Distributed ID/Locator Resolution System for Inter Mesh Networks

Masaaki Ohnishi
Tokyo Institute of Technology
Ookayama 2–12–1, Meguro-ku,
Tokyo, 152–8552, Japan
Email: ohnishi.m.aa@m.titech.ac.jp

Kazuyuki Shudo
Tokyo Institute of Technology
Ookayama 2–12–1, Meguro-ku,
Tokyo, 152–8552 Japan
Email: shudo@is.titech.ac.jp

***Abstract*—We propose an ID/Locator resolution system for super wide area wireless mesh networks constructed using Delaunay overlay networks. Unlike conventional mobile ad-hoc network protocols, the proposed system does not use flooding to spread the locator notification messages of each node. The proposed method sends one-hop locator notifications on skip links such as skip graphs. The proposed system realized scalability by controlling the route, frequency, and storing locations of the locator notification message. Specifically, when the number of nodes increases, the average load on communication links and the message database of each node are approximately O(log n), where n is the total number of nodes. The scalability of the proposed method is confirmed through simulations.**

I. Introduction

The relationships among the elements that comprise the propsed inter-mesh network concept are shown in Fig. 1. The lower part of the wireless mesh network group is expected to support emergency communication networks, e.g., networks used by local governments and the Japanese Self-Defense Forces when responding to disaster situations. We construct a super-wide area network in which such networks are combined and integrated by using a Delaunay overlay network [1], which is a type of geo-assisted routing network(Middle layer in Fig.1). This is expected to be applied to super-wide area disaster situations such as Nankai Trough great earthquake [2].

For example, a land scale wireless mesh network is constructed by automobile nodes such local governments, polices, fire departments, hospitals and others. However, the wireless mesh network to which such vehicle nodes of the scale of 100,000 units belongs can not be constructed by the mainstream wireless mesh network protocols using flooding.

The left of Fig. 2 indicates that the control messages reaches the entire network from central node due to flooding. The flooding route is indicated by arrows. All the nodes on the routes store the control message. This store nodes are indicated by diagonal lines. The control message includes the ID of the central node and the ID of its neighbor node. For this reason, the flooding method has no scalability. For example, OLSR [3] and AODV [4] are conventional MANET protocols that use ID routing tables maintained by flooding. These protocols can only be used in small networks. And, there is a gossip protocol [5] as a method similar to flooding. This protocol refrains from transferring messages by probability. As a result, the amount of data transfer is reduced. However, this protocol can not guarantee reachability of control messages to the whole area. Therefore, it is not appropriate for inter mesh network. Also, using a clustering technique can build a large network. However, clustering is also difficult in vehicle wireless mesh networks because the topology changes frequently.

So we use the Delaunay overlay network with the following two features.

- Delaunay overlay network can be constructed by control message exchanges between only close nodes.
- In the Delaunay overlay network, greedy routing based on the location coordinate the destination node always succeeds.

Because of these features, the Delaunay overlay network always succeeds in routing even if the network becomes huge. However, unlike the flooding network, each node in the Delaunay overlay network does not know location coordinates of other nodes in the network. Because, Dealunay overlay netowork is constructed by close area control messages. By the way, since the node ID in the flooding use network is a network locator, all nodes can know the locators of all nodes by flooding. Therefore, ID/locator resolution system is required separately to get the location of destination mobile nodes. Therefore, in this paper, we propose ID/Locator resolution system using the structure of Skip Delaunay overlay network [6] (Top layer in Fig.1). Skip Delaunay overlay network is a proposed overlay network structure to reduce the diameter of the Delaunay overlay network. We propose a protocol that spreads node information on it. The node information is ID and position coordinate pair. And, we also propose a protocol that gets the diffused node information corresponding to this node information spreading protocol based on its node ID. In this protocol, the transmission timing of node information is controlled to reduce the load on each link. In addition, this paper abstracts low layer wireless networks. This is because the Inter mesh network is oriented toward the best effort network like the Internet.

In this paper, we use the following metrics to evaluate the proposed method.

- Number of notification messages transferred per unit time per node.

