A DTN Routing Scheme Based on Publish/Subscribe Model

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Abstract - Delay Tolerant Networking (DTN) is attractive as an effective communication method in unstable network environments where frequent disconnections occur easily. DTN routing is based on the store-carry-forward paradigm. So far, various DTN routing schemes corresponding to the temporal and spatial characteristics of contacts between nodes have been proposed. However, name resolution between a source and a destination is difficult in a network environment that consists of only wireless terminals such as DTN. In this paper, we present a DTN routing scheme based on the publish/subscribe model that enables flexible communication by using topics of information. In the proposed scheme, messages are sorted by the subscription lists and the contact condition of nodes in order to deliver to destinations with a short delay. We compare the performance of the proposed scheme with that of existing schemes through simulations.

Keywords: Delay Tolerant Networking, Store-Carry-Forward, Publish/Subscribe Model.

1 INTRODUCTION

Recently, as a development of near field communication technology and mobile devices, network services are becoming available in areas where a communication infrastructure is not set up and disaster areas. However, if nodes move frequently in such environments, frequent disconnections occur easily, so users cannot use the networks continuously.

Delay Tolerant Networking (DTN) is attractive as an effective communication method in such unstable network environments [1]. DTN is intended to optimize communication performance and share network resources. To reach these goals, source nodes, relay nodes, and destination nodes work together and control the transmission of information. DTN has been primarily studied as a technology to be applied to communication in the sea, space, and disaster areas, etc. However, in recent years, the number of applications and experiments that use DTN technology is increasing, such as communication in developing countries and the delivery of local news and advertising.

DTN routing is based on the Store-Carry-Forward paradigm [2]. In this paradigm, each node moves while keeping messages until it becomes possible to communicate with other nodes. When it meets the other nodes, it forwards replications of the message to them.

Generally, in DTN routing schemes, the message delivery delay is shorter as the number of replications of a message increases. This is because the chance that the relay nodes having the replication meet the destination node is increased. However, buffer consumption of the relay nodes is larger as the replications of a message increase. Because of these properties, there is a trade-off between message delivery delay and buffer consumption.

So far, various DTN routing schemes have been proposed in order to resolve this trade-off and to transmit information effectively. Existing schemes are classified into several communication models. An example of these models is one-to-one communication models based on the host address. This communication model requires the name resolution between a source and a destination. However, the name resolution based on the host address is difficult in a network environment that consists of only wireless terminals such as DTN. Other examples of the models are the information dissemination-based communication model and information collection-based communication model for targeting all users. These models can be realized without the name resolution between a source and a destination. However, communication between the specified nodes is not possible. Therefore, in the DTN routing based on the existing communication models, each user in the network cannot select and get the information they wants.

In this paper, we present a DTN routing scheme based on the publish/subscribe model [3] that enables flexible communication by using topics of the information. The proposed scheme can communicate without checking each host address between sources and destinations because the name resolution is achieved on the basis of the topics of information. In addition, we proposed an algorithm that sort messages by the subscription lists and the contact condition of nodes in order to deliver to destinations with a short delay.

We compare the performance of the proposed scheme with that of existing schemes through simulations and show the effectiveness of the proposed scheme.

2 RELATED TECHNOLOGY

In this chapter, we discuss the functions of DTN routing and the publish/subscribe model as techniques related to our research. In addition, we discuss existing research on applying publish/subscribe model to DTN routing.

2.1 DTN Routing

Functions of DTN routing based on Store-Carry-Forward are classified into selecting relay nodes, selecting messages, and managing the buffer. In this section, we discuss the details of the three functions.

(1) Selecting relay nodes

With this function, each node selects the relay nodes to forward messages preferentially from several nodes within the communication range. The following is typical DTN routing schemes.

