DTN-based Delivery of Word-of-Mouth Information with Priority and Deadline

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Abstract

In this paper, we propose a DTN (Delay Tolerant Network) based data delivery method for an environment without communication infrastructures (e.g., disaster area, event place, etc) that takes into account relative importance and deadline of users' data requests. In this paper, as a target application, we suppose a system that allows users in a sightseeing area to exchange word-of-mouth information including photos on each sightseeing spot. We assume that multiple portable servers called "InfoBoxes" that collect/disseminate data from/to user terminals via short range wireless communication (e.g., Bluetooth) are deployed at sightseeing spots. In our proposed system, each user terminal sends, to an InfoBox, a query specifying (1) a destination spot on which the user wants to get information, (2) the importance of the query (to what extent the user satisfies when getting the query response), and (3) a receiving spot where the user wants to receive the query response. We propose a carry-and-forward based technique for delivering queries/responses so that the overall user satisfaction is maximized. Depending on a given probability of user movement between two spots, the proposed method appropriately adjusts the number of data replicas copied from each InfoBox to user terminals. In addition, the method discards the data which cannot meet the delivery deadline for efficient bandwidth utilization. Through computer simulations, we confirmed that the proposed method achieves better overall user satisfaction than other conventional methods.

Keywords: DTN, Data Delivery, MANETs, Priority Queuing

1 Introduction

Mobile ad hoc networks (MANETs) can be a useful communication means for an area where existing communication infrastructures such as cellular networks cannot be used (e.g., disaster area, depopulated area, isolated island, temporary event place, etc). For MANETs, various routing protocols such as OLSR, AODV, and DSR have been proposed. In MANETs, however, the whole network likely gets partitioned into multiple connected parts and some nodes get unreachable due to mobility and the non-uniform density of the mobile terminals. In such an environment, the *carry-and-forward* technique, where a terminal carries messages while moving until it comes across another terminal, is useful to improve message delivery ratio. In general, the network which is based on the carry-and-forward technique is called *Disruption/Delay Tolerant Network (DTN)* [1]. DTN has been considered to be useful for special purposes such as inter-satellite communication in space and inter-village communication in a depopulated area like a desert. However, since most of latest cell phones are equipped with short-range wireless communication capability like Bluetooth and ZigBee, it is natural to apply DTN technology to constructing an inexpensive ad hoc communication infrastructure among mobile users such as word-of-mouth information exchange, even in an area where communication infrastructure exists.

Thanks to research activity of a special interest group IRTF DTNRG [2] for standardizing DTN technology, there have been proposed several carry-and-forward based routing techniques for DTN. One of the earliest DTN routing techniques is Epidemic routing[3] where each terminal probabilistically replicates messages to encountered terminals while moving. As more advanced techniques, MED [4] and MEED [5] were proposed. MED assumes so-called *contact oracle* that tells when and which node each node comes across in the future, and minimizes the delay in delivering a message to a destination node. MEED uses the past contact information (i.e., when and which node each node has come across so far) and estimates the minimum delay DTN path to a destination node. In addition, Wang, et al. proposed a technique to predict the future network topology based on the node mobility. Most of existing techniques for DTN including the above studies aim to minimize delay and improve data delivery ratio. However, since they adopt the best-effort approach and cannot control the delivery ratio, it will be difficult to use them to realize a practical ad hoc communication infrastructure among mobile users.

