processes to calculate on sensor data. Output data is calculated on sensor data by an application process supported by a fog node and then is sent to other fog nodes to do further calculation on the output data.

The MFC (Mobile FC) model [2] is composed of mobile fog nodes which communicate with other fog nodes in wireless communication links. Mobile fog nodes communicate with other fog nodes only in the communication range of wireless ad-hoc networks. Thus, mobile fog nodes communicate with other fog nodes by taking advantage of opportunistic routing protocols [3], [4].

A PS (Publish/Subscribe) model is a contents-aware, event-driven model of a distributed system [5], [6]. In topic-based PS models [7], data carried by messages is denoted by topics. We consider the P2PPS (P2P (peer-to-peer) type of topic-based PS) model [5], [6] to realize the FC model. Each fog node f_i is a peer which can publish a message m with publication topics $m.P$ and subscribe messages by specifying subscription topics $f_i.S$. The subscription topics $f_i.S$ denote input data on which the fog node f_i can calculate. The publication topics $m.P$ denote output data od_i of the source fog node f_i. A fog node f_i only receives a message m published by a fog node f_j whose publication topics $m.P$ and the subscription topics $f_i.S$ include some common topic, i.e. $m.P \cap f_i.S \neq \phi$. Here, the fog node f_i is a target fog node of the source node f_j. Thus, topics denote data on which a fog node calculates and which a message carries to a target fog node. In the TBDT (Topic-Based Data Transmission) protocol [8], [9], [10], each fog node f_i sends a message of the output data to only a target node f_j in the communication range. In this thesis, we propose a PTBDT (Probability and Topic-Based Data Transmission) protocol. Every fog node f_i sends the output data to not only a target but also non-target node f_j in the communication range. In the PTBDT protocol, the non-target node f_j receives the output data with some probability. In the evaluation, we show the number of messages transmitted in the PTBDT protocol is fewer than the epidemic routing protocol [11] and the delivery ratio of messages is larger than the TBDT protocol.

In section II, we present the MPSFC model. In section III, we propose the PTBDT protocol. In section IV, we evaluate the PTBDT protocol.

II. Moblile Publish/Subscribe Fog Computing (MPSFC) Model

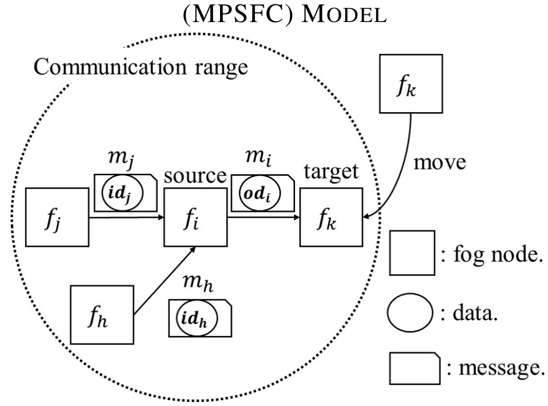

Fig. 1. MFC model.

In this thesis, we consider the MPSFC (Mobile topic-based Publish/Subscribe Fog Computing) model [8] to realize the MFC (mobile fog computing) model [2] of the IoT by taking advantage of the PS (publish/subscribe) model [5], [6]. The MPSFC model is composed of mobile fog nodes which communicate with one another by publishing and subscribing messages in wireless communication networks. Mobile fog nodes communicate with one another only in the communication range [11]. A mobile fog node is also equipped with sensors and actuators. A fog node collects data from sensors and activates actuators. In addition, a fog node f_i supports an application process $p(f_i)$ to calculate output data on the input data from sensors and other fog nodes and sends the output data to other fog nodes. A fog node f_i receives input data id_j from each source fog node f_j. Then, the fog node f_i calculates the output data od_i on the input data and then forwards the output data od_i to a target fog node f_k [Figure 1]. The data od_i is the input data id_i of the fog node f_k.

