A Consideration on Evaluation of Epidemic Information Sharing by Multiple UAVs

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Abstract: In epidemic communication, mobile nodes carry information, and send it to other node by direct wireless communication while moving. In this paper, we consider information sharing by epidemic communication as disaster communication, and we use a unmanned aerial vehicle (UAV) as a message carrier in a communication between shelters. A UAV travels along the predetermined route and exchanges the information when it arrives at a shelter. After information exchange, the UAV leaves the shelter and heads for the next shelter. The UAV must charge its battery in the shelters with charging equipments before their battery is empty. In this paper, we consider the several cases of information sharing between two UAVs at the common shelter. We evaluate the performance of the information sharing by UAVs by computer simulation.

Keywords-- **Epidemic transmission, UAV, Information sharing**

1. Introduction

Epidemic communication [1] can distribute information over the area by direct wireless communication between mobile nodes and movement of the mobile nodes having the information. Epidemic communication is an effective way for information sharing between the shelters at disaster situations [1]-[4]. Some articles proposed to use special vehicles as mobile terminals for epidemic communication during the time of disaster [2] [3]. Ref. [3] assumed that people do not often travel between shelters because of the disaster; however, some vehicles transporting relief goods travel shelters. In [3], the vehicles transporting relief goods are used as communication nodes for epidemic communication to deliver information to shelters. Ref. [2] assumed that special mobile nodes called message ferries move around the area, and proposed message ferrying scheme which exploits controlled mobility to transport data in delay tolerant networks. In [2], the use of multiple ferries was considered, and all ferries are controlled to exchange information with other ferries at certain places at certain times. So, this system is assumed to calculate the route and schedule of ferries in advance, and data exchanges between ferries are completely controlled.

In this paper, we consider the information sharing between the shelters using unmanned aerial vehicle (UAV) instead of vehicles transporting relief goods in [3]. A UAV is an aircraft without a human pilot aboard, and applications of UAVs to disaster situations are considered. In this paper, we assume that a UAV has a small electric motor and a battery. So, a UAV must charge its battery frequently before the battery becomes empty because limitation of battery life. Assume that a UAV travels along a route consisting of some shelters and some UAV travel different routes independently. These different routes include common shelters. A UAV must charge its battery at the shelter that has a charging equipment before the battery becomes empty. A UAV needs some time to fully charge its battery; therefore, the UAV may meet other UAVs at the charging place even without controlled scheduling necessary for the ferries in [2]. Then, by repeating such a traveling and charging, UAVs may exchange information while charging and spread it in an epidemic manner without scheduling. Such a distributed manner for information spreading is effective in the cases where preplanning of scheduling is difficult due to disasters. Hence, we consider information sharing between shelters using a UAV in the distributed manner.

In this paper, we consider epidemic information sharing between shelters by multiple UAVs. We assume that each UAV travels without knowing the routes and activities each other. Each UAV moves between shelters along its own route and receive information from the shelters. During a visit to a shelter with charging equipment, a UAV charges its battery. If the UAV meets other UAVs at the shelter while charging, these UAVs exchange information. We evaluate such a distributed method for shelters to share information by computer simulation. Furthermore, we evaluate effects of an additional waiting time to a charging time to improve performance of information sharing considering the trade-off between sharing performance and delay of arrival of information. We compare some methods in these evaluations.

2. System model and assumptions

Figure 1 shows distribution of shelters in the disaster area. As shown in Figure 1, all shelters exist randomly in the disaster area, and there are two types of shelters; the shelter that has charging equipment and the shelter without charging equipment. A UAV must charge its battery in the shelters with charging equipment before its battery becomes empty. Assume that each UAV preplans the route which it can travel reachable shelters by own flight capability and travels shelters along own route for information sharing. Some UAV travel different routes independently. These different routes include common shelters. We assume that each UAV travels without knowing the routes and activities each other.