In this paper, we propose a DTN-based data delivery method to realize a word-of-mouth information exchange for an area where communication infrastructure such as cellular network and Internet cannot be used (or is costly). As an example of a target area, in this paper, we suppose a sightseeing area with some spots as shown in Fig. 1. In the proposed method, we assume the following: (1) tourists (mobile users) are equipped with Bluetooth-ready mobile terminals; (2) a small battery-driven Bluetooth-ready server called *InfoBox* is deployed at each spot in the target sightseeing area; (3) word-of-mouth information and event information on each spot is stored in the InfoBox at the spot by mobile users or event organizers; (4) communication will happen only between InfoBox and mobile terminals (i.e., mobile terminals do not directly communicate with each other and InfoBoxes cannot directly exchange data with each other); and (5) for each pair of two neighboring sightseeing spots, the probability of mobile user at a spot to move to another spot is given. In our target system, as shown in Fig. 1, each mobile user at the spot SRC (who intends to visit spots RL and $DEST$ in this order) throws into SRC's InfoBox a request for required information on spot $DEST$ so that the user can receive the requested information from the InfoBox at spot RL when reaching there. Here, note that it makes no sense for the user to receive the requested data after leaving the receiving spot RL (i.e., there exists a deadline for each data reception).

In above system, if the issued requests exceed network capacity, the data delivery ratio will decrease due to many requests cannot be delivered within deadline. Also, depending on data size and distance to the destination spot, the network and storage resources consumed for the data delivery will vary. So, it is desired to consider cost performance of data delivery among multiple request/response data in order to increase the total system performance. For this purpose, in our proposed method, we associate user satisfaction and deadline with each data delivery, and propose a DTN data delivery method to maximize the overall user satisfaction. As the basic idea, we adopt (i) reducing the number of data replicas from each InfoBox to mobile terminals taking into account the probability of a user moving from a spot to another, (ii) discarding, in early phase, delivery of requests/responses which are estimated to arrive after their deadline, and (iii) at each InfoBox, processing requests/responses with high user satisfaction and early deadline prior to other lower/later ones.

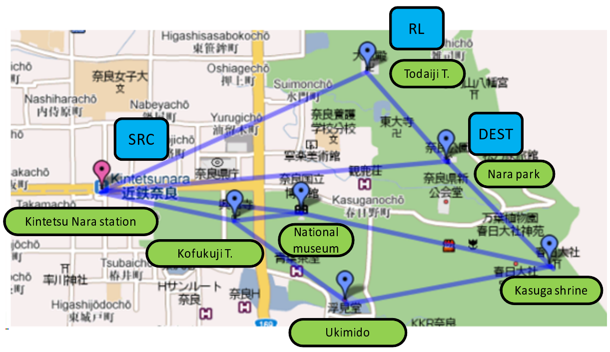

Figure 1: Example of Target Sightseeing Area

For evaluation, we conducted computer simulations of the proposed method supposing famous sightseeing area around Nara Park, Japan. As a result, we confirmed that our method outperforms other conventional methods (based on FIFO or considering either user satisfaction or deadline) in terms of overall user satisfaction of data delivery.

2 Related Work

In recent years, many efforts have been made in the DTN research field. Thanks to research activity of a special interest group IRTF DTNRG [2] for standardizing DTN technology, there have been proposed several DTN-based routing techniques.

Unlike message flooding, Epidemic routing[3], which is the simplest DTN routing technique, lets each terminal probabilistically replicate messages to other terminals encountered while moving. Epidemic routing can achieve good message delivery ratio by adjusting the replication probability, but it is considered to have some scalability problem in terms of consumed network bandwidth and terminal's message buffer[4].

There are various studies that try to reduce consumed bandwidth and buffer for DTN data delivery by utilizing the mobility characteristics of mobile nodes. In [4], Jain et al. formulated a minimum delay routing problem for DTN where disconnection patterns of communication links are known, and proposed several basic routing algorithms. In [6], Yong et al. proposed a FEC-based routing technique that encodes each message into $k \times r$ code blocks (k and r are constants) and sends those blocks to a destination node so that the destination node can extract the original message only from any k blocks received. The authors also showed that this method can reduce message delivery delay within certain overhead. In [7], Banerjee et al. thought that message delivery performance in DTN is improved by increasing each node's message sending/receiving opportunities and developed a fixed storage node called *ThrowBox* for storing data to be delivered. If more ThrowBoxes are deployed in the service area, each node's sending/receiving opportunities will increase. The authors proposed a mechanism that improves opportunities, delivery delay, and power consumption, and confirmed the effectiveness of the method through experiments on the testbed using buses called *UmassDieselNet*. In [8], Xuwen et al. conducted experiments for Epidemic routing based data sharing application system with data set collected at University of Notre dame. However, they could not obtain high data delivery ratio as shown in [3].

