Multi–Layered Information Management System for IoT-Based P2P Applications

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Abstract— *Network applications deployed on IoT environments can provide various benefits. Since the environments are constructed with many kinds of IoT devices and there are huge number of IoT devices, it is not easy to search IoT devices have required resources or services. Though information management method based on pure peer-to-peer network model is a scalable management method, there are issues in order to apply the peer-to-peer information management method to applications on IoT environments. One of the issues is trade-off about the amount of search packets and path length between a source node and a destination node. For this issue, our proposal method enables peer-to-peer applications to use information about delegate server and resources according to their degree of commonness by switching logical network layers. Effectiveness of the proposed system was evaluated by comparing both path length from a source node to a destination node and search hit rate. Prototype of the proposal system was implemented with APIs of existing peer-to-peer agent platform. The results showed followings. If scale of network is small, advantage of using logical network based on network distance can be expected. If scale of network is large, it is better to use both logical networks of network distance and contents trend.*

Keywords: IoT, P2P, Overlay network, Multi-layered, Clustering

1. Introduction

Network applications deployed on IoT environments can provide various benefits. Since the environments are constructed with many kinds of IoT devices and there are huge number of IoT devices, it is not easy to search IoT devices have required resources or services. Though information management method based on pure peer-to-peer network model is a scalable management method, there are issues in order to apply the peer-to-peer information management method to applications on IoT environments.

One of the issues is shortage of computing, network, or storage resources of IoT devices. Each node consists of peer-to-peer networks needs to process, send or receive, and store much data. In this paper, this issue was solved by deploying delegate server for IoT devices in the same network or organization. Other issue is variety of resource or services offered by IoT devices. This means that indexes which are used for search depends on the resources or services. Furthermore, the amount of data about information or resources of IoT devices will be increasing so large as the number of IoT devices is increasing. Search or management of IoT devices or resources should be therefore achieved effectively.

Our proposal method enables peer-to-peer applications to use information about delegate server and resources according to their degree of commonness by switching logical network layers. Delegate servers are connected with other servers by using clustering algorithms on each logical layer. On each logical layer, various criteria, which include network distance or similarity of resource, are used for clustering algorithms.

Effectiveness of the proposed method was evaluated by comparing both path length from a source node to a destination node and search hit rate. Network model used in evaluation was one of optical network model in Japan and delegate servers were located on cities of Japan according to population of the cities. Basic functions of delegate servers were implemented with peer-to-peer agent platform PIAX, that is, delegate servers and their functions were implemented with APIs provided by PIAX. The results showed that path length could be shorten and search hit rate is kept by switching layers to use information according to degree of commonness.

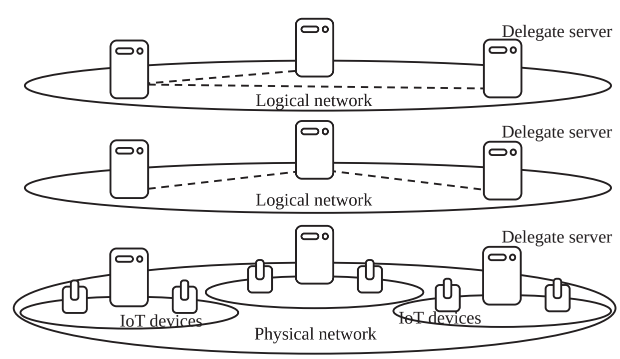

Fig. 1: Architecture of multi-layered IoT service platform

2. Information for peer-to-peer applications

Many peer-to-peer file sharing applications based on peer-to-peer network model have been implemented and used. Though some problems were caused by such file sharing applications, methods themselves for information distribution are useful and provide basis of appearance of other types of peer-to-peer applications such as voice chat application or on-line games. Each peer exchange information about peers and constructs peer-to-peer network. The peer-to-peer network is a logical network and peers connected with each other on the peer-to-peer network is not always connected physically. Pure peer-to-peer network model, which does not need centralized server for network or contents management, is especially useful for large-scale distributed system. In this section, methods of network management or offering information for network applications are explained.