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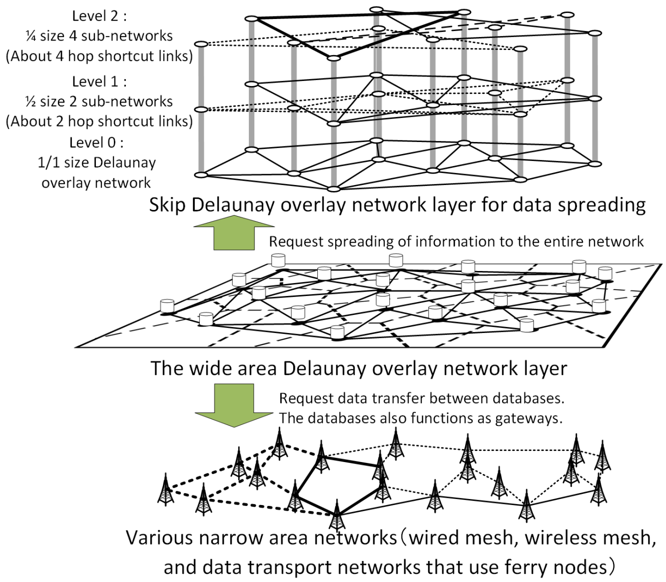

Fig. 1. Structure of inter mesh networks.

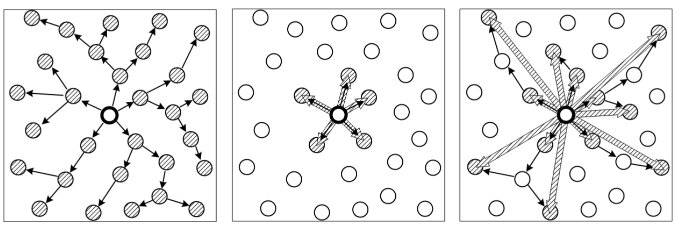

Fig. 2. Reachable range of network control messages.

- Number of notification message stored per node.
- Total number of messages transferred for ID/Locator resolution.

This paper is organized as follows. Premise of this network architecture and its related works are described in Section II. The analytical framework and basic idea of the proposed system are described in Section III. Simulation evaluations are described in Section IV, and conclusions are presented in Section V.

II. Premise of Inter Mesh Network Architecture and its Related Works

In this section, we describe the framework of inter mesh network architecture. And, we described related works used in inter mesh network architecture.

A. Environment of the proposed system

Fig. 3 shows the usage environment of inter mesh network architecture. Structured overlay networks are more vulnerable to malicious nodes than redundant flooding networks, the Delaunay overlay network is constructed with only trusted vehicle nodes. Other nodes are used as local networks to connect trusted nodes. Trusted nodes obtain their position coordinates from GPS. In this paper, we assume wireless mesh networks interconnected by Delaunay overlay network nodes with router functions.

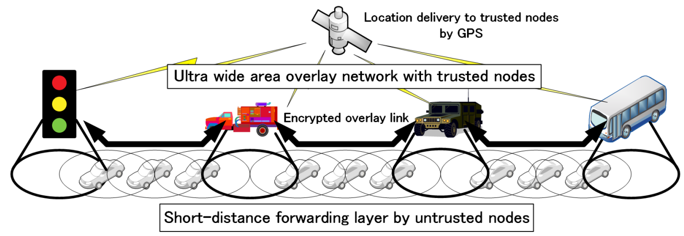

Fig. 3. Environment assumed for the proposed system.

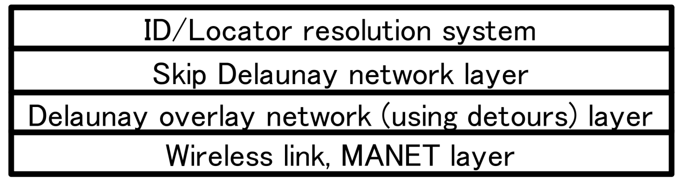

Fig. 4. Proposed system's Network stack configuration.