As described above, many research efforts have been made to improve message delivery ratio in DTN. In order to apply these existing techniques to real world application, we need to consider message size exchanged between two mobile nodes during their contact time. Depending on the message size and the contact time length, there may exist some cases that a message cannot be exchanged at one contact. Since more important message should be delivered prior to others and some message must be delivered within the deadline, we need a differentiation mechanism depending on the message priority, size, and deadline. However, most of existing techniques do not consider those factors.

Unlike the existing techniques, our proposed technique enables cost performance aware message delivery in DTN taking into account the deadline and user satisfaction of each message.

3 Assumptions

In this section, we give assumptions for the proposed method.

(1) Target Area and InfoBox

We assume that a target *service area* with some *spots* is specified in advance. In each spot, a storage capable of wireless communication called *InfoBox* is deployed. We assume that each InfoBox has (1) digital map and spot information on the target area, (2) sufficient size of buffer for storing data, (3) Bluetooth communication capability, and (4) the probability of a user to move from a spot to another for any pairs of neighboring spots. As InfoBox, we can use a laptop PC, a cell phone/PDA, and so on.

(2) User Behavior and Mobile Terminal

Each user does sightseeing in the service area by visiting some of the spots in arbitrary order. Each user is equipped with a mobile terminal (e.g., cell phone or PDA) which can communicate with InfoBox via short range wireless communication such as Bluetooth. In addition, we assume that each mobile terminal has (1) digital map of the target area, (2) sufficient size of buffer for storing data, and (3) Bluetooth communication capability. Hereafter, we refer to users/terminals as *nodes*.

(3) Wireless Communication

In our communication model, communication happens only between an InfoBox and a mobile node (we do not consider the communication between mobile nodes or between InfoBoxes). An InfoBox and a node can exchange data while they are within the common Bluetooth radio range. We suppose a circle with radius 10m for the radio range.

(4) Statistics about Sightseeing Spots

In general, the travel plan (route of visiting spots in the target sightseeing area and stay time at each spot) is decided in advance by users before they arrive at the first spot. Also, the travel plans of all users are considered to follow several typical patterns.

According to the above discussion, we assume that there are several typical travel plans as shown in Table 1 and Fig. 2 and each user follows one of the plans.

We also assume that each InfoBox knows the statistics of popularity of the plans. Thus, we can calculate the probability of a user to move from one spot to another for any pairs of neighboring spots in advance, and the probability information is given to each InfoBox. Table 2 shows an example of the moving probability.

Moreover, we assume that the statistics of moving time between any two spots and the stay time at each spot are given to each InfoBox.

Table 1: Example of Typical Routes

Route
$1 \rightarrow 3 \rightarrow 6 \rightarrow 7 \rightarrow 5 \rightarrow 2 \rightarrow 1$
$1 \rightarrow 2 \rightarrow 5 \rightarrow 7 \rightarrow 6 \rightarrow 3 \rightarrow 1$
$1 \rightarrow 4 \rightarrow 2 \rightarrow 1$
$1 \rightarrow 4 \rightarrow 7 \rightarrow 5 \rightarrow 2 \rightarrow 1$
$1 \rightarrow 6 \rightarrow 7 \rightarrow 4 \rightarrow 1$
$1 \rightarrow 3 \rightarrow 6 \rightarrow 1$