2.1 Provisioning of network information

Network information such as a network topology is useful for network applications. It is desirable that each node communicates with a node in a near network if the same data or contents can be obtained. Some architectures to provide information network have been proposed by several working groups.

Provider portal for application (P4P) [1] architecture has been proposed by P4P Working Group (P4PWG) of Distributed Computing Industry Association (DCIA). In this architecture, Internet Service Providers (ISPs) deploy hint servers called “iTracker” that offer network information for network application. The network information includes network distance, policy, or capability of networks.

Application-Layer Traffic Optimization (ALTO) protocol has been standardized as the Request for Comments (RFC). RFC is a technical document published by Internet Engineering Task Force (IETF) and many RFCs have been treated as de facto standards. Each node can get information of network cost from ALTO servers with ALTO protocol.

These architecture enable nodes in a network to get network information. However, hint servers should be deployed by ISPs in these architectures. If networks constructed individually from ISPs are assumed, other methods to construct network or logical network autonomously are needed.

2.2 Multi-layered P2P application platform

This subsection shows outline of a system that switches overlay networks according to situation for effective contents or peers search by peer-to-peer network applications. This system has been proposed by our research group[2], [3], [4].

The proposed system is based on pure peer-to-peer network model. Pure peer-to-peer network model does not have centralized server to manage information about peers. All peers behave individually when a peer joins into a network or leave the network. Search for contents or peers are therefore performed by exchanging and transmitting messages among peers in the network.

Some network applications, which are based on peer-to-peer network model, adopt clustering peers in order to collect information for search of contents or peers and to improve effectiveness of the searches. Logical networks are constructed by clustering and these are placed as overlay networks on a layer of physical networks. These logical network layers are constructed by various construction methods. Clustering algorithms can be included as one example of the methods. Figure 2 shows a basic concept of proposed system.

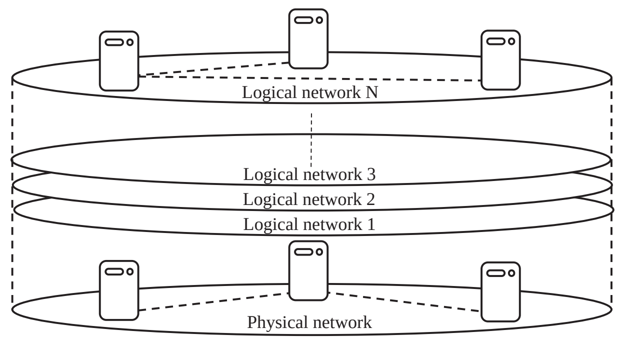

Fig. 2: Multi-layered logical networks

Peer-to-peer network applications obtain information about peers and data or resources that peers have from the logical network layers. One logical layer is selected to search peers or data effectively. Figure 3 shows relationships between peer-to-peer network applications and proposed multi-layered system. The proposed system improves effectiveness

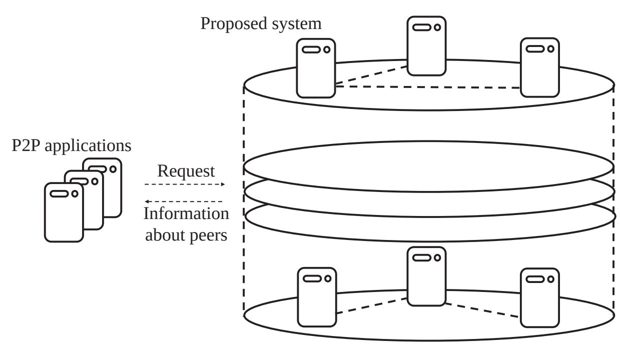

Fig. 3: Multi-layered logical networks

of contents or peers search by using information obtained from clusters on the layer. This is achieved by selecting a layer according to characteristics of contents.

