The effect of region-based message selective delivery strategy on post-disaster emergency network

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Abstract. Stricken areas are shut off from the world, as large-scale infrastructures (e.g. bridges, roads and power equipments) have been destroyed after earthquakes, floods, and other disasters. Large-scale and cross-regional communication in the disaster area is difficult to achieve due to the harsh communication environment, such as unstable communication links and limited network resources, especially for remote isolated areas. Delay tolerant networks (DTNs) use the way of a “store-carry-forward” to transfer messages, which is suitable for the large transmission delay and intermittent link communication. In this paper, the DTNs based on regional center node and Unmanned Aerial Vehicle (UAV) is proposed to build the post-disaster emergency communication network. Further, a region-based message selective delivery routing policy is proposed for the emergency communication network. The received messages are classified according to its destination address at the regional center node and the UAV ferry node. In this way, the data packets can be accurately delivered to the corresponding area, and redundant data packets will be reduced in the network. The effect of the routing policy on network performance is evaluated. Simulation results show that the policy can effectively improve the data delivery rate, reduce the overhead ratio and significantly reduce the transmission delay.

1. Introduction
After the disaster, large-scale infrastructure such as bridges, roads, and electrical equipment were destroyed. It is difficult to effectively repair damaged roads, bridges and power equipment in a short time. Stricken areas may be shut off from the world. How to quickly establish an effective emergency communication network after the disaster is a problem worth studying. Delay tolerant networks (DTNs) uses the way of a "store-carry-forward" to transfer messages, which is suitable for communication environment with large transmission delay and intermittent link. DTN is considered as one of the effective communication way to establish an emergency communication network. It plays an important role in disaster relief, post-disaster reconstruction and other fields [1-3].

People’s movement between regions are limited due to infrastructure damage. The distribution and movement of the affected people show a certain regularity [4, 5]. Their activities are centered on a safe area such as evacuation shelter, community center and hospital. Building DTN emergency communication network based on portable terminal equipment, emergency communication vehicles and UAVs is one of the effective means to achieve large-scale and cross-regional communication after
a disaster. Shibata et al. [4] proposed to use portable mobile terminal to set up post-disaster DTN for data transmission, and use emergency communication vehicles as ferry nodes to realize message transmission between the evacuation shelter and the disaster-response headquarter. Saha et al. [5] proposed a DTN urban disaster relief communication system based on ferry nodes. The system analyzed that people would gather in several disjoint safe areas after a fire. An effective post-disaster DTN emergency network can be established by the crowd and the wireless emergency communication vehicle as a ferry node. However, there are some problems with data collection difficulties and poor forwarding efficiency for randomly moving nodes. Throw boxes, as an auxiliary communication device, can play an important role in data collection and data forwarding in the network [6, 7]. Gupta et al. [7] proposed a post-disaster DTN communication network, which use throw boxes as communication relay node between mobile node and ferry node to achieve efficient transmission of messages. However, there is still a problem of excessive data transmission delay.

This paper focuses on improving the data delivery rate and transmission delay of integrated UAV based DTN after the disaster. A routing policy with selective delivery function is proposed. A throw box with large buffer capacity is placed in the crowd gathering point as a fixed regional center node to increase the contact opportunities of mobile nodes in the local area and stabilize the communication between ferry nodes and mobile nodes. The data packets are classified according to the destination address by the regional center node and the ferry node to implement accurate delivery of the message packet for a specific area.

The rest of the paper is organized as follows: System models are given in section 2. In section 3, a routing policy for post-disaster DTNs is proposed. The simulation results and performance analysis are presented in section 4. Finally, section 5 concludes this paper.

2. System model

In the post-disaster rescue process, safe places such as community centers, hospitals, schools are set up as shelters and disaster-response headquarter for victims (Figure 1). The destruction of infrastructure causes some areas to be cut off from others. In those isolated areas, people usually take a safe place as the center for activities. The UAVs can travel between the shelters and the disaster-response headquarter to achieve large-scale data collection and transmission after disaster.

![Figure 1. Post-disaster information delivery System](image1)

An effective emergency communication network can be constructed to connect damaged areas (Figure 2). Portable mobile terminals as mobile nodes can establish DTN in each local area. The UAV regularly cruises the areas to achieve message transfer between the areas. In order to ensure the stability of message delivery between ferry node and the mobile nodes, a fixed regional center node is set in a place where people gather in each area to store and forward messages. The regional center node can interact with UAV ferry node to implement inter-regional data transfer. The ferry node only
needs to cruise the regional center nodes of each area without considering the movement and communication status of the ordinary mobile nodes in the area.

