A Catastrophic Intensity-based Rescue Mobility Model for Earthquake Emergency Rescue Scenario

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***Abstract* — Rescuers have to build Disaster Area Wireless Networks (DAWNs) for communication in earthquake disaster scene as the communication infrastructure may be completely destroyed by the earthquake. This paper uses MANET (Mobile Ad Hoc Network) as the network architecture of DAWNs in order to adapt with the mobility of rescuers. According to the seriousness in different disaster areas, we propose the catastrophic intensity-based rescue mobility model (CIBRMM), which includes Opening Lifeline Stage (OLS) and Spreading Rescue Stage (SRS). In addition, we present rescue time calculating formulas in corresponding to the two stages as well as the trends of catastrophic intensity in different disaster relief areas. Simulation results show that under the CIBRMM, the most affected areas by earthquake can be reached as soon as possible, thus greatly reducing the loss of life and property, shortening rescue time and improving the efficiency of the rescue.**

Keywords - DAWNs; MANET; CIBRMM; OLS; SRS

I. INTRODUCTION

With the development of technology, public security is increasingly relying on the pre-deployed communication infrastructure. However, after man-made or natural disasters such as earthquakes, fires, floods, etc., the communication infrastructure may be partly or completely destroyed. People in these areas cannot communicate with their families, friends or relatives either because of the damage of communication infrastructure or the congestion of networks. While first responders need to communicate and exchange data through networks in disaster areas in order to build the bridge between the front and back. The damage of communication links impacts on the process of disaster relief as well as the duration of disaster, thus threating the lives and property of the affected refugees. The Wenchuan Earthquake of 2008 hit a wide area of Sichuan Province in China. Most social infrastructures, such as transportation, electric power, gas, water, and telecommunication services, suffered serious damages due to the tremor and succeeding disasters, which isolated the inhabitants of the disaster-affected areas from the rest of the world. For quite a long time, the outside cannot get any information in the disaster areas. The aftermath of the event raised serious concerns that require urgent consideration and resolution, especially in the communication and transportation areas. First responders have to establish disaster area wireless networks (DAWNs)in real time to accomplish rescue tasks until the fixed communication infrastructure becomes available.

With the characteristics of easy deployment, easy access and no wires [1], wireless is a promising solution for setting up temporary communication networks in emergency situations. Before deploying DAWNs, following aspects should be considered. Firstly, DAWNs can be rapidly deployed as substitution of destroyed communication infrastructure. Secondly, both fixed nodes and mobile nodes are used in DAWNs in order to adapt to the earthquake disaster scenario. Also, such combination satisfies the demands of effectiveness. Thirdly, unlike traditional wired and wireless networks, the topology of DAWNs changes frequently as mobile nodes usually change their positions. Thus, high transmission delay is needed in such frequently changed networks to avoid low data transmission rate [2].

In this paper, we mainly fulfill two tasks: Firstly, we design DAWN topology that suitable for earthquake emergency rescue scenario. Secondly, we propose catastrophic intensity-based rescue mobility model (CIBRMM) based on the DAWN we designed.

The rest of this paper is organized as follows. In Section 2, related works on Ad-hoc networks, disaster area networks as well as mobility models in disaster are presented. In Section 3, we first propose network structure in earthquake emergency rescue scenario, then we formulate mobility problem for rescuers. Section 4 describes mobility model in earthquake emergency rescue scenario, followed by simulations and results analysis in section 5. Finally section 6 concludes this paper.

II. RELATED WORKS

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts if possible. True-Type

1 or Open Type fonts are preferred. Please embed symbol fonts, as well, for math, etc.

In recent years, many scholars put great effort on Ad-hoc networks and mobility models. Synchronous communication is assumed in MANET for simplicity, while synchronous data transmission between source and target nodes cannot be guaranteed in reality. To cope with such problems, a distributed adaptive opportunistic routing schemefor multi-hop wireless ad hoc networks is proposed in [3]. In [4], authors discussed extreme situation of internet access and put forward a novel mobility model to adapt to the delay tolerant networks (DTNs). Although this model is important in DTNs, it leads to excessive dispersion, greatly reduces the data delivery rate. In [5], authors improved this model and enhance the data delivery rate. Pocket Switch Network (PSN) was proposed in [6]. It was one kind of opportunistic routing networks and was constructed by portable devices. The topology and performance were determined by mobility of people. This paper concentrated on the context of conference, took into account of storage, CPU performance, bandwidth and energy constraints of portable devices. In [7, 8], authors analyzed VANET-based Intelligent Traffic Control System. In this system, vehicles can communicate with each other as well as with the fixed nodes on roadside. Such system can provide reliable and instant information, paths selection, assistant decision for drivers without energy constrains, thus ensuring driving safety. However, nodes density changes constantly due to various vehicle speeds, which greatly affects communication between nodes. There are many researches [9-14] focusing on mobility models and routing protocols. In [9-13], authors introduced existing routing protocols for MANET and the problems in future networks. Considering more actual factors such as mobile and connected models, network traffic, node characteristics, etc., authors in [14] analyzed the significance of evaluation of mobility models and routing protocols.