Our research group designed a prototype of proposed system. The prototype of proposed system constructed two layers on a physical network. The layers consisted of a layer that based on network distance and a layer that based on contents trend.

When peers required information about common contents or not specific peers, network distance based layer was used for search them. We assumed that degree of network distances was calculated with Round Trip Time (RTT) or Time To Live (TTL). On network distance based layer, peers in near networks were grouped into the same group. Figure 4 shows concept of network distance layer.

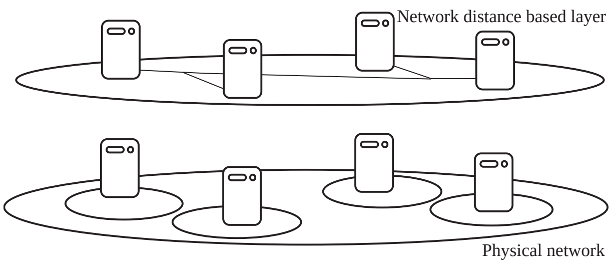

Fig. 4: Network distance based layer

As constructing methods for network based layer, PIC[5] and Vivaldi[6] are available. These methods can be categorized into network coordination methods. Nodes measure or calculate distances from other nodes by exchanging messages and update them consequently by drift of the distance. If the drift is less than threshold value, procedures are finished.

Although Decentralized Hierarchical Internet Hosts Clustering[7] is a clustering method, the method can be used for constructing logical network by adopting RTT, TTL, or hop count, as criteria. Hierarchical clusters are constructed by the method and peers in near networks are easily grouped into the same cluster.

When peers require information about specific peers or contents, contents trend based layer is used for search them. When peers search uncommon data or contents, the peers obtain information about them from information of this layer. Figure 5 shows concept of contents trend layer.

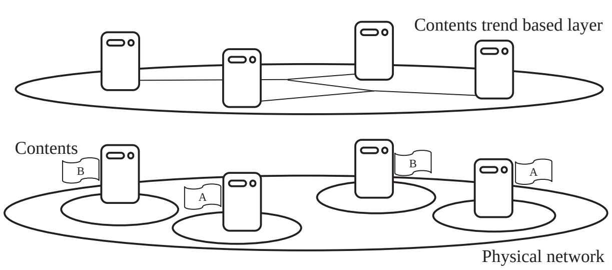

Fig. 5: Contents trend based layer

3. Multi-Layered Information Management System for IoT-Based P2P Applications

It is difficult for IoT devices to manage information about outer networks or nodes in the networks. Since our research group have been proposed a system to provide information about network and contents, we have proposed a system on which a server manges IoT devices and the server provides information about IoT devices by extending our proposal system. This server is delegated a role as a peer in a peer-to-peer networking model. This means that the server delegated to exchanges information in stead of each IoT device. The server is called “delegate server” in this proposed system. Delegate servers construct networks based on peer-to-peer network model. Peer-to-peer network is consists of many nodes and each node is called “peer”. In the proposed system delegate servers manage information about IoT devices and the information is used for construction of peer-to-peer network.

Delegate servers collect information about IoT devices that are managed by them. And delegate servers are characterized with data or resource that IoT devices have or provide. Delegate servers manage data or resources of IoT devices and response for requests in stead of IoT devices that are managed the delegate servers. If the data or resources are requested, delegate servers behave as proxy servers. Figure 6 shows relationship between delegate server and IoT devices.