B. Inter mesh network's protocol stack

The assumed network stack of inter mesh network is shown in Fig. 4. The second layer from the bottom is a Delaunay overlay network that uses a detour path with trusted nodes. The bottom layer is constructed by local networks that connect nodes in the Delaunay overlay network. A skip Delaunay network is constructed on the Delaunay overlay network layer using detour paths, and the proposed ID locator resolution system is constructed in the skip Delaunay network layer. Low layer communication is more efficient when the number of transfers in the overlay network is reduced. This improves the overall communication efficiency because the number of data exchanges between layers is reduced, and processing in the overlay layer is also reduced. In addition, skip Delaunay network reduces the diameter of the Delaunay overlay network. The skip Delaunay network is used for message spreading in the ID / locator resolution system. In the future, it will also be used as a distributed database platform for applications.

C. Delaunay overlay network layer on other other wireless communication systems

A Delaunay overlay network is a mobile ad-hoc network (MANET) protocol similar to the geographic position-assisted routing proposed in a previous study [7]. In this system, we use the overlay network as the overlay layer interconnecting the wireless communication systems of the low layer. Delaunay overlay network has Delaunay graph topology using the position coordinates of nodes. Therefore, greedy routing to the location of the destination node always succeeds in this network. This protocol can construct a large-scale network because it does not use flooding. Moreover, each node sends control signals to maintain the network structure in a local range. Basically each node of the Delaunay overlay network creates routing tables to about 6 nodes. The middle of 2 indicates that the control messages reaches only around about 6 nodes when Delaunay overlay network is constructed.

Distributed construction method of Delaunay overlay network using detours [1] is applicable to the wireless link group before networking. In this method, when there is no radio link between two nodes that need to be connected, the detour path is constructed by distributed method to replace the direct overlay link. In this paper, this method constructs the Delaunay overlay network and covers the wireless mesh layer. Then, the message transfer in the overlay network layer is transmitted via the wireless mesh network of the low layer. If the number of forwarding hops in the overlay network decreases, the number of via mesh networks also decreases. For this reason, the reduction in the number of hops in the overlay network leads to a reduction in the load on wireless mesh networks. In fig. 2, The overlay network transfer indicated by the diagonal arrow is realized by the transfer in the wireless mesh network with thin arrows.

D. Skip Delaunay network layer

This proposed system is constructed using a skip Delaunay network [6] that can be built on Delaunay overlay networks.

An example of skip Delaunay network is shown at the top layer of Fig. 1. This network has shortcut links similar to Skip Graphs [8]. In skip graphs, the node ID in rectangles also has a role as a network locator. In the skip delaunay network, since the node position is the network locator, the inside of this rectangle is the node position. Nodes are connected in order of ID to construct a base network. This base network is called Level 0 network. Each node has a random bit string called Membership vector (MV), and generates shortcut links based on the MV. The skip link sets of approximately 2^{Level} hop expected value length in Level 0 network. $Level$ is an integer equal to or greater than 0. $(1/2)^{Level}$ of the total node to join in the $Level$ sub-networks. The $Level$ 0 network is the Level 0 network wherein all nodes are joined. When a sub-network $Level$ increases by one, approximately one-half of the nodes are removed from the $Level-1$ sub-network. therefore, the $Level$ sub-network one-hop distance is approximately 2^{Level} times longer than that of the $Level$ 0 sub-network. Skip delaunay network also creates a sub-network in the same way, and there is a shortcut link of the length of $k^{Level}(k\ is\ a\ constant \risingdotseq 1.4)$ hops at Level 0. Originally, this shortcut link is used to reduce the diameter of the network. However, in this paper, we use this shortcut link for spreading data to the whole network. Skip graphs are easy to apply to the Delaunay overlay network because it is a method of stacking sub-networks. In skip Delaunay network in Fig. 1, sub-networks are stacked with the same structure. The right of 2 indicates the routes of the locator notification messages in this proposed method. The reachable range of messages different from flooding is limited.

In addition, Hojo et al. [9] And Fujita [10] describe shortcut link construction methods similar to Skip Delaunay network.

