A Topic-Based Publish/Subscribe System in a Fog Computing Model for the IoT

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Abstract. In order to reduce the traffic of networks and servers in the IoT, types of the fog computing (FC) models are proposed, which are composed of fog nodes. A fog node supports application processes to calculate output data on sensor data and forward the output data to servers. A topic-based PS (publish/subscribe) model is a new contents-aware, event-driven model of a distributed system. Here, a process publishes a message whose contents are denoted by publication topics. A process specifies subscription topics and only is delivered messages whose publication topics include some of the subscription topics. In our previous studies, the MPSFC (Mobile PS (publish/subscribe) Fog Computing) model is proposed where mobile fog nodes like vehicles are interconnected and fog nodes communicate with one another in wireless networks by the PS model. In this paper, we propose a TBDT (Topic-based Data Transmission) protocol for mobile fog nodes to deliver messages to target nodes. In the evaluation, we show the number of messages in the TBDT protocol is fewer than the epidemic routing protocol while the delivery ratio is smaller.

Keywords: IoT · Fog Computing (FC) model · Mobile Fog Computing (MFC) model · Topic-based publish/subscribe system · Mobile Publish/Subscribe Fog Computing (MPSFC) model

1 Introduction

In the IoT (Internet of Things) [10,16], millions of sensor and actuator devices are interconnected with clouds of servers in networks [8]. Due to the scalability of the IoT, networks are congested to forward sensor data to servers and servers are also heavily loaded to do the calculation on the sensor data. Fog computing (FC) models [11,17] are proposed to efficiently realize the IoT by reducing the traffic of networks and servers. The FC model is composed of fog nodes in addition to servers and devices. Output data is obtained by calculating on sensor data by

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an application process supported by a fog node and then sent to other fog nodes to further calculate on the data. In the TBFC (Tree-based Fog Computing) model [6,7,12,15], fog nodes are hierarchically structured in a tree to reduce the energy consumption of the fog nodes. In order to make the TBFC model tolerant of faults, the FTBFC (Fault-tolerant TBFC) model is also proposed [13–15].

In the IoT, mobile fog nodes like vehicles and smart devices are interconnected with wireless networks like V2V (vehicle-to-vehicle) networks [9] in addition to servers. Mobile fog nodes are communicating with other fog nodes in wireless ad-hoc networks. Since a fog node is moving, no other fog node may be in the wireless communication range of the fog node even if the fog node would like to send data. Thus, mobile fog nodes have to take advantage of opportunistic communication [3,19]. A fog node waits for opportunity that another fog node comes in the communication range.

A PS (Publish/Subscribe) model is a contents-aware, event-driven model of a distributed system [20,21]. In topic-based PS models [18,22], contents of messages are denoted by topics. Each message m carries publication topics $m.P$ in stead of the IP address [2] of a destination process, which denote the contents. Once a message m is published, the message m is only delivered to a process which is interested in the contents of the message m. A process p_i specifies subscription topics $p_i.S$ which denote interesting contents which the process p_i would like to get. We consider a P2P (peer-to-peer) type of topic-based publish/subscribe (PS) model [20,21] to realize the FC model. Each fog node is a peer which can publish messages with publication topics and subscribe messages by specifying subscription topics. If a fog node f_i is in the communication range of another fog node f_j, the fog node f_j publishes a message m with publication topics $m.P$. Then, only if the subscription $f_i.S$ of a fog node f_i and the publication $m.P$ of a message m include at least one common topic, the fog node f_i receives the message m. In this paper, we newly propose an MPSFC (Mobile Publish/Subscribe Fog Computing) model for mobile fog nodes by taking advantage of the PS model. In the MPSFC model, we propose a TBDT (Topic-based Data Transmission) protocol for each fog node to exchange data with other fog nodes in the communication range by publishing and subscribing messages. We evaluate the TBDT protocol with the epidemic routing protocol [1] in terms of delivery ratio of messages and the number of messages published. We show the number of messages in the TBDT protocol is fewer than the epidemic routing protocol.

In Sect. 2, we present a system model. In Sect. 3, we propose the MPSFC model. In Sect. 4, we propose the TBDT protocol in the MPSFC model. In Sect. 5, we evaluate the TBDT protocol compared with the epidemic routing protocol.