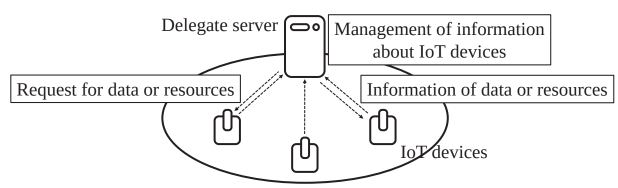

Fig. 6: IoT devices and delegate server

Resources and services of IoT devices are searched by using information of the logical network. The information includes data of the peer-to-peer network and contents that IoT devices have. When network applications search resources or services, the applications receive information about them from delegate servers that are included in a peer-to-peer network. The peer-to-peer network is constructed by various methods. For contents sharing systems, trend of contents that each peer has is considered when peer-to-peer network is constructed. This logical network is used for search of uncommon data or resources of IoT devices. Since common data or resources of IoT devices are managed by many delegate servers, delegate servers in near network probably manage the data or resources. However, the number of delegate servers that have uncommon data or resources is basically small. Desired data or resources should be searched by using information of contents trend logical network.

4. Performance evaluations

This section describes emulations with a prototype of the proposed system and effectiveness evaluation of the proposed system. Results of emulations include comparisons about differences of local transmission, that is, transmissions between delegate servers in the same network. Furthermore, difference of the number of search hits and transferred messages for searches.

In following subsections, emulation environments, clustering algorithm used for construction of logical layers, network model, emulation conditions, results of emulations and discussions are shown.

4.1 Emulation environments

As mentioned in the previous section, the prototype of proposed system had been designed. The prototype system was also implemented with platform and APIs of the peer-to-peer agent platform PIAX[8], [9]. The agent platform PIAX provides functionality of delegate servers that construct peer-to-peer network. delegate servers emulate actual behaviors as members of peer-to-peer network by using PIAX APIs. Results of emulations with PIAX based system were used for performance evaluations.

4.2 Clustering algorithm

Decentralized Hierarchical Internet Hosts Clustering[7] was adopted to execute clustering based on network distance and construct a network distance based layer. This method includes cooperative clustering algorithm and it is based on peer-to-peer network model. This method construct clusters hierarchically. This means that clusters are included in more larger clusters recursively. When a node sends a request, messages are transferred recursively, that is, messages are sent to nodes in the same cluster firstly and sent to nodes in the parent or child clusters next. Figure 7 shows that sequential queries for hierarchical clusters.

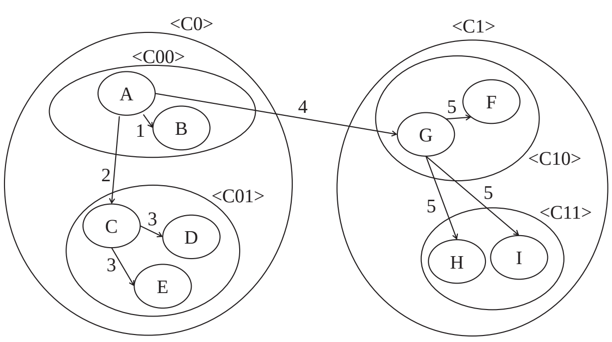

Fig. 7: IoT devices and delegate server

Keyword matching was adopted to execute clustering based on contents trend and construct a network based layer. Matching score between delegate servers was calculated by calculating length of common parts of keywords associated to contents that delegate servers have. Delegate servers selected delegate servers with high matching scores to connect to.

4.3 Network model

In the evaluations, we assumed that network distances among delegate servers were calculated according to cost of links based on the optical networks model in Japan[10], which is experimental model. Since previous evaluations were based on Euclidean distance among cities, not network topologies, this model was adopted in order to evaluate performance according to results that were obtained with a model of network topology. This model includes nodes and paths among the nodes. The nodes are associated to actual cities in Japan. There are three types in terms of the number of nodes and paths. The three types are 12 cities, 25 cities, and 48 cities. In the evaluations, we adopted the topology that includes 48 cities in the model.

In following subsections, results of emulations on different types of networks are shown. One of the network is a flat network. Flat network means that network distance between two delegate servers are calculated by adding all costs of shortest path from a source delegate server to a destination delegate server. Figure 8 shows one example of a flat network. Other type of the networks is a hierarchical network.