A fog node f_i specifies subscription topics $f_i.S$ which denote input data on which the fog node f_i can calculate. A message m is characterized by publication topics $m.P$ which denote output data od_j of the source fog node f_j. A fog node f_i only receives a message m whose $m.P \cap f_i.S \neq \phi$. This means, the fog node f_i supports a process $p(f_i)$ to calculate on data od_j carried by the message m. Here, the fog node f_i is a $target$ node of the fog node f_j and f_j is a $source$ fog node of f_i ($f_j \rightarrow f_i$). A fog node f_i receives a collection ID_i of input data, i.e. $ID_i = \{id_{ij} \mid f_j \rightarrow f_i\}$. Then, on receipt of messages from every source node, the fog node f_i calculates output data od_i on input data ID_i carried by the messages. The output data od_i is characterized by publication topics $od_i.P$ ($\subseteq P$). The publication topics $f_i.P$ of a fog node f_i show types of output data of a process $p(f_i)$.

Let D be a collection of data in a system. A process $p(f_i)$ supported by a fog node f_i is considered to be a function which uses inputs data id_{i1}, ..., id_{i,l_i} ($l_i \geq 1$) and returns outputs data od_i, i.e. $od_i = p(f_i)$ (id_{i1}, ..., id_{i,l_i}), where $id_{ij} \in D$ (j = 1, ..., l_i) and $od_i \in D$. Let T_{ij} be the publication topics $id_{ij}.P$ and T_i be $od_i.P$. Here, the process $p(f_i)$ is specified as $p(f_i)$: $T_{i1} \times \cdots \times T_{i,l_i} \rightarrow T_i$. Here, topics T_{ij} and T_i are referred to as $sorts$ of the process $p(f_i)$. Here, $T_{i1} \cup \cdots \cup T_{i,l_i} \subseteq f_i.S$ and $T_i \subseteq f_i.P$. The publication topics $m.P$ of a message m carrying the output data of a fog node f_i are $f_i.P$.

A fog node f_i can communicate with another fog node f_j ($f_i \leftrightarrow f_j$) only if the fog node f_j is in the communication range of the fog node f_i. Let $FN(f_i)$ be a set of fog nodes which are in the communication range of a node f_i, i.e. $\{f_j \mid f_i \leftrightarrow f_j\}$. Each fog node f_i can only communicate with another fog node f_j in the set $FN(f_i)$. A message m published by a source fog node f_i is only received by a target fog node f_j in the communication range, where $f_i \rightarrow f_j$, i.e. $m.P \cap f_j.S \neq \phi$.

III. Probability and Topic-based Data Transmission (TBDT) Protocol

In the TBDT (Topic-based Data Transmission) protocol proposed in our previous thesis [8], [9], each fog node f_i only delivers a message m of output data od_i to a target fog node f_j in the communication range, i.e. $f_i \rightarrow f_j$ and $f_i \leftrightarrow f_j$. A fog node which forwards the output data to non-target fog nodes is referred to as $epidemic$. The more number of fog nodes, the more number of messages are transmitted and stored in fog nodes, while the larger delivery ratio. In this thesis, a $PTBDT$ (Probability and TBDT) protocol to reduce the number of messages and buffer size.

First, suppose a fog node f_i obtains input data from sensors and calculates output data od_i on the sensor data. Then, a fog node f_i sends the output data od_i to a target fog node f_j if the target fog node f_j is in the communication range of the source fog node f_i ($f_i \leftrightarrow f_j$). Suppose a target fog node f_j is in the communication range of a fog node f_i, i.e. $f_i \leftrightarrow f_j$. Here, the fog node f_i includes the output data od_i to a message m_i. A message m_i carries a collection of data $d_{i1}, \ldots, d_{i,l_i}$. The fog node f_i publishes the message m_i to the target fog node f_j. $d_{ij}.P$ shows topics denoting the data d_{ij}. The publication $m_i.P$ of the message m_i is a set of the publication topics $d_{i1}.P, \ldots, d_{i,l_i}.P$ of the data $d_{i1}, \ldots, d_{i,l_i}$ carried by the message m. Then, the message m_i arrives at the fog node f_j. Here, only at most one third of the maximum size of the buffer $f_j.M$ can be used to store the data of the message m_i.