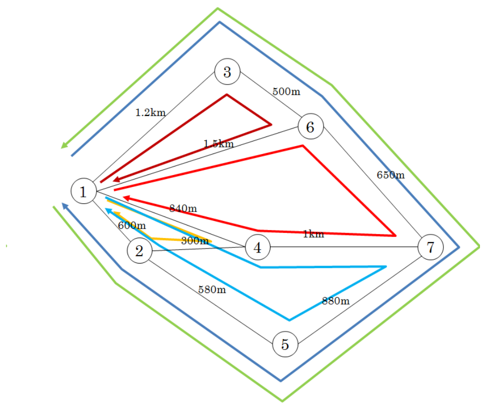

Figure 2: Graph of Typical Routes

4 User Satisfaction Based DTN Data Delivery

In this section, first we give our target problem and goal, then describe the details of our proposed method to achieve the goal.

4.1 Target Problem and Goal

As we mentioned in Sect. 1, in our target system, each user wants to receive some word-of-mouth information on sightseeing spots that the user will visit in the future. For this purpose, each user sends the following request to an InfoBox when they are in communication range each other.

$$(SRC, DEST, RL, Deadline, Satis, Size, Payload) \quad (1)$$

Here, SRC, $DEST$, and RL are the InfoBox ids where the request is sent, the requested information is stored, and the user wants to receive the response, respectively. $Deadline$ is the time when the user is expected to leave the radio range of InfoBox RL, and $Satis$ is the user's satisfaction degree if the user receives the response for this request[1]. $Size$ is the size of this message, and $Payload$ contains the query expression.

The response message is also constructed in the format of expression (1), where payload contains the information (arbitrary type of data such as text, photo, movie, etc) on spot $DEST$.

The goal of our proposed method is to design and develop a protocol between mobile nodes and InfoBoxes that enlarge the overall user satisfaction, under the assumptions given in Sect. 3.

4.2 Overview of Proposed Method

To achieve the goal, each request needs to be transferred from the source InfoBox SRC to the destination InfoBox $DEST$ and the response needs to be transferred from $DEST$ to RL. From assumptions in Sect. 3, only a means for data transfer is to replicate data (request/response) to user nodes.

[1]For fairness among users, we assume that each user is given the fixed points (e.g., 100) and can distribute the points among multiple requests.

Table 2: Example of Moving Probability between Spots

Sight view Spot	Box ID	Average stay time (minutes)	Neighboring Box ID	Moving probability
Kintetsu Nara station	1	60	2, 3, 4, 6	1/6, 1/3, 1/3, 1/6
Kofukuji Temple	2	60	1, 4, 5	3/4, 0, 1/4
Todaiji Temple	3	60	1, 6	1/3, 2/3
National museum	4	60	1, 2, 7	1/3, 1/3, 1/3
Ukimido	5	60	2, 7	2/3, 1/3
Nara park	6	60	1, 3, 7	1/4, 1/4, 1/2
Kasuga shrine	7	60	4, 5, 6	1/4, 1/2, 1/4

Our proposed method calculates the appropriate number of replicas for each request/response message based on the moving probability between spots given in Sect. 3. In order to consider the user satisfaction, we define *Expected Cost Performance* (hereafter, ECP) which is the value of the user satisfaction divided by the total size of packets for replicas. In our method, each InfoBox sorts the messages in the descending order of ECP so that the messages with higher ECP are sent earlier.

In order to deliver data within its deadline, in our proposed method, each InfoBox investigates if the response can reach the requesting user by the deadline. If it estimates that a message can not be delivered until the deadline, it discards the message.

We show how the proposed method works using an example. In Sightseeing of Nara as shown in Fig. 1, suppose that a mobile user at Kofukuji Temple (SRC in Fig. 1, Box ID 2 in Table 2) wants to receive some word-of-mouth information stored in Nara park ($DEST$ in Fig. 1, Box ID 6 in Table 2) during the sightseeing tour until the user leaves Todaiji Temple (RL in Fig. 1, Box ID 3 in Table 2). In this case, the user creates a request message which specifies the above locations in the format of equation (1).