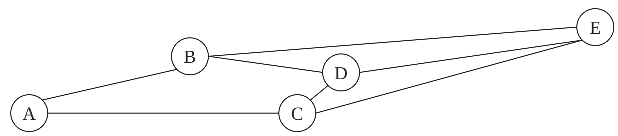

Fig. 8: Example of flat network

Some networks are contained by other larger networks. On the hierarchical network a sender delegate server can not always transmit data or resources on short path even if a receiver delegate server is in near area. In such case, the data or resources are transferred via top level networks or network devices. Figure 8 shows one example of hierarchical networks. In this example, although the network node F

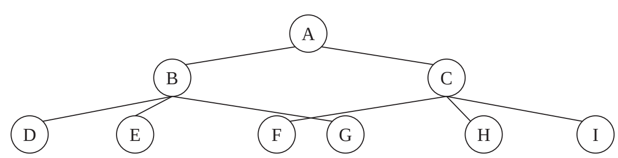

Fig. 9: Example of hierarchical networks

is near the network node G, data are transferred from the network node F to the network node G via the network node A.

4.4 Emulation conditions

The number of delegate servers was set to 1,000. Locations of delegate servers were randomly decided by considering distribution of population in Japan. Since 48 cities were assumed in the network model, the locations were associated to prefecture capital basically. Since only Tokyo had two nodes, the are of Tokyo was divided into two areas. One of them was all Wards of Tokyo and other is rest of the area in Tokyo. If two delegate servers were allocated into the same node, distance between the delegate servers was set to 0.

Degree of commonness was decided and resources were distributed in the network according to Zipf's Law[11]. Zipf's law is related discrete power law probability distributions. The number of existence is in proportion to $\frac{1}{k}$ (k is order of commonness). Table 1 shows distribution when the number of delegate servers was 1,000. If degree of commonness is 50%, 500 delegate servers have the resource when the number of delegate servers is 1,000. Searches for the data or resources with same commonness were repeated 10 times.

Table 1: Degree of commonness (nodes: 1,000)

order	degree of commonness
1	100.0%
2	50.0%
3	33.3%
...	...
1000	0.1%

4.5 Criteria for evaluations

Following subsection describes the results of emulations. The results include three perspectives of performance evaluation. There are about the number of local transmissions, the number of search hits, and the number of transmission messages.

The number of local transmissions, that is, between in the same network, is used for evaluation about saving network resources to transmit data or other resources. It is better for the same data or contents to be transmitted with more shorter path in terms of network resource consumption. The number of search hits is used for evaluation about basic performance of data or resources sharing system. The number of transmission messages is also used for evaluation about data or resource sharing system. However, these criteria and the number of local transmissions have relationships of trade-off.

The differences were calculated by taking the number of local transmission in case of contents trend logical network from it in case of network distance. If a value is positive, the number in case of network distance logical layer is used is high.

4.6 Evaluations on a flat network

Figure 10 shows difference of the number of transmissions between delegate servers in the same network. These results show that delegate servers search data or resources by using logical layer based on network distance could find delegate servers in near network. The trend of differences show that delegate servers could find data or resources in near network when degree of commonness was high. On the other hand,

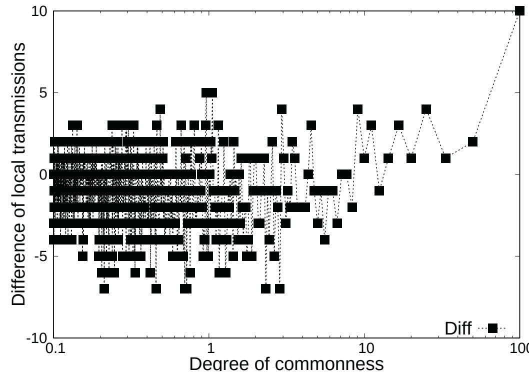

Fig. 10: Difference of the number of local transmission (flat network)

there were variations in case of commonness of the contents were low. It was estimated that scale of network was small for the types of data or resources and the results depended on locations of delegate servers had the contents.