The DTN in the local area is composed of three different types of nodes, i.e., the ordinary mobile node, the regional center node, and the ferry node (e.g., UAV). Regional center node can collect and forward the intra-regional data, and interact with the UAV ferry node to achieve cross-regional data transmission.

We assume that there are \( m \) local regions in the entire disaster area, each of local region consists of 0 to \( n \) mobile nodes. The disaster area can be expressed as

\[
C = \{ C_i(j) | C_i(j) \in C_i, 1 \leq i \leq m, 0 \leq j < n \}
\]

where \( i \) indicates the area number, and \( j \) indicates the node number. \( C_i(j) \) represents the \( j \)-th node in the \( i \)-th region. \( C_i(0) \) is regional center node in the \( i \)-th local area.

The set of ferry nodes is expressed as

\[
f = \{ F_i | F_i \in f, 1 \leq x \leq k \}
\]

where \( x \) indicates the ferry node number, and its value ranges from 1 to \( k \).

3. Message selective delivery routing policy

3.1 Message Packet Classification

Message packets are classified by destination address. Each regional center node adds the node ID to a name list of the local nodes when it encounter the mobile node in the local area. By using this name list, the regional center node can divide the received message packets into intra-regional packets and inter-regional packets, and determine whether the message packet is an inter-regional message packet that needs to be forwarded to the ferry node.

Ferry node communicates with the regional center node to get the name list of nodes in the current region. The data packets stored by ferry node are also classified according to the destination address, which are divided into data packages of area 1, data packages of area 2, data packages of area N, and so on. When ferry node cruises to a regional center node, only data packets belonging to this area are forwarded to the regional center node. Then the packets will be sent to the destination node through the regional center node.

3.2 Selective Message Packets Switching Routing Policy

In order to improve the transfer efficiency and reduce the data transfer overhead, we propose a selective packets switching routing policy (SPSRP).

Table 1. Selective message packets switching process

| Process of SPSRP between the ferry node and the regional center node |
|---------------------------------------------------------------|
| 1. Ferry node arrives at the location of a regional center node \( C_i(0) \), and asks the regional center node for the area identification number and the name list of local nodes; |
| 2. The regional center node \( C_i(0) \) sends the area identification number \( x \) and a name list of local nodes to the ferry node; |
| 3. The ferry node updates the node list of the area \( x \) and reclassifies the stored data packets, and then sends the packets belonging to area \( x \) to the regional center node \( C_i(0) \); |
| 4. \( C_i(0) \) receives the data packets, it uploads inter-regional packets to the ferry node; |
| 5. The ferry node classifies and stores the received data packets according to the destination address; |
| 6. The ferry node moves to the next area; |
| 7. Repeat steps 1 to 6. |

When the ferry node cruises to a regional center node, a selective packet switching process is executed as shown in Table 1. The SPSRP is based on the classification of the message packets by the
ferry node and the regional center node. When the ferry node arrives at a regional center node, it first queries the area identification number and the local node name list of the area. According to those information, ferry node reclassifies the stored message packets, and sends the packets belonging to the current area to the regional center node. The regional center node also uploads inter-regional messages to the ferry node. After receiving the data packet uploaded by the regional central node, the ferry node will cruise the next area to implement inter-regional data transmission.

4. Simulation results

In this paper, the ONE (The Opportunistic Network Environment) simulation tool is used to simulate the post-disaster scenario of Yushu Jiegu Town (Figure 3) where a magnitude 7.1 earthquake occurred on April 14, 2010. The performance of the SPSRP is evaluated by comparing Epidemic routing protocol with a center point-based routing policy (CRP).

![Figure 3. Yushu Jiegu Town map used in simulation](image)

In the simulation, we selected five safe areas such as schools, hospitals and community centers as the shelters and the disaster-response headquarter. Mobile nodes in each area are taken activities by using Cluster Movement model. The UAV cruises the regional center nodes of each area on a fixed path by using MapRoute Movement model to achieve communication between remote areas. After UAV arrives at the regional center node, it take a random residence time from 0 to 300 s to complete the data transmission between regional center node and ferry node and to implement the necessary energy supplement including replacement of UAV batteries. In addition, the regional center node has two wireless communication interfaces: Bluetooth and WiFi. In order to reduce the energy consumption of mobile node, Bluetooth is used as the communication mode between ordinary nodes, and WiFi with larger coverage radius is used as the communication mode between ferry node and the regional center node. Simulation parameters are listed in Table 2 and 3. The performance is evaluated by three respective metrics defined as follow:

Data Delivery Ratio: \[ P_d = \frac{N_{de}}{N_c} \] (3)

Overhead Ratio: \[ P_{overhead} = \frac{N_{cope} - N_{de}}{N_{de}} \] (4)

Delivery Delay: \[ D_{avg} = \frac{T_{de}}{N_{de}} \] (5)
where $N_s$, $N_c$, $N_{cp}$, and $T_p$ represent the number of successfully delivered messages, the number of created messages, the number of relayed messages, and the sum of the delays of the all delivered messages, respectively.