If a node is carrying some messages and detects an InfoBox inside its Bluetooth wave range, it transfers the messages to the InfoBox. If the node receives from the InfoBox some messages that are the responses for the node, it shows them to the user. While a node does not find any InfoBox, it does not make any communication and it just moves.

When an InfoBox receives messages from a node, it calculates ECP of the messages from their $Satis$, $Size$, and the necessary number of replicas n (the calculation method will be explained in Sect. 4.3). Then, the messages are stored in the buffer of the InfoBox and the buffer entries are sorted in the descending order of ECP value. Whenever the InfoBox is going to send a message, it will estimate the arrival time of the message at the destination. If a request message is not likely delivered to the destination $DEST$, or a response message does not likely reach RL by $Deadline$, such a message will be removed instantly.

In the following subsections, we will describe the techniques to calculate the appropriate number of replicas and to estimate the message arrival time.

4.3 Estimating Number of Replicas

From the assumptions in Sect. 3, each InfoBox knows the moving probability between neighboring spots. To increase the message delivery ratio, the proposed method makes message replicas to the user nodes. However, an excessive replication causes a heavy network load, and the message delivery ratio may decrease due to packet collision.

From the moving probability, the InfoBox can calculate the appropriate number of replicas for each message to achieve an expected delivery ratio to the neighbor InfoBox. For example, in Table 2, if an InfoBox with id 1 ($Box1$) wants to send a request message to a neighboring box with id 2 ($Box2$) by an expected delivery ratio more than δ ($0 \leq \delta \leq 1$), the number of replicas n can be calculated by the following equation (2).

$$1 - (pMove(Box1, Box3) + pMove(Box1, Box4) + pMove(Box1, Box6))^n \geq \delta \tag{2}$$

Here, $pMove(Box_i, Box_j)$ represents the probability that a user at Box_i moves to Box_j. In Table 2, the moving probability from *Box1* to *Box3* is $1/3$ ($pMove(Box1, Box3) = 1/3$), from *Box1* to *Box4* is $1/3$ ($pMove(Box1, Box4) = 1/3$), from *Box1* to *Box6* is 1/6 ($pMove(Box1, Box6) = 1/6$). So, the sum ($1/3 + 1/3 + 1/6 = 5/6$) is the probability that a node does not go to *Box2*. The probability that n nodes at $Box1$ do not go to *Box2* is $(5/6)^n$. If we set $\delta = 0.8$, we can find the number of replicas $n = 9$ by equation (3). That means if the *Box1* copies a message to 9 nodes, the expected message arrival ratio at *Box2* will be 0.81.

$$1 - (\frac{5}{6})^n \geq 0.8 \tag{3}$$

The expected cost performance ECP of a message in a single hop delivery can be calculated by user satisfaction $Satis$, expected delivery ratio δ, data size $Size$, and the replication number n by the following equation (4).

$$ECP = \frac{Satis \times \delta}{Size \times n} \tag{4}$$

ECP shows the user satisfaction per byte. As shown in equation (4), a higher delivery ratio δ achieves a higher ECP.

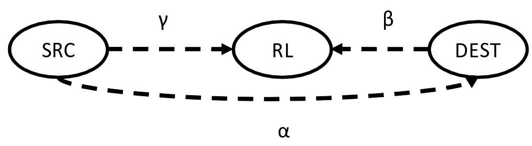

Figure 3: Estimation of Message Delivery Time

However, a higher δ also causes a larger number of replicas, which decreases the ECP as a result. Therefore, we need to find appropriate δ value which achieves the highest ECP.

Moreover, when a message is delivered through a multi-hop path (via multiple InfoBoxes), the delivery ratio at the destination will rapidly decrease depending on the number of hops. In this case, in order to keep the high delivery ratio, more replicas are needed. We show ECP formula for multi hop cases in equation (5), where δ_i and n_i ($1 \leq i \leq k$) mean the expected delivery ratio and the number of replicas at i-th InfoBox, respectively.

$$ECP = \frac{Satis \times (\delta_1 \times \delta_2 \times \cdots \times \delta_k)}{Size \times (n_1 + n_2 + \cdots + n_k)} \quad (5)$$

4.4 Estimating Message Arrival Time

4.4.1 Estimation of Deadline

For a request message posted at SRC, the requesting user wants to receive the response message until the user leaves the receiving location RL for the destination $DEST$.