- Epidemic Routing [4]
  Each node forwards the replications of the message to all nodes that it contacts. In this scheme, many replications of a message are generated, so the message delivery delay is short but buffer consumption is large.
- Two-Hop Forwarding [5]
  Source nodes forward the replications of the message to all nodes that they contact, but relay nodes forward the replications of the message to only destination nodes. In this scheme, few replications of a message are generated, so the message delivery delay is long but buffer consumption is small.
- Spray and Wait [6]
  In this scheme, the limit on the number of replications that can be generated from a message is set. After this limit is reached, each node waits to make contact with the destination nodes. In this scheme, the limited on the number of replications is set, so it is possible to control the trade-off between message delivery delay and buffer consumption.
- PRoPHET [7]
  The relay nodes that are most likely to meet the destination node is selected from records of past communications of each node, and they receive the replication.

(2) Selecting Messages

With this function, the order to send messages is decided. It is expected that the session between nodes breaks down before each node forwards all messages to communication partners in DTN routing. Therefore, when they meet other nodes, they decide which message preferentially is forwarded from their buffer in order to improve the communication performance. Examples of the algorithm are FIFO (First In First Out), which messages in the order from oldest received time, and LIFO (Last In First Out), which messages in the order from newest received time.

(3) Buffer Management

In this scheme, each node decides which message is removed in their buffer if the capacity of their buffer is exceeded because of an accumulation of messages. Examples of the algorithm are FIFO and LIFO as well as the function that select messages. In addition, another approach is to use recovery schemes that remove messages that are no longer needed after reaching destination nodes [8].

2.2 Publish/Subscribe Model

The publish/subscribe model [3] is a communication model that implements asynchrony between senders and receivers. The structure of this model is shown in Fig. 1. It consists of three systems: publishers to send information, subscribers to receive information, and an event broker to relay information between publishers and subscribers. Publishers send the event broker the information they want to provide in the network. Subscribers send the event broker requests for information they want to get from the network. An event broker checks the requests from subscribers and the information from publishers and sends subscribers the information that matches the requests.

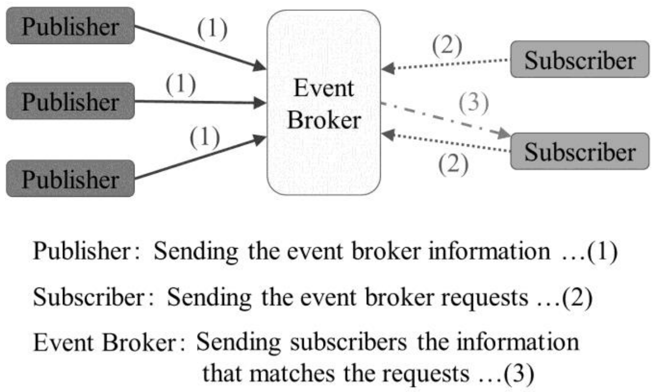

Figure 1: publish/subscribe model

Using a communication model based on the name resolution based on the host address is difficult in a network environment that consists of only wireless terminals such as DTN. In contrast, the publish/subscribe model can communi-cate without checking the host address between sources and destinations because the event broker achieves the name resolution based on the topics of information. Therefore, this model has the following advantages.

- It is not necessary that senders and receivers are synchronized temporally and geographically. Therefore, when the senders send messages, receivers do not need to be in the network.
- It is not necessary that senders and receivers notify their presence to each other because information is distributed on the basis of the content and topic of information.
- One-to-many communication, many-to-many is possible.

2.3 Publish/Subscribe-based DTN Routing

DTN assumes unstable network environments where frequent disconnections occur easily. The publish/subscribe model achieves asynchrony between the sender and the receiver. Therefore, these technologies are considered compatible, so the combination of them is attractive. In this section, we discuss related researches on DTN routing schemes based on the publish/subscribe model.