If a UAV meets another UAV at the shelter while charging, these UAVs can exchange information. We assume that routes of UAVs include common shelters. Then, each UAV can exchange information each other when they arrive at common shelters in the same time. In this paper, we assume that the number of common shelters is 1 and this common shelter is named S. Furthermore, we assume an additional waiting time to a charging time. We expect that this assumption causes improvement of performance of information sharing because each UAV stay longer at S. In this paper, we consider three methods for information sharing as follows:

Method 1: Each UAV travels own routes independently.
Method 2: Each UAV waits until other UAV arrive at S in order to exchange information if the UAV cannot exchange information while charging.
Method 3: Assume that S has a relay node for information exchange. Using this relay node, each UAV can exchange information indirectly.

3. The methods for information sharing

In this paper, as a performance metric of information sharing, we use average time interval between information exchanges at S and average elapsed time of information after finishing collecting. In this section, we analyze these metric of three methods.

In this paper, we use two UAVs as message carriers for information sharing between shelters. One is named x_1 and another is named x_2. Assuming that the route of x_1 and x_2 is given, originally each route of UAVs is a complicated route as shown in Figure 1. In this paper, for simplification of analysis, we model Figure 2 by replacing complicated routes by the simple route with weight which is calculated by travel time and charging time. x_1 and x_2 leave the S simultaneously at the time 0, and travel along each own route. x_1 and x_2 can charge simultaneously at the S. When x_1 and x_2 are charging at S in one unit time, they can exchange information.

At first, t_i denote interval between time when x_i leave S and time when x_i arrive at S. t_i is decided by traveling time between shelters and charging time at some shelters. C denotes a staying time of x_i that means sum of a charging time and an additional waiting time at S. T_i denotes time interval between departure time of x_i from S and departure time in next cycle. Then, $T_i = t_i + C$. So, T_i means the total time that x_i require in one circuit traveling. In this paper, for simplification, we assume that t_i and C are a positive whole number. d denotes least common multiple of T_1 and T_2.

3. 1 Method 1

In order to exchange information at S, x_1 and x_2 must charge one and more unit time simultaniously. Let us consider x_1 which is finished traveling for m cycles. Then, x_1 arrives at S at the time $mT_1 - C$, and leaves S at the time mT_1. Next, let us consider x_2 which is finished traveling for n cycles. Then, x_2 arrives at S at the time $nT_2 - C$, and leaves S at the time nT_2. So, x_1 and x_2 can exchange information if m and n are satisfy the Equation (1).

$$\max\{ mT_1 - C, nT_2 - C \} + 1 \leq \min\{ mT_1, nT_2 \} \tag{1}$$

In this situation, information exchange time is $\max\{ mT_1 - C, nT_2 - C \} + 1$. Then, both UAVs arrive at S at the same time because it is same that time when x_1 finished traveling for d / T_1 cycles and time when x_2 finished traveling for d / T_2 cycles. Therefore, we confirm which all set of (m, n) will satisfy Eq. (1) for all $1 \leq m \leq d / T_1$ and $1 \leq n \leq d / T_2$. Let h denote the number of set of (m, n) which is satisfied on Eq. (1), then average time interval can be calculated by d / h.

3. 2 Method 2

In Method 2, a UAV which arrived at S earlier wait until other UAV arrives if the UAV cannot exchange information while charging. Suppose that $t_1 < t_2$. Then, when t_1 is passed, x_1 arrives at S before x_2. In this situation, x_1 must wait until x_2 arrives at S in order to exchange information of x_2. In this case, x_1 leaves S at the time $t_2 + 1$ because x_1 exchanges the information of x_2 in the same time when x_2 arrives at S. On the other hand, x_2 leaves when $C - 1$ passed after x_1 leaves. So, both average time intervals between information exchanges at S are T_2 because such situation of information exchange is repeated after m cycles. Average elapsed time of x_2 is $(C - 1 + t_2) - t_1 = T_2 - t_1 - 1$. On the other hand, average elapsed time of x_1 is 0 because x_1 can load information of x_2 just after x_2's arrival at S. This is advantage of the method 2.

3. 3 Method 3

In Method 3, S has a relay node for information sharing, and the relay node keeps information of UAV temporarily. When a UAV arrives at S, the UAV begins to charge. Then, during the charging, the UAV begins store own information and load information of other UAV. Namely, UAV can exchange information using the relay node indirectly. It takes one unit time to store and load information.