Let γ denote the sum of the moving time from SRC to RL and the stay time at SRC and RL. Then the deadline will be set to γ.

The value of γ is easy to estimate from the statistics about the moving time between spots and the stay time at each spot, and is automatically assigned in the request message.

4.4.2 Estimation of Response Arrival Time

Let α denote the moving time of a user from location SRC to $DEST$. Let β denote the moving time of a user from location $DEST$ to RL. Since the data delivery between InfoBoxes are done by movement of users, the minimum required time $MinRepTime$ for a response message to reach the receiving location RL since the request message is sent at SRC is defined as the following equation.

$$MinRepTime = \alpha + \beta \quad (6)$$

Therefore, if a node wants to receive a response message until the user leaves RL for the next spot, the following condition must hold.

$$Deadline \geq MinRepTime \quad (7)$$

If $MinRepTime$ is larger than the deadline, this message cannot be delivered within the deadline. Thus such a message will be discarded at an InfoBox.

5 Performance Evaluation

To show the performance of the proposed method, we conducted simulation-based experiments. A sightseeing area around Nara Park in Nara, Japan (Fig. 1) was used as a simulation field.

5.1 Simulation Environment

We implemented a simulator using Java language. The simulation field is shown in Fig. 1, the simulation parameters in Table 3 and users' behavior model in Table 4.

Table 3: Simulation Parameters

wireless transmission radius	10m
transmission rate	1Mbps
sightseeing area	2.5km $\times$ 2.5km
response message size	100KB
request message size	1KB
simulation time	6hours

Table 4: Users' Behavior Model

walking speed	1m/s
walking path	one of routes in Fig. 2 and Table 1
probability to send a request at each spot	50 %
satisfaction	20 (50 %), 50 (25 %), 80 (25 %)

We used the following simulation scenario: one node appears near $BOX1$ (Kintetsu Nara station) every 60 seconds and moves to a neighboring sightseeing spot along one of the routes shown in Fig. 2 and Table 1. Once a node arrives at a sightseeing spot, it will stay there for a certain time shown in Table 2. During the stay time, we assume that a node can communicate with an InfoBox for some time period called $ContactTime$.

We assume that $ContactTime$ is a time that a node passes through the wireless transmission range of an InfoBox as shown in Fig. 4. The $ContactTime$ can be calculated by the following equation (8).

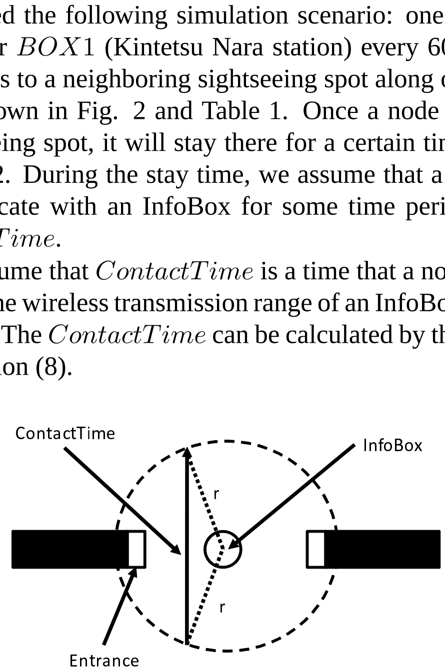

Figure 4: Contact Time

$$ContactTime = \frac{\text{wireless transmission radius} \times 2}{\text{walking speed}} \quad (8)$$

From the parameters in Table 3 and Table 4, the contact time is calculated to be about 20 seconds. We also consider that if a node passes through the transmission range of an InfoBox twice when arriving in and leaving from the spot, the total $ContactTime$ will be 40 seconds.