In the PTBDT protocol, the fog node f_j checks if the publication $m_i.P$ of the message m_i and the subscription $f_j.S$ of the fog node f_j include at least one common topic, i.e. $m_i.P \cap f_j.S \neq \phi$. Here, if $m_i.P \cap f_j.S \neq \phi$, the message m_i is received by a fog node f_j since f_j is a target node of f_i. Otherwise, the fog node f_j receives the message m_i at probability λ. At probability 1 - λ, the fog node f_i neglects the message m_i Then, if the fog node f_j receives the message m_i, each data d_{ij} in the message m_i is stored in the buffer $f_j.M$.

Each fog node f_i publishes and receives a message m and calculates output data on input data carried by the message m in each protocol as follows:

We present the procedure of the PTBDT protocol as follows:

[Fog node f_i publishes a message m_i to a fog node f_j]

1) A fog node f_i finds a fog node f_j in the communication range of the fog node f_i, i.e. $f_i \leftrightarrow f_j$;
2) The fog node f_i adds the output data od_i in the buffer $f_i.M$ to a message m_i;
3) The publication $m_i.P$ is a set of topics $od_i.P$ ($\subseteq T$), i.e. $m_i.P = od_i.P$;
4) The fog node f_i **publishes** the message m_i to the target fog node f_j;

[Fog node f_i receives a message m_j from a fog node f_j]

1) A message m_j from a node f_j arrives at a fog node f_i;
2) If $m_j.P \cap f_i.S \neq \phi$, the fog node f_i **receives** the message m_j. If $m_j.P \cap f_i.S = \phi$, f_i randomly receives m_j with the probability λ. Otherwise, the fog node f_i **neglects** the message m_j;
3) If the buffer $f_i.M$ of the fog node f_i is full, the fog node f_i **deletes** the data d_k whose TTL is smallest and where $f_i.P \cap d_k.T = \phi$ in the buffer $f_i.M$;

4) The fog node f_i stores the data od_j as the input data id_i in the buffer $f_i.M$;

[Fog node f_i calculates on input data id_i]

1) The fog node f_i calculates output data od_i on the input data id_i in the message m_j using the process $p(f_i)$;
2) The output data od_i is stored in the buffer $f_i.M$;

IV. Evaluation

We evaluate the PTBDT protocol of the MPSFC model in terms of the number of messages exchanged among fog nodes and delivery ratio of messages compared with the TBDT [8], [9] protocol and the epidemic routing protocol [11]. There are mobile fog nodes f_1, ..., f_n ($n \geq 1$) and sensor nodes n_1, ..., n_5 on an $m \times m$ mesh M. We assume the distance d between a pair of neighboring points is one in the mesh M. Each fog node f_i moves on the mesh M in a random walk way. Let cr_i be the communication range of a fog node f_i and a sensor node n_i. Each fog node f_i moves with velocity s_i in a random walk.

Let T be a set of all topics $t_1, \ldots, t_l$ ($l \geq 1$) in a system. Let D be a collection of data in a system. First, each sensor node n_i has one data d_i and a topic $T(d_i)$ of the data d_i is randomly taken from the set T. Then, each fog node f_i has a process $p(f_i)$. Each fog node f_i supports a process $p(f_i) : T_{i1} \times \cdots \times T_{i,l_i} \rightarrow T_i$. The subscription $f_i.S$ and the publication $f_i.P$ of a fog node f_i are a collection $\{T_{i1}, \ldots\ T_{i,l_i}\}$ of input sorts and the output sort T_i, respectively. Then, data has a TTL (time-to-live) field. Initially, the TTL field ttl_{f_i} of the fog node f_i is 70. Value of the TTL field ttl_i of the data d_i is set up by the fog node f_i when f_i stores the data d_i in the buffer $f_i.M$, i.e. ttl_i = 70. The TTL field is decremented by one at one simulation step. If TTL field of the data is 0, the data is deleted from the buffer.