Kure proposed a routing scheme in which all nodes have the functions of the publishers, subscribers, and event brokers in DTNs constructed in disaster areas [9]. In the affected areas, all users who own a wireless terminal can be subscribers and publishers. In addition, special nodes that mediate between publishers and subscribers do not exist in the network all the time. Assuming these cases, each node processes communication on the basis of functions of subscribers, publishers, and event brokers. With the function of publishers, the nodes that generated messages forward the replications to all nodes in communication range at the present moment. With the function of subscribers, the nodes forward requests that contain the topics of information they want to all nodes that they meet. In addition, the requests that they receive from other nodes in the past are forwarded. With the function of event brokers, if the nodes receiving the requests have messages corresponding to the request in their buffer, they propagate the messages by Epidemic Routing and deliver them to the node requesting. This routing scheme makes it possible for all the nodes in disaster areas to share the information with request and response. However, messages to be forwarded to the relay nodes are sorted by FIFO. Therefore, it is not always possible to deliver messages efficiently to all the destination nodes in the network.

Janico proposed a communication process (DPSP) for when two nodes meet [2]. The sequence of the communication based on DPSP is shown in Fig. 2. When two nodes establish a session, they first exchange their subscription lists that contain the topics of information they want (1). Then each node builds a queue of the replications of the message from the local storage in order to forward the messages to the partner (2). After building the queues, the messages whose probability to be delivered is not improved when they are replicated to the partner are removed (3). This process has the effect of reducing the buffer usage of the relay nodes. Then, each node sorts the messages in their queue by their priority (4). After that, the nodes send the messages from the queues until the queues are empty or the session breaks down (5).

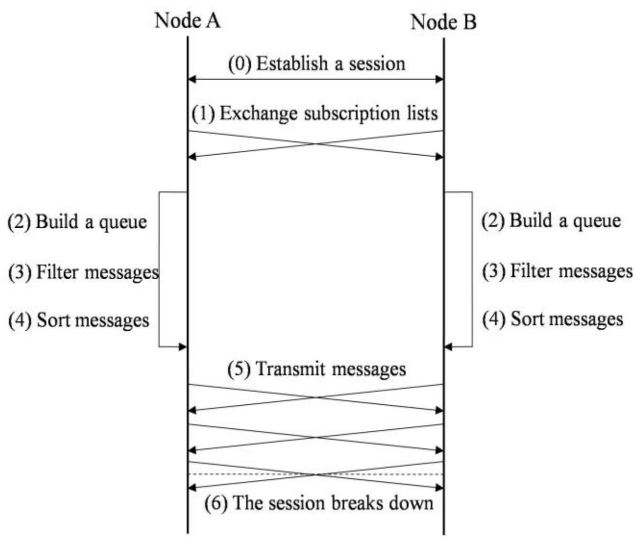

Figure 2: Communication process based on DPSP

In addition, Janico discussed several approaches for (3) filtering and (4) sorting the messages. Janico believed that message delivery rate and delivery delay are optimized by using these approaches properly depending on the network environment such as the message creation interval and the number of nodes. However, it is difficult for either approach to maintain consistently high communication performance without depending on the changes of the network environment. In addition, when the messages are sorted on the basis of the subscription lists, the communication performance of each topic may be uneven because of the difference in the number of subscribers.

3 RESEARCH TASK

In this paper, we aim to establish a flexible system in which each user can select and get the information they wants in a network environment that consists of only wireless terminals. Therefore, we need to discuss the efficiency of DTN routing based on the publish/subscribe model that communicates with topics of information. The challenge of this routing scheme is ensuring that the messages of each topic are delivered to subscribers with high probability and a short delay.

The capacity of each node's buffer and the time that it can communicate with other nodes are limited in a DTN environment. We need to improve the efficiency of message delivery under these constraints. In addition, our task is to reduce the bias in the communication performance of each topic without depending on the number of subscribers.

4 PROPOSED SCHEME

In this chapter, we propose a DTN routing scheme based on the publish/subscribe model detailed in section 2.3 and chapter 3. In the following, we discuss the assumed network environment and give a summary of the proposed scheme.

