

# 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 simultaneously. 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).

$$\max\{mT_1 - C, nT_2 - C\} + 1 \leq \min\{mT_1, nT_2\} \quad (1)$$

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).

$$mT_1 - 1 \geq nT_2 - C \quad (2)$$

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.

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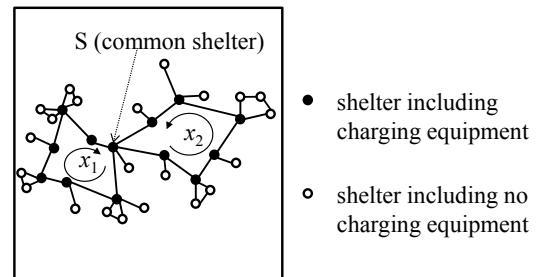


Figure 1 distribution of shelters in the disaster area.

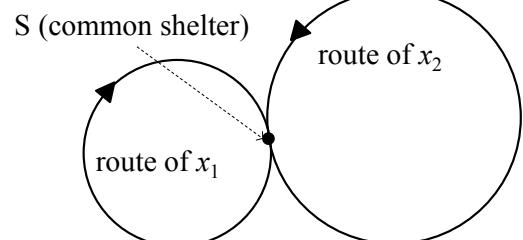


Figure 2 Netowrk model.

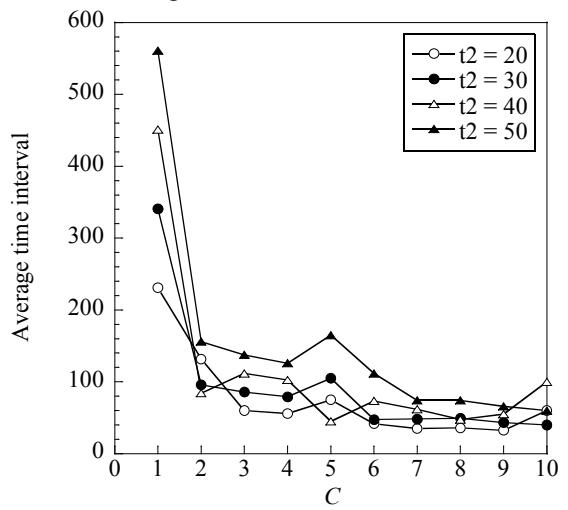


Figure 3 Average time interval in Method 1.

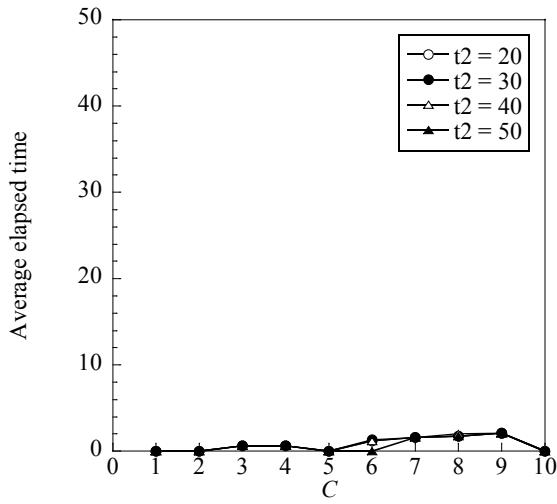


Figure 4 Average elapsed time in Method 1.

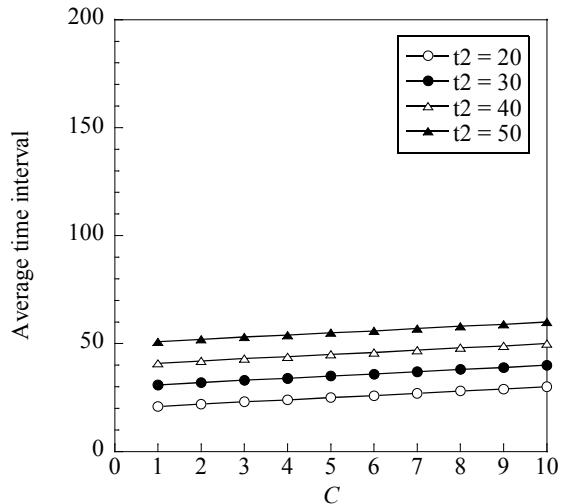


Figure 7 Average time interval in Method 3.