Next, every fog node f_i randomly moves in the mesh M with the velocity s_i for each simulation step. Let d_{ij} show the distance between a pair of fog nodes f_i and f_j or a pair of a sensor node s_i and a fog node f_j. If each sensor node n_i finds a fog node f_j in the communication range cr_i, i.e. $d_{ij} \leq cr_i$, the sensor node n_i sends sensor data sd_i to the fog node f_j. If each fog node f_i also finds a fog node f_j in the communication range cr_i, i.e. $d_{ij} \leq cr_i$, the fog node f_i publishes a message m_i to the fog node f_j. Here, the message m carries the output data od_i of the fog node f_i. The publication $m_i.P$ of the message m_i is the publication topics $od_i.P$ of the output data od_i. Then, the message m_i arrives at the fog node f_j. The fog node f_j receives a message m_i and stores output data od_i as the input data id_i in the buffer $f_j.M$. The fog node f_j calculates the output data od_j on the input data id_i by using the process $p(f_j)$. The output data od_j is stored in the buffer $f_j.M$. Finally, the delivery ratios of messages in the PTBDT protocol and the epidemic routing protocol [11] are calculated. In the epidemic routing protocol [11], if a message m arrives at the fog node f_i, the fog node f_i receives the message m and stores data in the message m in the buffer $f_i.M$.

In the evaluation, an application process is composed of four stages. In the first stage, the process calculates the average value on input data. In the second stage, the process merges input data into output data. In the third stage, the process joins input data into output data. The processes $p_1, \ldots, p_5$ do the first stage. The processes $p_6, \ldots, p_{10}$ do the second stage. The processes $p_{11}, \ldots, p_{15}$ do the third stage. The processes p_{16}, $\ldots$, p_{20} receive the final data. The processes $p_1, \ldots, p_5$ have five sorts of sensor data $sd_1, \ldots, sd_5$ and five sorts of output data $od_{1,1}, \ldots, od_{1,5}$. The processes $p_6, \ldots, p_{10}$ also have five sorts of input data $id_{1,1}, \ldots, id_{1,5}$ and five sorts of output data $od_{1,6}, \ldots, od_{1,10}$. The processes $p_{11}, \ldots, p_{15}$ also have five sorts of input data $id_{1,6}, \ldots, id_{1,10}$ and five sorts of output data $od_{1,11}, \ldots, od_{1,15}$. Then, each fog node f_i is equipped with a buffer $f_i.M$. In the simulator, the size of each buffer $f_i.M$ is 10 and size of sensor data sd_i is 1. Then, the output ratio of each process is 0.5. There are a 500 $\times$ 500 mesh (m = 500), and twenty topics (l = 20). In the evaluation, we change the number fn of fog nodes which support each process. For example, if each process is supported by two fog nodes (fn = 2), there are forty fog nodes in the simulator. Then, fog nodes are divided into two types: vehicle fog node and human fog node. The velocity s_i of each vehicle fog node and human fog node f_i is 1 and 2 at one simulation step, respectively. Here, the communication range cr_i of each fog node f_i is 3.

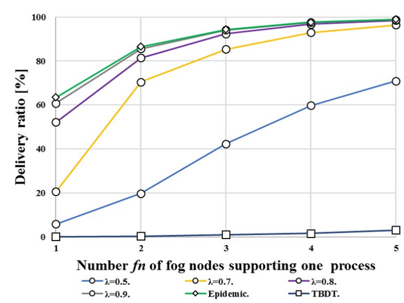

Fig. 2. Delivery ratio.

Figures 2 show the delivery ratios of data to the root node in the each protocol. In the PTBDT protocol, probability λ is 0.5, 0.7, 0.8, 0.9. Then, the PTBDT protocol with the probability λ = 1.0 means the epidemic routing protocol and the probability λ = 0 stands for the TBDT protocol. The delivery ratios of the PTBDT protocol with probability λ = 0.9 and the epidemic routing protocol are almost the same. The delivery ratios of the PTBDT protocol with probability λ = 0.7 and the epidemic routing protocol are almost the same when the number fn of each fog node which supports one process is four (fn = 4).