In our simulations, when each user passes through an InfoBox, the user sends a request by a 50% of probability as shown in Table 4.

5.2 Simulation Metrics and Comparison Methods

In order to evaluate the improvement of total user satisfaction and the effectiveness of the cost performance based delivery, we use the following metrics.

- Delivery ratio
- Expected Cost Performance (ECP)
- Total user satisfaction

To the best of our knowledge, since there are no DTN-based data delivery methods taking into account user satisfaction, we compared the following three conventional queuing methods with the proposed Expected Cost Performance (ECP) queuing method.

FIFO: messages are delivered in the order of their arrival.

deadline: messages are delivered in the increasing order of their deadline

satisfaction: messages are delivered in the descendant order of user satisfaction degrees.

In our simulations, for the sake of simplicity, we do not consider the difference in message size (1KB request message and 100KB response message).

5.3 Expected Delivery Ratio (δ) vs Delivery Ratio

In Fig. 5, we show the data delivery ratio when changing the expected delivery ratio δ. In all methods, the delivery ratio increases as we set a higher value to δ, although the highest delivery ratio reaches just around 0.45 even when δ is set to 0.95. The reason is that there is a large queuing delay in each InfoBox due to sporadic arrival of users. In other words, when a big size data (response) is transfered, the queuing delay will be large because of insufficient number of users arriving, thus the deadline for the data cannot be met. The proposed method achieves the highest delivery ratio, while the deadline method achieves the lowest. This is because in the deadline method, the messages are stored in the increasing order of deadline, and many messages with later deadline cannot meet the deadline while processing the earlier deadline messages.

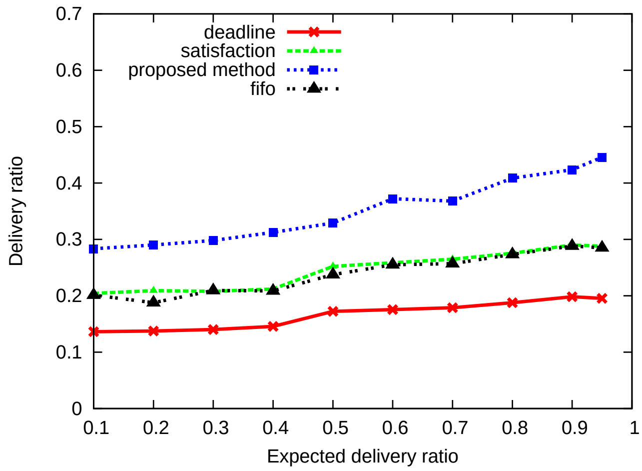

Figure 5: Expected Delivery Ratio (δ) vs. Delivery Ratio

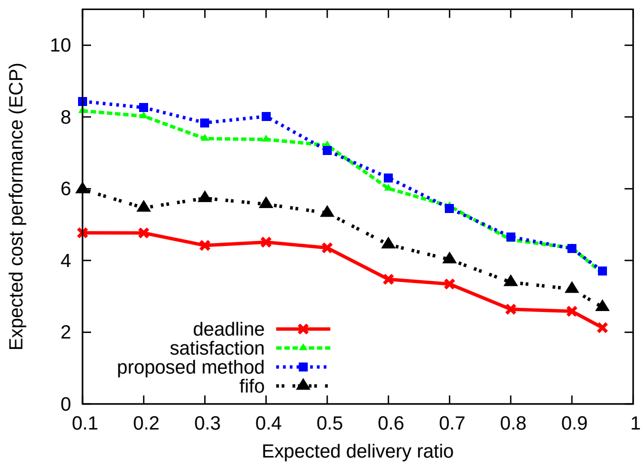

Figure 6: Expected Delivery Ratio δ vs. Expected Cost Performance ECP

5.4 Expected Delivery Ratio δ vs Expected Cost Performance ECP

Fig. 6 shows the expected cost performance (ECP) when changing the expected data delivery ratio δ. Here, we calculated ECP as the user satisfaction per packet. The figure shows that the proposed method and the satisfaction method achieve the highest ECP. In all methods, ECP value decreases as δ value increases. The reason is that higher δ creates more replicas (packets), thus the ECP value decreases.