2 System Model

A mobile fog computing (MFC) model [4,5] is composed of clouds of servers and fog nodes which are interconnected in wired and wireless networks [17]. Fog nodes are mobile fog nodes like vehicles. Mobile fog nodes communicate with one another in wireless ad-hoc networks [1]. A mobile fog node is equipped with sensors and actuators in addition to application processes. A fog node collects data from sensors and activates actuators. In addition, a fog node calculates output data on the sensor data and sends the output data to other fog nodes. On receipt of input data from another fog node, a fog node also calculates the output data on the input data and forwards the output data to other fog nodes. Servers in clouds finally receive data which is obtained by fog nodes. Then, a server makes a decision on actions to be done by actuators and deliver the actions to fog nodes which support the actuators.

In the TBFC (Tree-based Fog Computing) model [13,15], a fog node f_i supports an application process $p(f_i)$ to calculate output data on input data from sensors and other fog nodes supporting the actuators. A fog node which supports an application process to calculate the output data on the input data is a *target* node of the input data. The sensor data id_i is first received by a target node f_i. Then, the output data od_i is calculated on the input data id_i by the fog node f_i through performing the process $p(f_i)$ on the input data id_i. The output data od_i has to be sent to a target fog node f_j which supports a process $p(f_j)$ to calculate on the output data od_i.

A mobile fog node f_i can communicate with another fog node f_j only if the fog node f_j is in the communication range of the node f_i as shown in Fig. 1. In papers [4,5], the data transmission (DT), process transmission (PT), data exchange (DE), parallel data transmission (PDT) algorithms are proposed for a fog node to communicate with another node in the communication range. In the PDT algorithm [5], a source node f_i divides output data to segments and sends segments to multiple target nodes in the communication range of f_i. In the PDT1 algorithm, a source node f_i sends a segment of same size to target nodes. In the PDT2 algorithm, a source node sends a segment of different size to each target node so that the total size of the segment and the input data is the same.

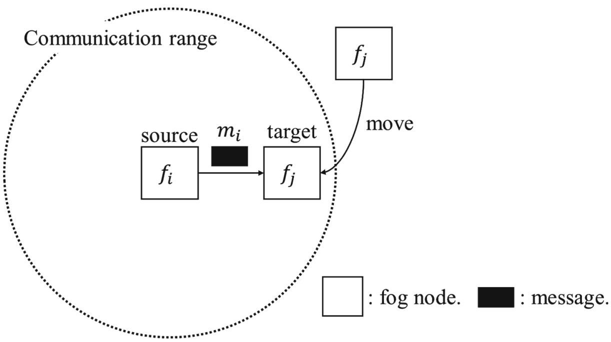

Fig. 1. MFC model.

In a P2PPS (P2P (peer-to-peer) model of a topic-based PS (publish/subscribe)) system [20,21], each process is a peer process (peer) which can both publish and subscribe messages. In addition, there is no centralized coordinator to do the communication among the peers. Let T be a set of topics in a system. Contents of a message are denoted by topics. Each peer p_i specifies interesting topics named *subscription* topics $p_i.S$ $(\subseteq T)$. Possible topics on which a peer p_i publishes messages are named *publication* topics $p_i.P$ $(\subseteq T)$ of the peer p_i. Each peer p_i gives a message m publication topics $m.P$ $(\subseteq p_i.P)$ which denote the contents of the message m and then publishes the message m. Once a message m is published, the message m is only delivered to a peer p_i where $p_i.S \cap m.P \neq \phi$. Here, the peer p_i is a *target* fog node of the message m.

In this paper, we newly propose an MPSFC (Mobile Publish/Subscribe Fog Computing) model to realize the mobile fog computing (MFC) model of the IoT by taking advantage of the PS model. The MPSFC model is composed of mobile fog nodes and fog nodes communicate with one another by publishing messages and receiving messages with respect to topics. A fog node f_i delivers each message m to another fog node f_j in the communication range only if the fog node f_j is interested in the message m, i.e. $m.P \cap f_j.S \neq \phi$.

3 Mobile Publish/Subscribe Fog Computing (MPSFC) Model

In this paper, we consider the MFC (mobile fog computing) model [4,5], where each fog node f_i moves and communicates with other fog nodes in wireless networks. We discuss how fog nodes communicate with one another to calculate output data on input data and exchange the output data.