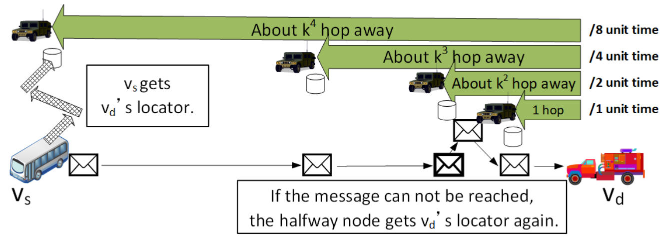

Fig. 5. One-hop notifications and acquisition by source nodes.

III. PROPOSED ID/LOCATOR RESOLUTION SYSTEM OVERVIEW

In this section, we present an overview of the proposed ID/Locator resolution system.

The proposed system has the following unique features.

- In this proposed method, membership vectors are generated from each node ID.
- This proposed method has messages spreading method.
- The proposed method has a method to get the locator from arbitrary node ID by local search.
- The notification message transmission frequency is controlled. As a result, the load on each link is suppressed.

A. An outline of the proposed method

An outline of the proposed method is shown below.

In Fig. 5, a node v_d broadcasts its locator notification messages to the entire network. node v_s sends a message to v_d after obtaining the locator from v_d's neighbors including shortcut link neighbors. Note that v_d has links to its neighbor nodes based on skip Delaunay network rules. The thick arrows in Fig. 5 represents sending notification messages on the skip Delaunay network links. The number of hops at Level 0 to neighbors of each shortcut link is indicated by using k. In many cases k is roughly 1.4. In the case where the node is positioned linearly, it becomes the largest and the expected value becomes 2. When k is 2, the load on the each link is the largest. For this reason, after this section, the value of k is assumed to be 2.

In Fig. 5, v_d sends locator notification messages to all $Level$ link neighbors. The $Level$ notification frequency is set to 2^{Level} unit time because, notification messages with many way nodes increase the load on the way nodes significantly. Here the number of nodes n increases; thus, number of messages stored and transferred for each node is $O(log\ n)$, where n is the total number of nodes. Thus, this method is scalable.

Moreover, when each node receives locator information, the locator notification message is obtained from surrounding nodes based on the skip Delaunay network structure. Thus, when a message arrives at its destination, there is that the destination node is not already stay at the destination. In this case, additional locator information is obtained at the location around has been reached. In this case, the message is closer to the destination node; thus, it is possible to obtain additional new locator information about the destination node. When this

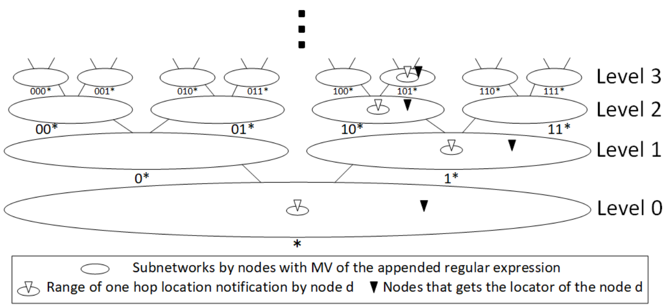

Fig. 6. Sub-networks of repeated two split based on MVs.

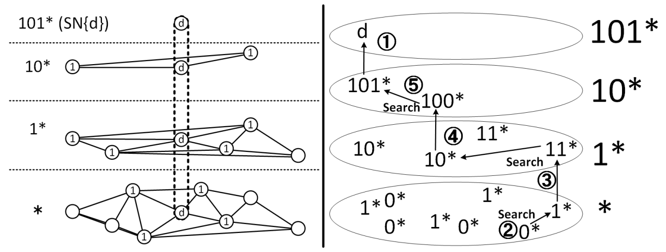

Fig. 7. Left side : Example of sending locator notification messages by a node. Right side : Notification message discovery mechanism in a skip Delaunay network.

occurs, the number of nodes is $O(log\ n)$, where n is the total number of nodes.

B. Locator notification mechanism for scalability

As whown in Fig. 6, all nodes in the skip Delaunay network are bisected repeatedly to construct sub-network groups of various sizes. In Fig. 6, ellipses represent node sets of sub-networks to which $1/1,\ 1/2,\ 1/4,\ 1/8,\ 1/16,\ \ldots$ of all nodes belong. When two sub-networks are connected by a line, approximately one-half of the lower sub-network's nodes belong to the upper sub-network.