4.1 Assumed Environment

The proposed scheme is assumed to distribute information in a DTN that consists of only mobile nodes. Examples of the applications are services to deliver information on events, advertisements in the surrounding areas and news with high locality.

The nodes in the network are mobile phones, tablet devices, laptops, etc. All the nodes in the network can distribute information (messages) and receive it. Each message that is distributed in the network is belongs to a topic. Topic types are determined in advance, and new topics are not added. Each message is completed as one packet, and it is removed when TTL (Time To Live) expires.

4.2 Summary of Proposed Scheme

In the proposed scheme, all nodes have functions of publishers, subscribers, and event brokers that are based on the publish/subscribe model. Each node relays messages on the basis of the subscription lists and the contact condition of communication partners in order to deliver each message to the nodes subscribing to them. A use case diagram of the proposed scheme is shown in Fig. 3.

Each node generates messages on topics that are specified as publishers. The header of a message is shown in Table 1. The nodes register the topics in which they have an interest in their subscription lists as subscribers. The elements of the subscription list are shown in Table 2. The nodes can set the order to receive messages and the priorities of the topics when registering the topics.

The nodes that receive messages and subscription lists relay the messages to the nodes that they meet as event brokers. The messages are sorted on the basis of the subscription list and contact condition of each node. In addition, each node delivers the messages matching the topics in the communication partner's subscription lists as event brokers.

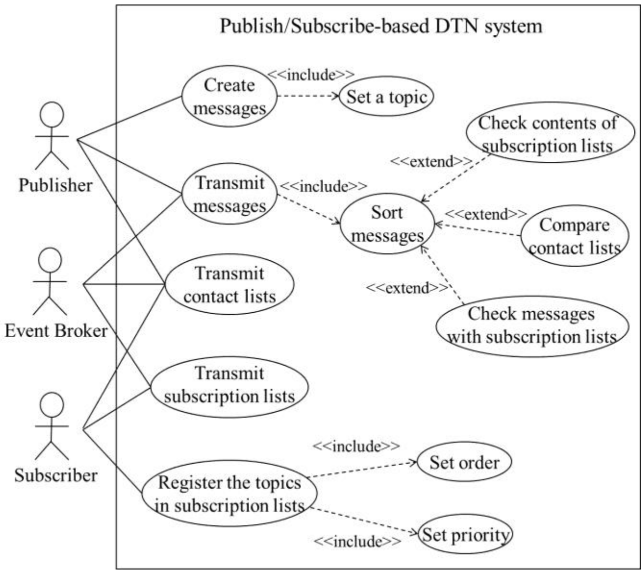

Figure 3: Use case diagram

Table 1: Header of a message

Element	Detail
From	Address of the node that generates a message
TopicID	Topic ID to which a message belongs
MsgID	Message ID, which contains a sequence number of a message to be counted independently for each node
CreateTime	Time that a message was generated
ReceivedTime	Time that a node received a message
TTL	TTL (Time To Live) of the message

Table 2: Elements of the subscription list

Element	Detail
SubID	Unique ID that a subscription list has
TopicID	Topic ID to which a message belongs
Order	Order in which to receive the message, which is selected from the ascending *CreateTim*e of a message or descending
Priority	Priority of a topic
ContactCnt	Number of times that a node meets other nodes registered to the same topic

End to end communication is realized by each node processes communication on the basis of the above functions when it meets other nodes. The communication process between two nodes is shown in Fig. 4.