Let F be a set $\{f_1, ..., f_n\}$ of fog nodes and T be a set $\{t_1, ..., t_l\}$ $(l \geq 1)$ of topics in a system. Each fog node f_i subscribes a collection $f_i.S$ $(\subseteq T)$ of subscription topics. Each fog node f_i also specifies a collection $f_i.P$ $(\subseteq T)$ of publication topics. Each fog node f_i publishes a message m with publication topics $m.P$ $(\subseteq f_i.P)$ which denote contents, i.e. data in the message. 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 fog node f_i cannot communicate with any fog node which is not in the set $FN(f_i)$. A message m published by a fog node f_i is only received by a target node f_j where the publication $m.P$ and the subscription $f_j.S$ include some common topic, i.e. $m.P \cap f_j.S \neq \phi$.

A fog node f_i *precedes* a fog node f_j with respect to a subset ST $(\subseteq T)$ of topics $(f_i \rightarrow_{ST} f_j)$ if the publication $f_i.P$ of the fog node f_i and the subscription $f_j.S$ of the fog node f_j have common topics ST, i.e. $ST \subseteq f_i.P \cap f_j.S$. Here, the fog node f_j is a *target* node of the fog node f_i with respect to the topic subset ST $(\subseteq T)$. A target node f_j of a fog node f_i may receive a message published by the fog node f_i. It is noted, the fog node f_j receives a message m published by the fog node f_i only if $m.P$ ($\subseteq f_i.P$) $\cap f_j.S \neq \phi$. A fog node f_i *precedes* a fog node f_j ($f_i \rightarrow f_j$) iff $f_i \rightarrow_{ST} f_j$ for some topic subset ST ($\subseteq T$).

Let $TN(f_i)$ ($\subseteq F$) be a set $\{f_j \mid f_i \rightarrow f_j\}$ of target nodes of a node f_i. Let $TFN(f_i)$ ($\subseteq F$) be a set of target nodes of a fog node f_i with which the fog node f_i can communicate, i.e. $\{f_j \mid f_i \rightarrow f_j$ and $f_j \leftrightarrow f_i\}$, i.e. $TFN(f_i) = TN(f_i) \cap FN(f_i)$. A fog node f_i can only deliver a message m to a target fog node f_j in the set $TFN(f_i)$.

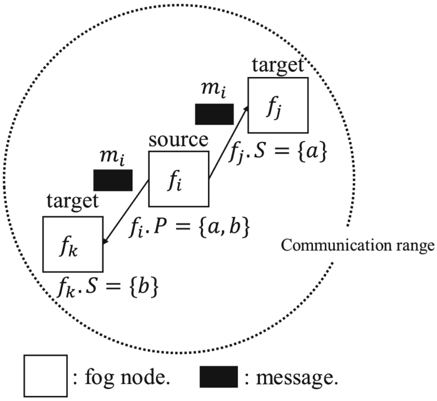

Fig. 2. MPSFC model.

In Fig. 2, a pair of fog nodes f_j and f_k are in the communication range of a fog node f_i ($\subseteq f_i.S$), i.e. $FN(f_i) = \{f_j, f_k\}$. Let T be a set $\{a, b, c\}$ of topics in a system. Here, $f_i.P = \{a, b\}$, $f_j.S = \{a\}$, and $f_k.S = \{b\}$ ($\subseteq T$). Hence, the fog node f_i precedes the fog node f_j in terms of the topic a, i.e. $f_i \rightarrow_{\{a\}} f_j$. In addition, the fog node f_i precedes the fog node f_j, i.e. $f_i \rightarrow f_j$. The fog node f_i precedes the fog node f_k with respect to the topic b, i.e. $f_i \rightarrow_{\{b\}} f_k$. A fog node f_i publishes a message m_i whose publication topic is a, i.e. $m_i.P = \{a\}$ ($\subseteq f_i.P$). Since the publication $m_i.P$ of the message m_i and the subscription $f_j.S$ of the fog node f_j include a common topic a ($\in m_i.P \cap f_j.S$), the fog node f_j receives the message m_i. Since the publication $m_i.P$ of the message m_i and the subscription $f_k.S$ of the fog node f_k include no common topic, the fog node f_k does not receive the message m_i although $f_i \rightarrow_{\{b\}} f_k$. Then, the publication $f_i.P$ of the fog node f_i and the subscription $f_j.S$ of the fog node f_j also include a common topic a. In Fig. 2, the fog node f_j is a target node of the fog node f_i with which f_i can communicate in wireless networks, i.e. $TFN(f_i) = \{f_j\}$ because $FN(f_i) = \{f_j, f_k\}$ and $TN(f_i) = \{f_j\}$.