Figure 11 shows difference of the number of search hits. From these results, trend of difference seemed that hit rate

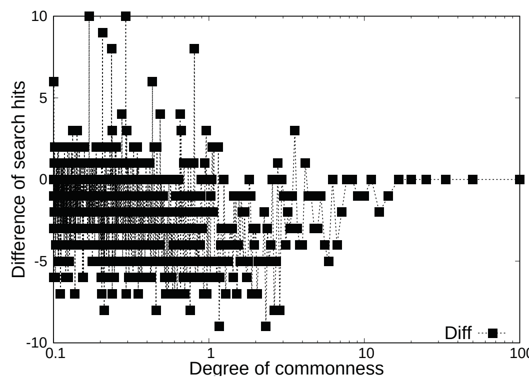

Fig. 11: Difference of the number of search hits (flat network)

of search was high in case of using contents trend logical network when degree of commonness was low. This means that delegate servers could not find uncommon data or resources in near network in many situations. This was because the number of delegate servers were not large against the number of cities and possibility of search hit in the same city was not high.

Figure 12 shows difference of the number of messages for contents search. These results show that difference of the number of messages for contents search were totally small. This was estimated from the same reason in case of difference of the number of search hit.

4.7 Evaluations on hierarchical networks

Figure 13 shows the number of transmissions between delegate servers in the same network. These results also

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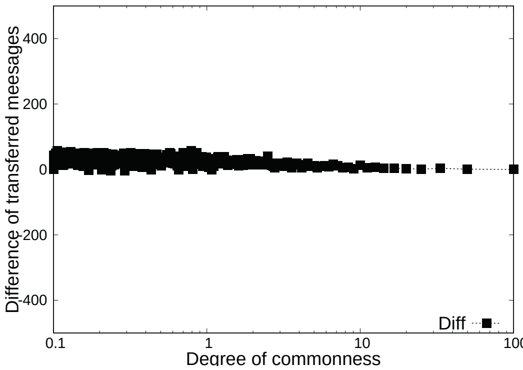

Fig. 12: Difference of the number of messages for contents search (flat network)

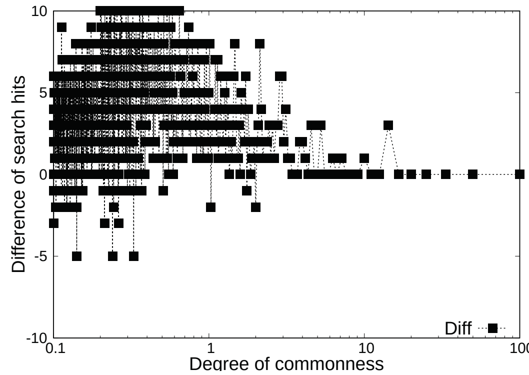

Fig. 14: Difference of the number of search hits (hierarchical networks)

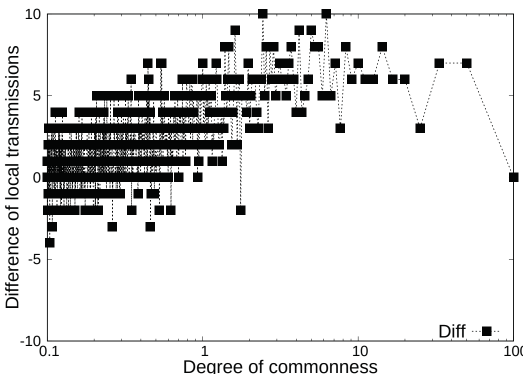

Fig. 13: Difference of the number of local transmission (hierarchical networks)