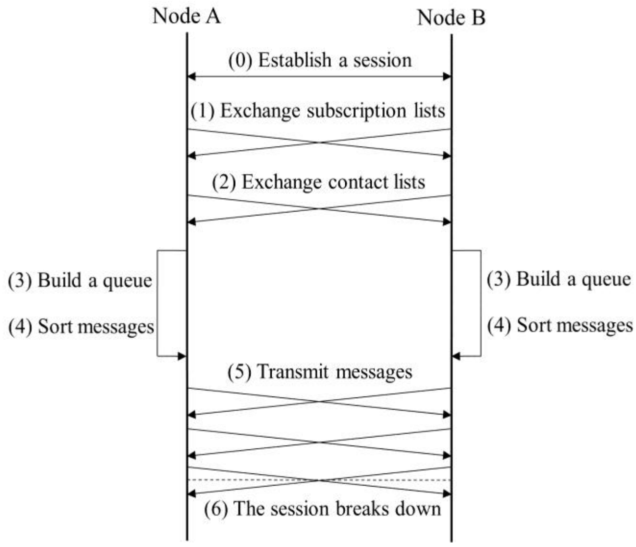

Figure 4: Communication process between two nodes

When two nodes meet, they first exchange their subscription lists (1). The subscription lists contain topics of information for each node and the nodes that it met in the past want.

After exchanging the subscription lists, they exchange their contact lists (2). The contact lists contain the average value of the contact time (i.e., how long each node is in contact with other nodes) and the average value of inter-contact time (i.e., the time between the end of a previous contact and the beginning of a new contact). They judge which of their contact condition is better by comparing their contact lists each other.

Then each node builds a queue of messages from the local storage to forward to the partner (3). After building the queue, the nodes sort the messages by the subscription lists and the contact lists (4). The details of this sorting algorithm are discussed in Section 4.3. After that, the nodes send the messages from the queues until the queues are empty or the session breaks down (5).

4.3 Sorting Messages

In a DTN environment, the session between nodes may break down before each node forwards all messages to a communication partner. Therefore, in the proposed scheme, the messages are sorted and transferred to the communication partner in the order of the highest priority.

The sorting of messages has two steps. In the first step, the priority of the topics to which the message belongs is determined (sorting topics). In the second step, the priority of messages that belong to the same topic is determined (sorting messages). Each node forwards the messages in the order that is determined through these steps.

In the proposed scheme, the messages are forwarded to the communication partner in three phases on the basis of the subscription lists and the contact lists. The procedure of forwarding the messages is shown in Fig. 5.

(a) Forwarding the subscribed messages

Each node forwards messages belonging to the topics that the communication partner registers. The sorting of topics is done in ascending the *Priority* that the partner sets when registering the topic. The sorting of messages follows the *Order* that the partner sets when registering the topic.

(b) Relaying messages on the basis of the contact lists

Each node forwards the messages belonging to the topics in the subscription lists with the nodes that the partner met in the past. First, two nodes compare each contact condition by using the contact lists. Then, the messages with low reachability are relayed to the node whose contact condition is better, while the messages with high reachability are relayed to the node whose contact condition is worse. The messages of all topics are evenly propagated in the network by this process.

$V_{contact}$ is defined below as the indicator for evaluating the contact condition.

$$V_{contact} = \frac{T_{contact}}{T_{inter}} \quad (1)$$

In general, the number of messages that can be transferred during contact tends to increase as contact time $T_{contact}$ increases. The number of opportunities that for the node to contact with other nodes tends to increase as inter-contact time T_{inter} decreases. Therefore, a node whose $V_{contact}$ is large can communicate with many nodes for a long period of time. In this phase, as a result of comparing each node's $V_{contact}$, a node whose $V_{contact}$ is large relays messages with step (b-i), and a node whose $V_{contact}$ is small relays the messages with step (b-ii).

(b-i) A node whose $V_{contact}$ is large forwards messages with high delivery probability to a node whose $V_{contact}$ is small. The sorting of topics is done in descending *ContactCnt* in the partner's subscription lists. If some topics have the same *ContactCnt*, the topics are sorted in descending *Priority*. The sorting of messages follows FIFO.