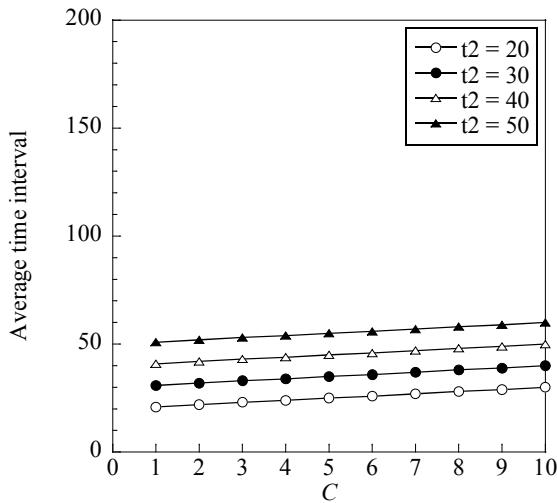


Figure 5 Average time interval in Method 2.

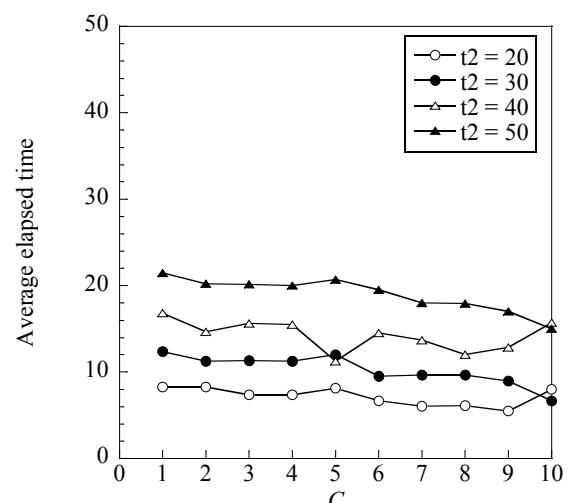


Figure 8 Average elapsed time in Method 3.

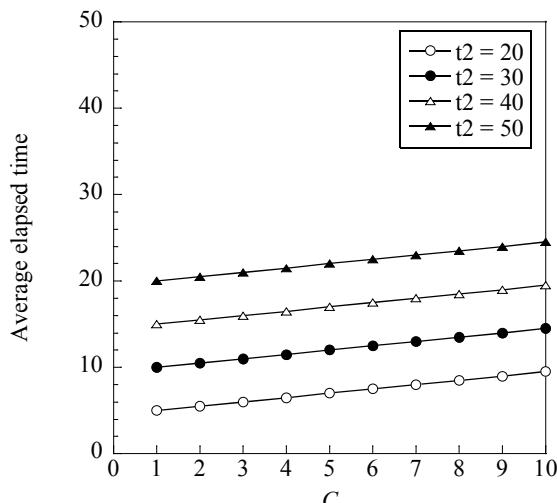


Figure 6 Average elapsed time in Method 2.

● x1 (Method 2, t2 = 20)	▲ x1 (Method 2, t2 = 50)
● x2 (Method 2, t2 = 20)	▼ x2 (Method 2, t2 = 50)
○ x1 (Method 3, t2 = 20)	△ x1 (Method 3, t2 = 50)
◇ x2 (Method 3, t2 = 20)	▽ x2 (Method 3, t2 = 50)

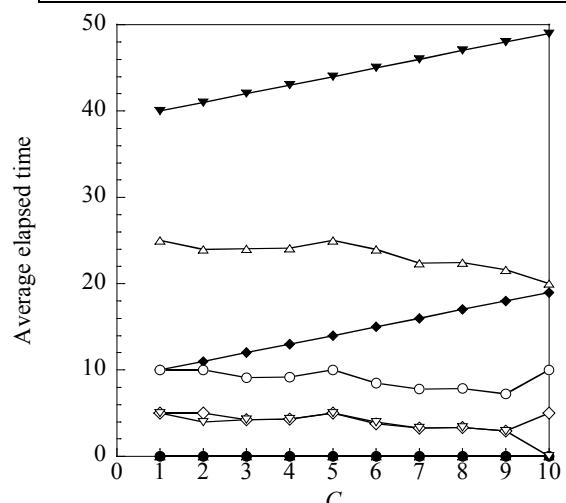


Figure 9 Average elapsed time in Methods 2 and 3.