At first, we consider an average elapsed time. Let us consider x_1 which is finished traveling for m cycles. Then, x_1 leaves S at the time mT_1. Next, let us consider x_2 which is finished traveling for n cycles. Then, x_2 stores information at the time $nT_2 - C$. So, x_1 can load n-th information of x_2 if m and n are satisfy the Equation (2).

$$mT_1 - 1 \geq nT_2 - C \tag{2}$$

Here, if x_2 arrive at S while x_1 is charging, elapsed time of x_1 is 0. Contrarily, if x_2 does not arrive at S while x_1 is charging, elapsed time of x_1 is $(mT_1 - C) - (nT_2 - C) = mT_1 - nT_2$. So, we can obtain elapsed time of x_1 which is finished traveling for m $(1 \leq m \leq d)$ cycles. Therefore, we can calculate average elapsed time of x_1. Similarly, average elapsed time of x_2 is obtained in the same way of x_1. Further, average time interval is obtained using computer simulation.

4. Numerical results and discussions

In this section, we show the numerical results for three methods. At first, we show the performance in Method 1 when $t_1 = 10$ and $t_2 = 20, 30, 40, 50$. Figures 3 and 4 show the numerical results of average time interval and average elapsed time, respectively. From Figure 3, average time interval decreases as C increases. This is because the influence of a gap of round trip becomes smaller when charging time of both UAVs becomes longer as C increases. However, in the case of some combination of the value of t_2 and C, average time interval increases as C increases in construct. This is because total amount of round trip increase as C increases. Also, it is considered that the value of d and the value of h changes immediately as C increases. From Figure 4, average elapsed time is almost 0 when C is small. But value in some case is more than 0 when C is large. This is because UAV stays at S for a long time as C increases.

Next, we show the performance in Method 2 when t_1 = 10 and t_2 = 20, 30, 40, 50. Figures 5 and 6 show the numerical results of average time interval and average elapsed time, respectively. From Figure 5, average time interval increases as C increases. This is because the average time interval is T_2. From Figure 6, average elapsed time increase as C increase. It is considered that because one round trip increases because T_2 increase.

Next, we show the performance in Method 3 when t_1 = 10 and t_2 = 20, 30, 40, 50. Figures 5 and 6 show the numerical results of average time interval and average elapsed time, respectively. From Figure 7, both average time intervals between information exchanges at S are T_2. Average time interval of x_1 is T_2 because information of x_2 is stored with a period T_2. On the other hand, x_2 can only load information of x_1 with own period T_2 even if information of x_1 is stored frequently. From Figure 8, average elapsed time increases as t_2 increases, and average elapsed time decreases as C increases. However, in the case of some combination of the value of t_2 and C, average time interval increases as C increases in construct. This is considered that the difference between the time when x_1 load information of x_2 and the time when x_2 stores information immediately as C increase.

Finally, Figure 9 shows average elapsed time of each UAV in Methods 2 and 3 when t_2 = 20, 50. From these results, the average elapsed time of x_2 in Method 3 is less than in Method 2 without depending on a value of t_2. On the other hand, in Method 3, we can see that average elapsed time of x_1 when t_2 = 20 and 50 is about 10 and 20, respectively. In Method 2, average elapsed time of x_1 when t_2 = 20 and 50 are always 0. Furthermore, we can also see that average elapsed time of x_1 in Method 3 is less than average elapsed time of x_2 in Method 2. So, when a relay node is set at S, average elapsed time in system will be improved generally. However, average elapsed time of x_1 in Method 3 increases as compared with Method 2. Consequently, we can confirm that all values do not necessarily improve even if a relay node is set at S.

5. Conclusions

In this paper, we consider epidemic information sharing between the shelters using two UAVs that travel along different routes. In the epidemic information sharing, we consider the several cases of information sharing that a UAV contacts another UAV at a common shelter that is included in both of the two routes of UAVs, and evaluate the performance of information sharing using UAV in such cases by computer simulation. From results, we confirmed effects of an additional waiting time to a charging time on performance of information sharing. Then, we also confirmed that all values do not necessarily improve even if a relay node is set at common shelter. Future work will focus on the evaluation of the proposed method in other network model that the number of UAV is more than 2.

This work was partially supported by Grant-in-Aid for Scientific Research (25420360, 16K06344, 24246068).