4 Topic-Based Data Transmission (TBDT) Protocol

We propose a TBDT protocol for mobile fog nodes to deliver messages to target mobile fog nodes in the MPSFC model. Each fog node f_i specifies the subscription $f_i.S$ ($\subseteq T$) and the publication $f_i.P$ ($\subseteq T$). Here, each fog node f_i is assumed to hold data d_i. The publication $d_i.P$ of the data d_i are assumed to be the publication $f_i.P$, i.e. $d_i.P = f_i.P$. Each fog node f_i is assumed to move in networks.

First, suppose a 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 data d_i to a message m_i. The fog node f_i publishes a message m_i to the node f_j. The publication $m_i.P$ of the message m_i is the publication $d_i.P$ of the data d_i. Then, the message m_i arrives at the fog node f_j. 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 a 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 fog node f_j is delivered a message m_i and stores data d_i in the memory $f_j.M$. If $m_i.P \cap f_j.S = \phi$, the fog node f_j neglects the message m_i.

Each fog node f_i publishes and receives a message m_i as follows:

[Fog node f_i publishes a message m_i]

1. The fog node f_i finds that another fog node f_j is 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 data d_i to the message m_i;
3. $d_i.P$ = publication topics in $f_i.P$ of the fog node f_i ($\subseteq T$);
4. $m_i.P = d_i.P$;
5. The fog node f_i **publishes** the message m_i;

[Fog node f_j receives a message m_i]

1. A message m_i arrives at a fog node f_j;
2. If $m_i.P \cap f_j.S \neq \phi$ and the fog node f_j did not receive a message m_i, the fog node f_j **receives** the message m_i;
3. Otherwise, the fog nodes f_j **neglects** the message m_i;
4. If the fog node f_j is delivered the message m_i, the message m_i is stored in the memory $f_i.M$;

5 Evaluation

We evaluate the TBDT protocol of the MPSFC model in terms of the number of messages exchanged among fog nodes and delivery ratio of messages. There are mobile fog nodes f_1, ..., f_n ($n \geq 1$) on an $m \times m$ 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. Each fog node f_i moves with speed s_i in a random walk.

In order to evaluate the TBDT protocol, we develop a time-based simulator in C language. Let T be a set of all topics $t_1, \ldots, t_l$ ($l \geq 1$) in a system. First, topics in the subscription $f_i.S$ of each fog node f_i are randomly taken from the set T. The number stn_i (≥ 1) of topics in the subscription $f_i.S$ of each fog node f_i is randomly selected from 1 to 5. Then, topics in the publication $f_i.P$ of the fog node f_i are also randomly selected from the topic set T. The number ptn_i (≥ 1) of topics in the publication $f_i.P$ of a fog node f_i is one. Each fog node f_i

holds data d_i. Here, publication $d_i.P$ of the data d_i is the same as the publication $f_i.P$, i.e. $d_i.P = f_i.P$.

Next, every fog node f_i randomly moves in the mesh with the speed s_i for each simulation step. Let d_{ij} show the distance between a pair of fog nodes f_i and f_j. If each fog node f_i finds a fog node f_j in the communication range cr_i, i.e. $d_{ij} \geq cr_i$, the fog node f_i sends a message m_i with data d_i to the fog node f_j. Here, each message m_i is given the time-to-live $m_i.ttl$. At each time unit, $m_i.ttl$ of each message m_i in every fog node is decremented by one. If $m_i.ttl$ in the memory $f_j.M$ of each fog node f_j is 0, the message is deleted in the memory $f_j.M$. Finally, the delivery ratios of messages in the TBDT protocol and the epidemic routing protocol [1] are calculated.

In the TBDT protocol, on arrival of a message m, the fog node f_i checks if the publication topics $m.P$ of the message m and the subscription topics $f_i.S$ of the fog node f_i include a common topic. Here, if $m.P \cap f_i.S \neq \phi$, the fog node f_i receives a message m and stores the message m in the memory $f_i.M$, i.e. the message m is delivered to the fog node f_i. If $m.P \cap f_i.S = \phi$, the fog node f_i neglects the message m. If the fog node f_i had already received the message m, the fog node f_i also neglects the message m.

In the epidemic routing protocol [1], if a message m arrives at the fog node f_i, the fog node f_i receives the message m and stores the message m in the memory $f_i.M$. If the fog node f_i had already received the message m, the fog node f_i neglects the message m.

Figure 3 shows the delivery ratios of messages in the TBDT protocol and the epidemic routing protocol. Here, there are thirty mobile fog nodes ($n = 30$) on a 150×150 mesh ($m = 150$), and thirty topics ($l = 30$). Then, the speed s_i and communication range cr_i of each fog node f_i is 1 and 5, respectively.