(b-ii) A node whose $V_{contact}$ is small forwards messages with low delivery probability to a node whose $V_{contact}$ is large. The sorting of topics is done in ascending *ContactCnt* in the partner's subscription lists. If some topics have the same *ContactCnt*, the topics are sorted in ascending *Priority*. The sorting of messages follows FIFO.

(c) Forwarding the unregistered messages

The node forwards the messages that the partner's subscription lists are unregistered to. The messages are sorted by FIFO without sorting topics.

Both the messages of the popular topic and those of the unpopular topic are evenly propagated in the network by sorting the messages on the basis of the contact lists, not only the subscription lists. Therefore, the proposed scheme makes it possible for messages to be delivered to all subscribers more evenly than by sorting the messages on the basis of only the subscription lists.

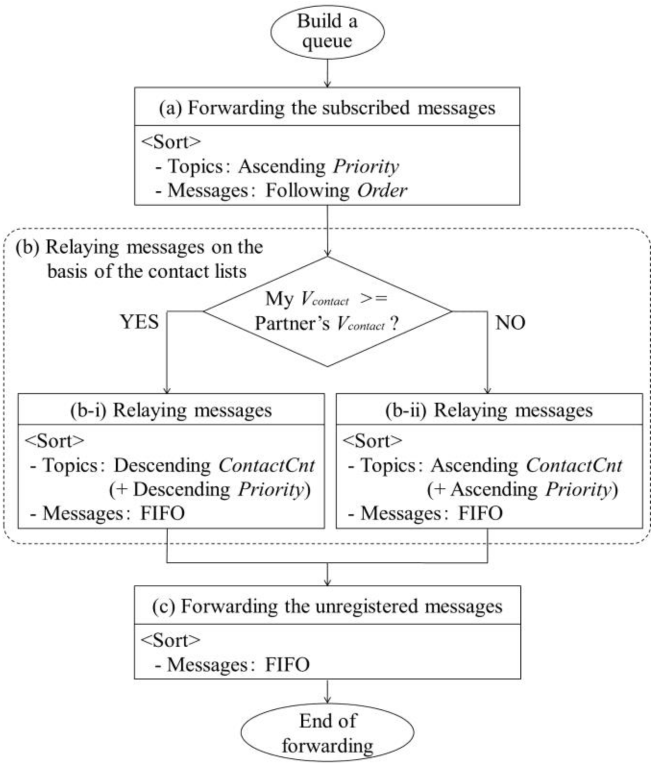

Figure 5: Procedure of forwarding messages

In addition, the messages are removed by FIFO if the capacity of their buffer is exceeded because of an accumulation of messages. This is because it is considered that the oldest message that each node has is relayed to other nodes sufficiently.

5 EXPERIMENTAL EVALUATION

5.1 Experiment Environment

We implemented the proposed scheme on the network simulator The ONE (The Opportunistic Network Environment Simulator) [11] and compared the performance of the proposed scheme with that of existing schemes in order to evaluate the effectiveness of the proposed scheme. The ONE is a simulator that was developed for evaluating of routing and application protocols in DTN environments.

The structure of the network that was used in this simulation is shown in Fig. 6, and the simulation parameters that are shown in Table 3. There are three types of message topics that are distributed in the network: topics A, B, and C. There are 240 nodes that subscribe to topic A, and half of them move in Cluster P, and the other half move in Cluster S. There are 120 nodes that subscribe to topic B, and half of them move in Cluster Q, and the other half move in Cluster S. There are 40 nodes that subscribe to topic C, and half of them move in Cluster R, and the other half move in Cluster S.

Therefore, the nodes that subscribe to the same topic frequently contact with each other in Clusters P, Q, and R, and the nodes that subscribe to a different topic frequently contact with each other in Cluster S. In the simulation, it was evaluated whether messages belonging to each topic are delivered to the nodes whose contact condition is different in the network.