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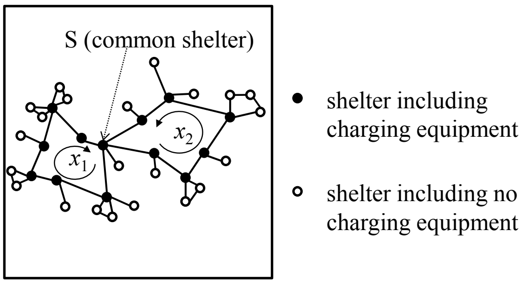

Figure 1 distribution of shelters in the disaster area.

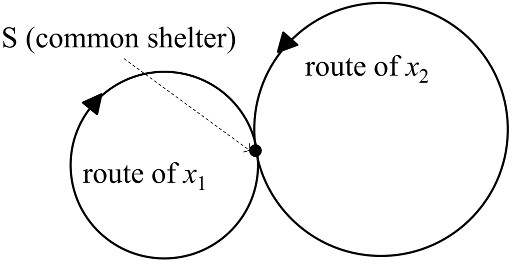

Figure 2 Netowrk model.

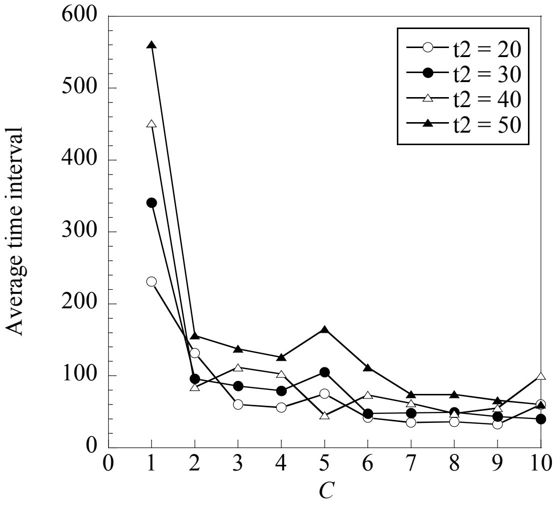

Figure 3 Average time interval in Method 1.

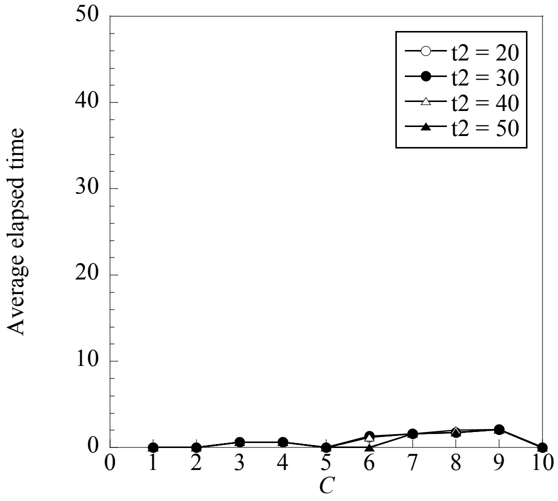

Figure 4 Average elapsed time in Method 1.

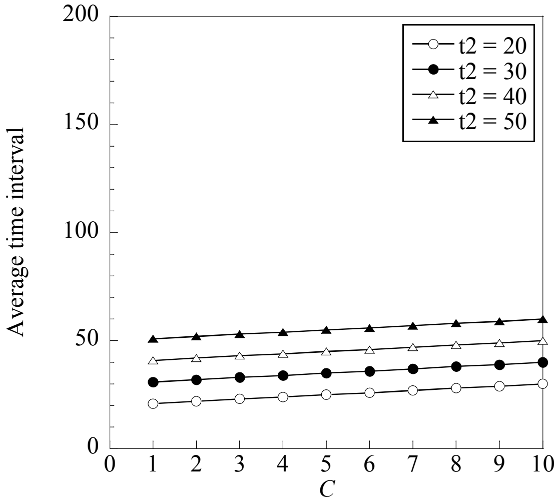

Figure 5 Average time interval in Method 2.