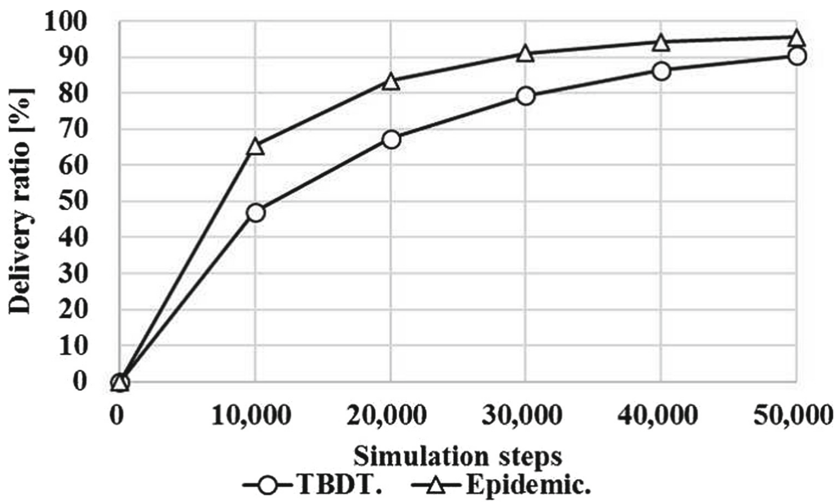

Fig. 3. Delivery ratio.

The time-to-live (*ttl*) $m.ttl$ of each message m is 500. The delivery ratio of the TBDT protocol is smaller than the epidemic routing protocol. For example, the delivery ratio of the TBDT protocol at 50,000 simulation steps and the delivery ratio of the epidemic routing protocol at 30,000 simulation steps are almost same.

Figure 4 shows the number of messages exchanged among fog nodes in the TBDT protocol and the epidemic routing protocol. Here, the parameters like the number n of mobile fog nodes and number l of topics of Fig. 4 are the same as Fig. 3. The number of messages in the TBDT protocol and the epidemic protocol are linearly increases for each simulation step. The larger number of messages are exchanged among fog nodes in the epidemic routing protocol than the TBDT protocol.

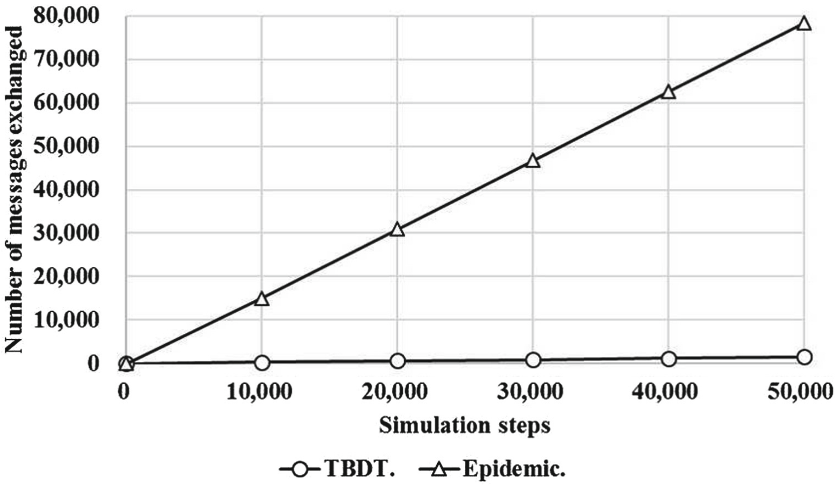

Fig. 4. Number of messages exchanged.

6 Concluding Remarks

In order to increases the performance of the IoT (Internet of Things), types of the FC (Fog Computing) models are proposed. In this paper, we considered the MFC (Mobile Fog Computing) model [4,5] where mobile fog nodes communicate with other nodes in wireless networks while moving like vehicles. Here, each mobile fog node calculates the output data on the input data and forwards the output data to other mobile fog nodes in the opportunistic way. In this paper, we newly proposed the MPSFC (Mobile Publish/Subscribe Fog Computing) model of mobile fog nodes where each mobile fog node is delivered only interested messages by taking advantage of the topic-based PS model. We evaluated the TBDT protocol in the MPSFC model compared with the epidemic routing protocol. In the TBDT protocol, the number of messages exchanged among fog nodes can be reduced compared with the epidemic protocol.

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