The white triangle is node d. When node d spreads its locator, d sends locator notifications to one-hop neighbors in each sub-network belonging to node d. In this case, the locator notification is sent to more distant nodes in smaller sub-networks. Note that most nodes in smaller sub-networks receive notification messages. Thus, node s can find notification messages by searching smaller sub-networks. In Fig.6, node s cannot find the node d locator messages in a large sub-network. However, in the 101* sub-network, the node d locator messages are delivered to node s. Thus, node s can search for locator information successfully.

We want to find a sub-network that belongs to node d using its ID. Thus, in this system, unlike original skip Delaunay network, its membership vector (MV) is generated using a hash function from its ID. In original skip Delaunay network, MVs are generated by randomly connecting 0 and 1 repeatedly. In Fig. 6, node d's MV = "101 …" is generated from its ID using a hash function. As a result, based on MV d is belong to the following sub-networks based on the MV = "101 …" node d belongs to sub-networks "*","1*","10*" and "101*".

An MV is defined as a bit sequence of infinite length. Therefore, an MV can generate length until a unique MV string. Thus, node d can only belong to sub-network $SN\{d\}$. Note that when the MV is increased by one order of magnitude, the size of the MV sub-network will be reduced by 1/2. Therefore, for n number of nodes, the number of sub-networks to which node d belongs becomes $O(log\ n)$. Therefore, this method is scalable, i.e., the number of nodes can be increased. If some nodes in a sub-network are checked, a node with an MV part any 1 bit is added to the sub-network MV is found. If this is repeated, sub-networks with an MV can be identified quickly.

1) Amount of stored data by each node: Left side in Fig. 7 shows node d neighbors in skip Delaunay network. Node d sends locator notification messages to neighbor nodes (indicated by "1") in each sub-network and receives locator notification messages from those nodes. In the Delaunay graph, each node has approximately six neighbors. Then, the number of sub-networks belonging to each node is $O(log\ n)$. Thus, each node receives $O(log\ n)$ messages.

C. Notification messages discovery mechanism in the skip Delaunay network

As shown in right side of Fig. 7, the node indicated by "2" is searching for a locator notification message spread by node d. The search behavior is described as follows. Search entity is the subject executor of the search.

- In right side of Fig. 7, 101* sub-network is $SN\{d\}$.
- Node d's MV can be obtained by inputting its ID to a hash function.
- An MV = 1* node in the * sub-network is discovered. Then, the search entity is transferred to the node.
- An MV = 10* node in the 1* sub-network is discovered. Then, the search entity is transferred to the node.
- Similarly, MV = 101* nodes in the 10* sub-network are discovered.

Then, the search entity is transferred to the node. The node is a d. Thus, the d locator notification message is found and forwarded to the node that the search.

1) Number of nodes to be searched by the locator notification search mechanism: For n total number of nodes, the number of nodes searched by the notification message search mechanism is described as follows. Several nodes are searched in a single sub-network. Entity is transferred to a smaller sub-network, Note that this process is repeated, and the maximum number of repetitions is the maximum $Level$ in the given sub-network. Thus, in the worst case scenario, the number of searches is $O(log\, n)$.

D. Notification frequency adjustment for long-distance transmission load reduction

In the proposed method, a one-hop notification message is transferred in each sub-network. The transfer of the notification message is realized by multiple hops in the lower layer networks. In other words, high $Level$ one-hop notification

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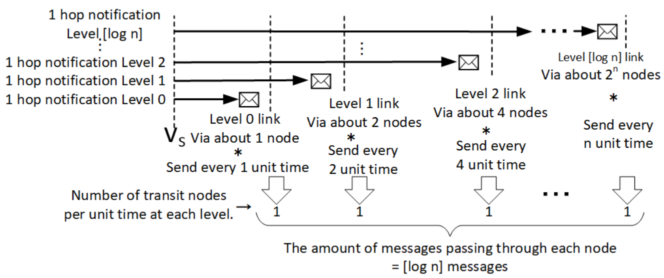

Fig. 8. Range of nodes that receive notification messages by v_s

messages require many hops in lower layer networks, thus, the load is increased. Therefore, we consider the loads of the one-hop transfers in each Level to each node of the lower layer networks. The transmission frequency of the high $Level$ notification messages in the proposed method is reduced based on this consideration. The number of locator notification messages passed through each node is reduced to $O(log\, n)$ by reducing the transmission frequency.