Table 2. System simulation parameters

| Parameter                          | Values          |
|------------------------------------|-----------------|
| The simulation time (h)            | 24              |
| Range of simulation area (m²)      | 1600 × 1800     |
| Radius of each local area (m)      | 150             |
| Number of mobile nodes in each local area | 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 |
| Number of fixed nodes in each local area | 1              |
| Mobile node residence time (s)     | 0 to 30         |
| Number of ferry nodes              | 1               |
| Ferry node residence time (s)      | 0 to 300        |
| Packet size (KBytes)               | 50 to 1024      |
| TTL (h)                            | 24              |
| Packet generation interval (s)     | 25 to 120       |

Table 3. Simulation parameters for various types of nodes

| Parameter                          | Values          |
|------------------------------------|-----------------|
| Parameter                          | Mobile node     | Center node | Ferry node |
| Movement speed (m/s)               | 0.5 to 1.5      | 0           | 10 to 20   |
| Link capacity (Mbps) (Bluetooth)   | 2               | 2, 18       | 18         |
| Radius of the coverage area (m)    | 10              | 10, 40      | 40         |
| Buffer size (MB)                   | 50              | 1000        | 1000       |

Figure 4. The results of the Delivery Ratio, the Overhead Ratio and the Average Delay of intra-regional data transmission are shown in (a), (b) and (c).
The data delivery ratios of the three routing policies for intra-regional data transmission are more than 90% (Figure 4(a)), the delivery ratio of SPSRP is the best among these three. With the increase of the number of nodes, the overhead ratios of the three routing policies have clear upward trend (Figure 4(b)). There is little difference between the overhead ratios of CRP and ER (Epidemic Routing). Due to the increased message packet selective delivery function at the regional center node and the ferry node, the SPSRP overhead ratio is significantly lower than that of the ER and CRP, which is less than half of them. The intra-regional transmission delay of SPSRP is slightly better than ER and CRP (Figure 4(c)).

Figure 5. The results of the Delivery Ratio, the Overhead Ratio and the Average Delay of inter-regional data transmission are shown in (a), (b) and (c).

Figure 6. The results of the Delivery Ratio, the Overhead Ratio and the Average Delay under integrated network environment are shown in (a), (b) and (c).

The data delivery ratios of inter-regional data transmission of CRP and SPSRP are about 80%, which is significantly higher than ER (Figure 5(a)). This is because the added regional center node can
collect and store the inter-area data packets and send them to the ferry node, which improves the data delivery ratio. With the increase of the number of nodes, the overhead ratios of the three routing policies have obvious upward trend (Figure 5(b)). The overhead ratio of SPSRP is better than that of ER and CRP. The average overhead ratio of SPSRP is about 70% of ER and about 80% of CRP. As the regional center node collects and forwards inter-regional data packets, the forwarding efficiency of the data packet is improved. The average delays of SPSRP and CRP are greatly reduced compared with ER (Figure 5(c)), which are only about 30% of ER.

Under the integrated network environment, SPSRP is better than ER and CRP in terms of data delivery ratio, overhead ratio and average transmission delay (Figure 6). Since the regional center node stores and forwards data packets, the data delivery ratios of SPSRP and CRP are both above 80%, and the data delivery ratio of SPSRP is close to 90% (Figure 6(a)). The overhead ratio is lower than that of ER and CRP due to the introduction of the selective packet switch processing step, which is about 75% of CRP and 67% of ER. (Figure 6(b)). The average delay of SPSRP is slightly lower than that of CRP, and is significantly lower than that of ER, which is about 35% of ER (Figure 6(c)).

5. Conclusion
In this paper, a region-based message selective delivery routing policy is proposed for the emergency DTN communication network. And further more, the effect of the routing policy on network performance is evaluated. A high-performance node, which has a large buffer capacity and can communicate with UAV ferry nodes, is proposed as the regional center node. The regional center node can divide the received message packets into intra-area and inter-area packets, and only transmits the inter-area packets to the ferry node. The ferry node classifies the received message packets by its destination address and transmits the packets to the corresponding area to reduce redundant message packets in the network. The simulation results show that the proposed routing policy can improve the performance of the post-disaster DTNs which effectively improve the data delivery rate, reduce the overhead ratio and achieve lower transmission delay.

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