A node is assumed pedestrian and moves by Random Waypoint. A message is assumed advertisements and news and is generated by a node selected randomly from all nodes. The message size is determined by a normal distribution when the message is generated. Messages are generated until 30 minutes before the end of the simulation time. A communication standard of a node is assumed Bluetooth.

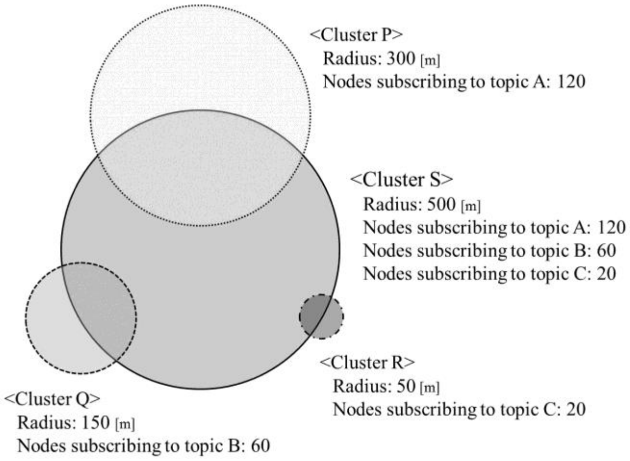

Figure 6: Structure of network

Table 3: Simulation parameters

Simulation time	12 [hour]
Moving speed of node	1.8 - 5.4 [km/h]
Wait time	0 - 120 [sec]
Communication range	10 [m]
Communication speed	250 [kbps]
Buffer size	50 [MB]
Message size	0.5 - 3.0 [MB]
Message creation time	11.5 [hour]
TTL	120 [min]

5.2 Evaluation Policy

In the experiment, the proposed scheme is compared with the existing schemes in terms of average message delivery rate and average delivery delays as the message creation interval changed. In addition, the standard deviation of each scheme was compared in order to evaluate the effect that the number of subscribers has on the communication performance. The definition of each evaluation indicator is the following.

- Message delivery rate (Avg.)
  The rate of the subscribing nodes who received each generated message.
- Message delivery delay (Avg.)
  The average time between the creation and arrival of the message that was delivered to the subscribing node.

The existing schemes compared with the proposed scheme are Epidemic Routing, Two-Hop Forwarding, and Subscription-based Routing (SBR). The SBR is basically the same mechanism as the proposed scheme, but the messages are sorted on the basis of only the subscription lists without the contact lists. Therefore, the messages are forwarded to all nodes in the order of (a), (b-i), and (c) in Fig. 5. In addition, the messages are sorted by FIFO in Epidemic Routing and Two-Hop Forwarding.

5.3 Results of Experiment and Discussion

The average message delivery rate is shown in Fig. 7, and the average message delivery delay is shown in Fig. 8.

As shown in Fig. 7, the average message delivery rate of the proposed scheme was always more than 99% in parallel with Epidemic Routing and SBR. It is considered that the DTN routing scheme based on the publish/subscribe model can reliably forward messages to each subscribing node through this result.

As shown in Fig. 8, the average message delivery delay of the proposed scheme was about 80 - 100 seconds shorter than that of Epidemic Routing and SBR, and about 400 seconds shorter than that of Two-Hop Forwarding. This is because messages with a lower priority were propagated actively by the nodes with good contact condition.

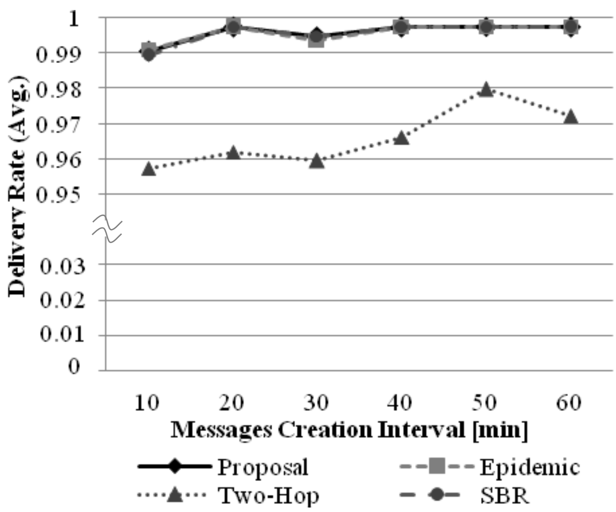

Figure 7: Message delivery rate (Avg.)