1) Consideration of notification message transfer count at each node: When greedy routing is performed to gradually reduce the remaining distance in the skip Delaunay network, nodes forward messages between the locator notification message sending and receiving nodes. When a message is transferred to one-hop neighbors using a high Level link, the message passes through many nodes in the lower layer.

The relationship between nodes is approximately symmetrical in the transmission of the locator notification message; therefore, the total number of nodes through the notification messages sent by a node is substantially equal to the number of messages that arrive at the node. Furthermore, when the node arrangement is extreme, in some cases, some nodes can receive more messages than others. However, this case should be addressed by local load distribution. Therefore, we do not consider this case in this paper.

In Fig. 8, node v_s and its neighbors are shown in the skip Dealunay network constructed by n nodes. Here, v_s roughly belongs to a sub-network of the highest $Level\, [log\, n]$. Then, v_s belongs to less sub-network, the number is approximately $[log\, n]$. When sending a message to a one-hop destination node in the $Level$ sub-network, the message is transferred via 2^{Level} nodes using the $Level\, 0$ sub-network. In Fig. 8, the reach of the notifications in the $Level$ are represented by the dotted lines and message icons. The number of nodes to receive the message is also shown. The one-hop notifications of each $Level$ are received by 2^{Level} nodes. In other words, $O(log\, n)$ cannot be achieved. To address this problem, the proposed method suppresses the notification transmission frequency and the number of messages per unit time.

2) Suppressing notification message transmission frequency per unit time: When, one notification message is sent per unit time in $Level\, 0$, in other $Level$s, one notification message is sent per 2^{Level} unit time. Thus each $Level$ number of messages will be per unit time average 1 message. Maximum of $Level$ is $O(log\, n)$. Therefore, the number of messages that pass through v_s per unit time becomes $O(log\, n)$. This ensures the scalability of the proposed method.

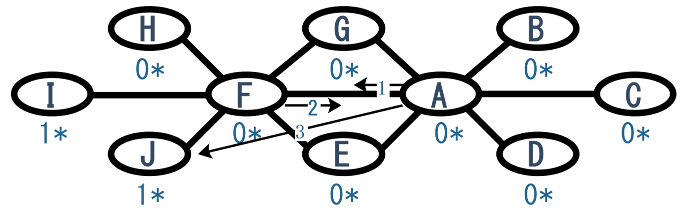

Fig. 9. Search example of a node with arbitrary MV in a sub-network.

E. Behavior during search for a node with any MV in a sub-network

When searching for a node with an arbitrary MV in the subnetwork, the proposed system searches as in the example below.

Fig. 9 is an example. Node A look up neighbor nodes having MV = 1* from its database. However, node A cannot get. So, A sends a neighbor discovery message to the closest known node F(Arrow 1). Node F that received the message sends own neighbor node list to node A(Arrow 2). If, Node A find nodes having MV = 1* in the list, Node A sends search entity to the node(Arrow 3). If, Node A can't finde find nodes having MV = 1* in the list, A sends a neighbor discovery message to the 2nd closest known node. By the way, from the characteristics of MV, node A can find a target node with a high probability by examining a small number of nodes.

IV. Behavior Confirmation and Evaluation by Simulation

We developed a Java-based simulator to examine the load of the entire network caused by broadcasting locator notification messages. Moreover, we examined the number of transmission hops for the ID/locator resolution in the given environment. The initial state of the simulation is described as follows.

- The size of the simulation space is a 1.0×1.0.
- The simulation was performed while changing the number of nodes from 100 to 1000 in increments of 100.
- Each node was assigned with position coordinates according to a uniform distribution.
- The skip Delaunay network was constructed on the arranged node.