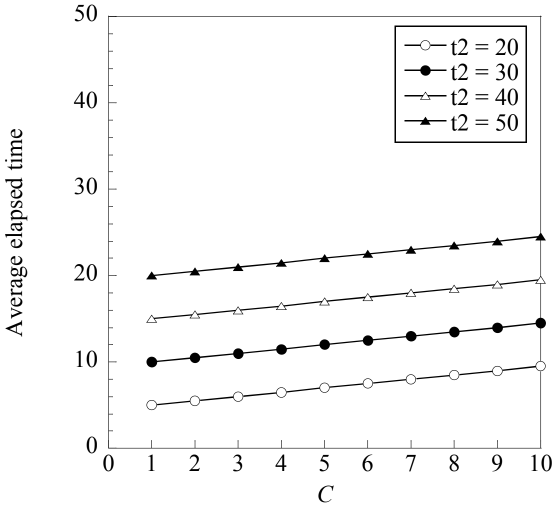

Figure 6 Average elapsed time in Method 2.

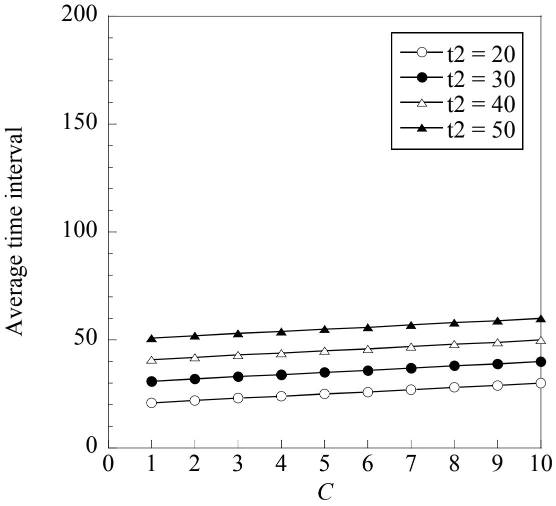

Figure 7 Average time interval in Method 3.

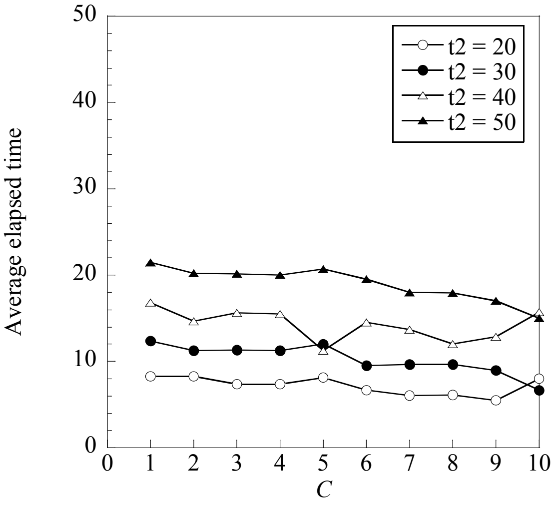

Figure 8 Average elapsed time in Method 3.

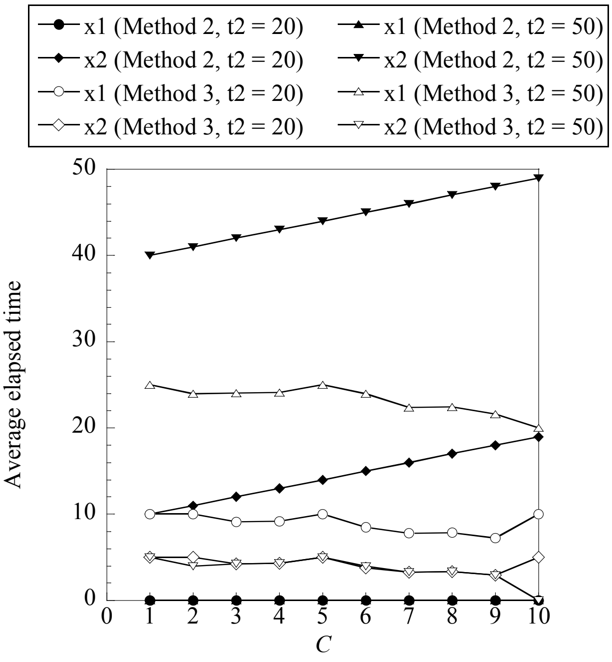

Figure 9 Average elapsed time in Methods 2 and 3.