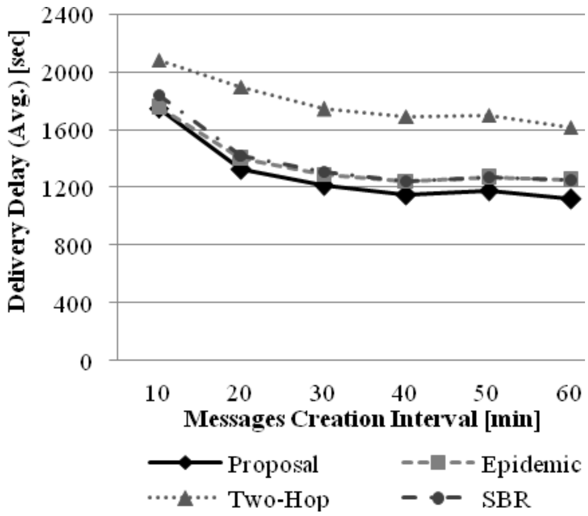

Figure 8: Message delivery delay (Avg.)

In addition, the standard deviation of the message delivery delay of the proposed scheme, Epidemic Routing, and SBR are shown in Fig. 9. The standard deviation of the proposed scheme was smaller than that of other schemes as the message creation interval decreased. It is considered that the proposed scheme prevents an increase in the message delivery delay due to the number of subscribing nodes because each message is relayed in accordance with the priorities and the contact condition even if the message is generated frequently.

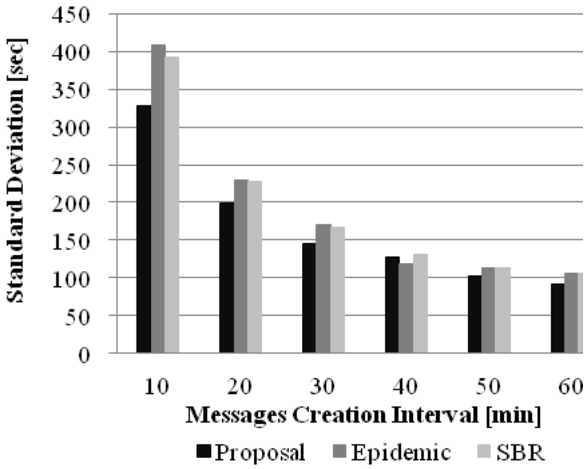

Figure 9: Standard deviation of message delivery delay

6 CONCLUSION

In this paper, we proposed a DTN routing scheme based on the publish/subscribe model with the aim of establishing a flexible system with which each user can select and get the information they wants in the network environment that consists of only wireless terminals. We compared the performance of the proposed scheme with that of existing schemes on the network simulator The ONE in order to evaluate the effectiveness of the proposed scheme. Through the results of the experiment, the proposed scheme was confirmed to deliver messages to subscribing nodes with high probability. In addition, message delivery delay of the proposed scheme was about 80 - 100 seconds shorter than that of the existing schemes, and its dependence on the number of subscribing nodes was low.

It is considered that the effectiveness of the proposed scheme increased as the simulation map had a high characteristic of the mobility of nodes, because the messages are sorted by the contact condition of the nodes, although the mobility model of the nodes was set for Random Waypoint in this experiment. Therefore, we will implement a map and a mobility model that are closer to the real world and evaluate the effectiveness of the proposed scheme. In addition, our challenge is also to study approaches that reduce buffer consumption.

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