Under the above conditions, the change in load on each node associated with the changing number of nodes was measured.

First, the number of times the locator notification messages were transmitted was measured for each unit time at each node. Each node sends a locator notification message once to each level neighbors in the skip Delaunay network. These messages were transferred in the $Level\, 0$ Delaunay overlay network by greedy routing. Each node counts the number of times the notification message was transferred, and the average value was calculated. The high Level message was

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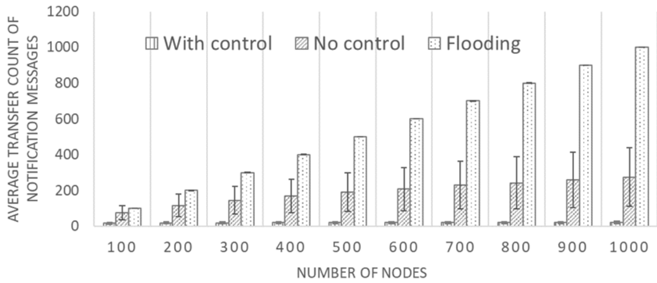

Fig. 10. Average and standard deviation of the number of messages received by each node.

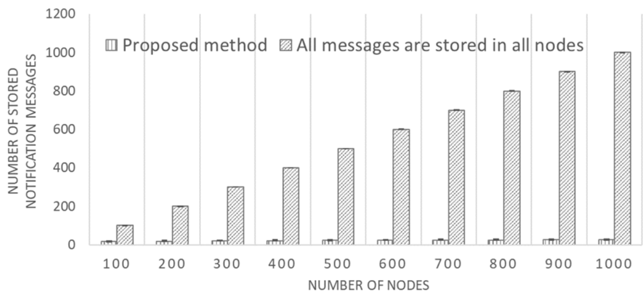

Fig. 11. Average and standard deviation of the number of messages stored in each node.

also calculated when reducing the transmission frequency. Specifically, $(1/2)^{Level}$ number of messages per unit time were calculated. Fig. 10 shows the results. If uncontrolled, the transfer count increased proportionally with the increasing number of nodes. If the sending frequency was controlled, the transfer count remained constant. In a flooding case, the number of messages passing through each node was the same as the total number of nodes.

Next, the number of notification messages stored in each node was measured. Fig. 11 shows the results. Increases in the number of stored messages were suppressed by increasing the number of nodes. In a flooding case where all messages were stored in each node, each node stored the same number of messages as the total number of nodes.

Furthermore, we measured the total number of transmitted messages used in the ID/Locator resolution. Here, all nodes performed ID/Locator resolution for all nodes. Then, the average value was calculated. Fig. 12 shows the results. In the skip Delaunay network, Increases in the number of hops were suppressed by increasing the number of nodes. One-hop transfer in the skip Delaunay overlay network is realized by $Level\,0$ forwarding or underlay forwarding. Therefore, we measured the number of hops when this forwarding process is realized in the $Level\,0$ network. This case was more proportional than the skip Delaunay network case. In addition, in a flooding case where all messages were stored in each node, there was no need to search for messages.

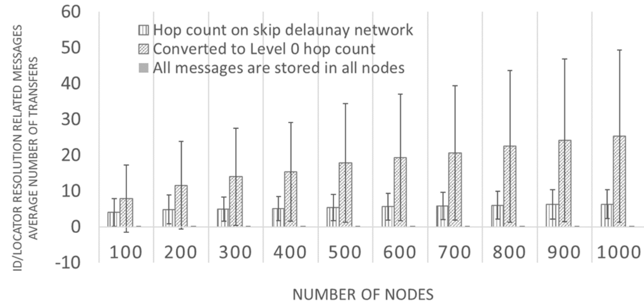

Fig. 12. Message transfer for ID/Locator resolution Average value and standard deviation of the number of hops.

V. Conclusion

In this paper, we have proposed an ID/locator resolution system for a Delaunay overlay network using detour paths, and we have confirmed the scalability of the mechanisms of the system in simulations.

Acknowledgements

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