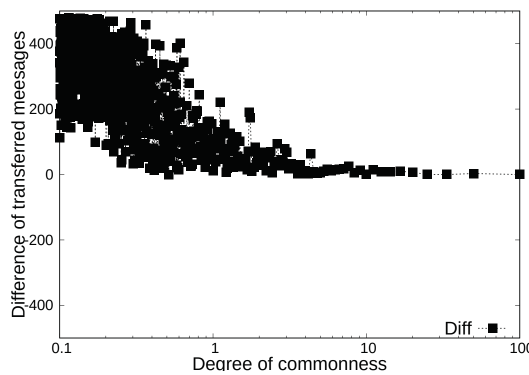

Fig. 15: Difference of the number of messages for contents search (hierarchical networks)

show that delegate servers search data or resources by using logical layer based on network distance could find delegate servers in near network. In addition, the trend of differences show that delegate servers could find data or resources in near network when degree of commonness was high more easily than case of a flat network. The differences were totally higher than case of using logical layer of contents trend. We estimated that each distance between delegate servers was far compared with a flat network and the effect of network distance appeared clearly.

Figure 14 shows difference of search hits. From these results, the numbers of search hits in case of using logical layer of contents trend were totally small. Basically, it was expected that the search rate would be higher when logical layer of contents trend was used for searches. About this mismatch, we assumed that length of paths between delegate servers was longer than case of a flat network and logical layer of contents trend was not constructed effectively.

Figure 15 shows difference of the number of messages for contents search. These results also show that the number of messages for contents search were totally small when overlay networks constructed by considering contents trend. The differences were large compared with cases of a flat network. We estimated that shapes of clusters on the logical network based on network distance because of longer paths between delegate servers.

4.8 Discussions

From trends of these results, we concluded that switching layers according to degree of commonness was effective. However, it is not easy to decide threshold for switching layers because appropriate value of the threshold depends on applications, environments, and situations. If scale of network is small, advantage of using logical network based on network distance can be expected. If scale of network is large, it is better to use both logical networks of network distance and contents trend.

5. Conclusion

Network applications deployed on IoT environments can provide various benefits. Since the environments are constructed with many kinds of IoT devices and there are huge number of IoT devices, it is not easy to search IoT devices have required resource or services. Though information management method based on pure peer-to-peer network model is a scalable management method, there are issues in order to apply the peer-to-peer information management method to applications on IoT environments.

One of the issues is shortage of computing, network, or storage resources of IoT devices. Each node consists of peer-to-peer networks needs to process, send or receive, and store much data. In this paper, this issue was solved by deploying delegate server for IoT devices in the same network or organization. Other issue is variety of resource or services offered by IoT devices. This means that indexes which are used for search depends on the resources or services. Moreover, it is desirable for the same data or contents to be transmitted with more shorter path in terms of network resource consumption. For this issue, our proposal method enables peer-to-peer applications to use information about delegate server and resources according to their degree of commonness by switching logical network layers. Delegate servers are connected with other servers by using clustering algorithms on search logical layer. On each logical layer, various criteria, which conclude network distance or similarity of resource, are used for clustering algorithms.

Effectiveness of the proposed method was evaluated by comparing both path length from a source node to a receive node and search hit rate. Network model used in evaluation was one of optical network model in Japan and delegate servers were located on cities of Japan according to population of the cities. Basic functions of delegate servers were implemented with peer-to-peer agent platform PIAX, that is, delegate servers and their functions were implemented with APIs provided by PIAX. The results showed followings. If scale of network is small, advantage of using logical network based on network distance can be expected. If scale of network is large, it is better to use both logical networks of network distance and contents trend. However, threshold for switching logical layers should be decide carefully because of there were advantages to use each logical layer and assumed that the effectiveness depends on applications, environments, or situations.

As future works, we consider use of more layers constructed by clustering algorithms. In the evaluations, only two layers were constructed and used. In addition, effectiveness of the proposed method should be evaluated with more scenarios. For example, amount of packets transmitted for contents or delegate servers search depends on a scenario.

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