5.5 Total User Satisfaction

Fig. 7 shows the total user satisfaction for different ECP values. In all methods, the total user satisfaction decreases as ECP value increases. This is because as the number of packets increases, the delivery ratio (and the total user satisfaction) increases but the ECP value decreases. However, the proposed method achieves the highest total user satisfaction

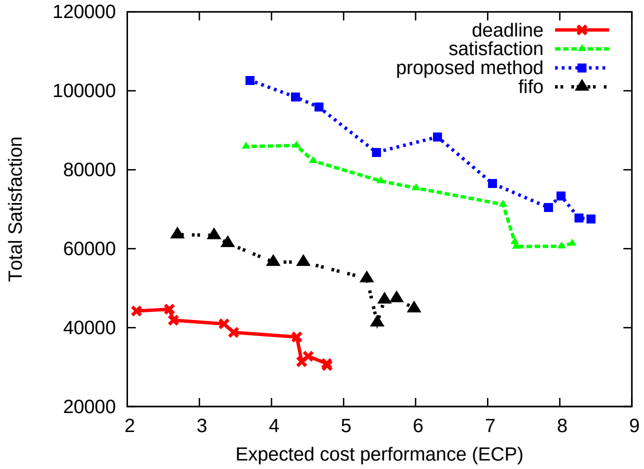

Figure 7: Expected Delivery Ratio δ vs. Total User Satisfaction

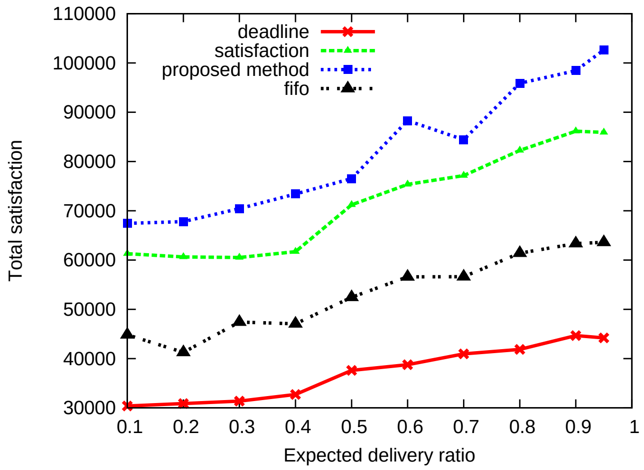

Figure 8: Variation of Total User Satisfaction

for any ECP value. This result shows that our ECP-based queuing technique is effective to achieve the satisfactory data delivery.

5.6 Total System Performance

Fig. 8 shows the total user satisfaction when changing the expected delivery ratio δ. The proposed method achieves the highest total user satisfaction for any δ value. The proposed method takes into account not only the user satisfaction degree of each message but also the deadline of the message delivery, so the data can be delivered at higher probability than the satisfaction method and the deadline method. The satisfaction method delivers the data in the descendant order of the user satisfaction degree attached to the messages, but it likely misses deadline of a large message (response) because it does not consider ECP value of the message.

6 Conclusion

In this paper, we proposed a new DTN-based data delivery method for efficiently exchanging word-of-mouth information in an area without communication infrastructure, that takes into account priority and deadline of the information. Through simulation study, we showed that our proposed technique based on user satisfaction per packet (ECP) can achieve the higher overall user satisfaction than other conventional methods.

As part of future work, we would like to compare the performance of the proposed method with other carry-and-forward based techniques such as Epidemic routing and evaluate our method in a real environment.

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