Figures 3 show the number of messages exchanged among fog nodes in each protocol. The numbers of messages exchanged among fog nodes in the PTBDT protocol with probability λ = 0.9, and the epidemic routing protocol are almost the same. The number of messages exchanged among fog nodes in the epidemic routing protocol is a little bit larger than the PTBDT protocol with probability λ = 0.8, 0.9. Thus, in the PTBDT protocol with probability λ = 0.8, 0.9, the number of messages received and the number of messages exchanged among fog nodes can be reduced in a same delivery ratio compared with the epidemic routing protocol.

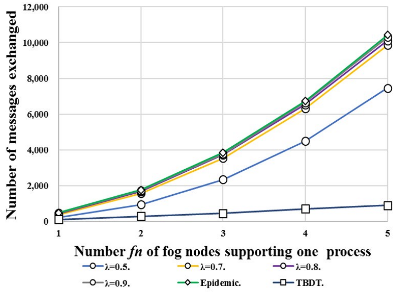

Fig. 3. Number of messages exchanged.

V. Concluding Remarks

In this thesis, we considered the MPSFC (Mobile Publish/Subscribe Fog Computing) model to efficiently realize the IoT, where mobile fog nodes like vehicles communicate with other nodes in wireless networks. Here, each fog node calculates the output data on the input data received from other fog nodes and forwards the output data to target fog nodes in the epidemic routing way. In this thesis, we newly proposed the PTBDT (Probability and TBDT) protocol where each fog node f_i is delivered not only messages of data on which the fog node f_i can calculate by taking advantage of the topic-based PS model but also data on which the fog node f_i cannot calculate. In the evaluation, we showed the delivery ratio can be increased in the the PTBDT protocol compared with the TBDT protocol.

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References

[1] A. M. Rahmani, J.-S. P. P. Liljeberg, and A. Jantsch, *Fog Computing in the Internet of Things*. Springer, 2018.

[2] K. Gima, R. Oma, S. Nakamura, T. Enokido, and M. Takizawa, "A model for mobile fog computing in the iot (accepted)," in *Proc. of the 22nd International Conference on Network-Based Information Systems (NBiS-2019)*, 2019.

[3] S. K. Dhurandher, D. K. Sharma, I. Woungang, and A. Saini, "An energy-efficient history-based routing scheme for opportunistic networks," *International Journal of Communication Systems*, vol. 30, no. 7, 2015.

[4] E. Spaho, L. Barolli, V. Kolici, and A. Lala, "Evaluation of single-copy and multiple-copy routing protocols in a realistic vdtn scenario," in *Proc. of the 10th International Conference on Complex, Intelligent, and Software Intensive Systems (CISIS-2016)*, 2016, pp. 285–289.

[5] S. Tarkoma, *Publish/Subscribe System : Design and Principles (FIRST Edition)*. John Wiley and Sons, Ltd., 2012.

[6] S. Tarkoma, M. Rin, and K. Visala, "The publish/subscribe internet routing paradigm (psirp) : Designing the future internet architecture," in *Future Internet Assembly*, 2009, pp. 102–111.

[7] V. Setty, M. van Steen, R. Vintenberg, and S. Voulgais, "Poldercast: Fast, robust, and scalable architecture for p2p topic-based pub/sub," in *Proc. of ACM/IFIP/USENIX 13th International Conference on Middleware (Middleware-2012)*, 2012, pp. 271–291.

[8] T. Saito, S. Nakamura, T. Enokido, and M. Takizawa, "A topic-based publish/subscribe system in a fog computing model for the iot," in *Proc. of the 14th International Conference on Complex, Intelligent and Software Intensive Systems (CISIS-2020)*, 2020, pp. 12–21.

[9] ——, "Topic-based processing protocol in a mobile fog computing model," in *Proc. of the 23nd International Conference on Network-Based Information Systems (NBiS-2020)*, 2020, pp. 43–53.

[10] ——, "Epidemic and topic-based data transmission protocol in a mobile fog computing model," in *Proc.of the 15th International Conference on Broad-Band and Wireless Computing, Communication and Applications (BWCCA-2020)*, 2020, pp. 34–43.

[11] V. Amin and B. David, "Epidemic routing for partially-connected adhoc networks," *Technical Report*, 06 2000.