All papers [3-14] motioned above discussed mobility models and Ad-hoc network protocols under normal circumstances rather than special scenes (e.g. in disaster areas). An overview of data transfer and mobility models in disaster areas was proposed in [15]. Authors also introduced application software and networks in emergency scenario. In [16], authors propose a hybrid model that considered the human movement, group mobility and obstacles. This model made combinations of Levy model, RPGM model and Voronoi model. All models mentioned in [15, 16] were based on theoretical research, while a novel mobility model in disaster scenario was proposed in [17], basing on a large catastrophe maneuver that took place in May 2005 in Cologne, Germany. Authors gave three factors influencing DAWN performance: 1, heterogeneous area-based movement; 2,movement on optimal paths avoiding obstacles; 3,nodes join and leave the scenario. Unfortunately, this model was simple as it was restricted in a small disaster area. Fixed nodes placement problems were not considered either. Analyzing unreasonable assumption of traditional mobility model in disaster areas, authors in [1, 18] proposed Disaster Area Mobility Model (DAMM) and solved relay nodes placement (RNP) problems. However, the two pieces of articles considered communications only between fixed nodes rather than mobile nodes, so increasing of fixed nodes is inevitable.

III. Network Structure AND Problem Formulation

After catastrophic disasters, reliable communications are needed by civil protection forces, such as troops, fire brigades, rescue teams, etc. Before building the DAWN, we should analysis the nodes mobility. The DAWN serves all nodes within its scale, but nodes positions change frequently for requirements of relieving missions, so the structure of DAWN has to change accordingly. Traditional assumption is made that mobile nodes are connected to the backbone network all the time. However, such assumption does not always apply in reality as rescue teams are moving further away from the access point, they risk losing connection with the backbone network. Considering all possible factors in earthquake scenarios, we design rescuers mobility model, based on which DAWN is built as is shown in Fig.1.

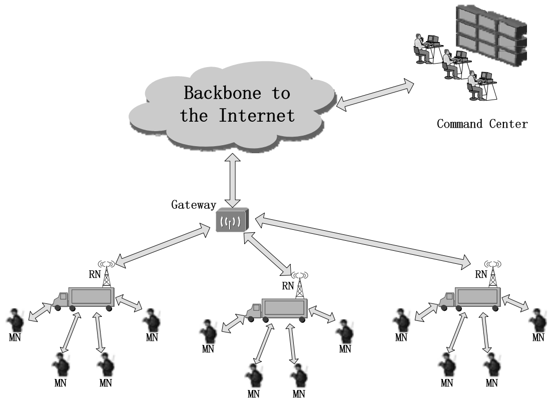

Figure 1. DAWN topology.

In Fig.1, MN stands for rescuer who carries portable devices that can communicate with each other as well as RN. RN stands for fixed node that can communicate with command center with backbone network.

After an earthquake, catastrophic intensity (CI) value is used to show how serious severe the disaster situation is in that area. The larger the CI value is, the more time and rescuers are required. The shape of seismic intensity is generally oval in near field, while it gradually changes to circle as in far field. In this paper, we only consider the impact of the earthquake in the near field and propose a novel mobility model for rescuers. Notations used in this paper are listed in Table I.

Before the establishment of mobility model, we make the following assumptions.

Assumption 1: CI values are equal in the same seismic intensity area.

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TABLE I. PARAMETERS DEFINITIONS

Parameters	Definitions
t	Time counter to record the current time
CI_i	Catastrophic intensity value in the i*th* area. This value is proportional to seismic intensity
$CI_{t,i_{m,n}}$	CI value of squares in Row m, Line n of the i*th* intensity square at time t
$MN_{t,i_{m,n}}$	Mobile nodes in Row m, Line n of the i*th* intensity square at time t
a_i	The major axis of the i*th* ellipse
b_i	The minor axis of the i*th* ellipse
s_{a_i,b_i}	Square of rectangular with length a_i and width b_i
Δs_i	s_{a_i,b_i}-$s_{a_{i-1},b_{i-1}}$
M	Midpoint of length.
T_1	Time required for rescuers moving from point M to boundary of Δs_1
T_2	Time required for rescuers spreading from Δs_1 to Δs_n
T	Total time required for relieving whole disaster areas
C_{MN}	Number of mobile nodes
C	Max numbers of mobile nodes that each fixed node can be accessed in
RN	Fixed nodes
MN	Mobile nodes
ε	How much CI value one MN can reduce in one unit of time
a	Length of single busy square in grid model
R	Transmission range of RNs
CS	Cleaned square
BS	Busy squares
RW	Raw squares

Assumption 2: The CI value in area which outside the boundary of affected area is zero.

Assumption 3: The major and minor axes of ellipse are far longer than the side length of each divided square.

Assumption 4: The mobility model for responders in BS areas is RWP (Random Way Point) [19].

Assumption 5:For simulation, we assume that ellipse with major axis ai and minor axis bi can be substituted by rectangular with length ai and width bi, as is shown in Fig.2.

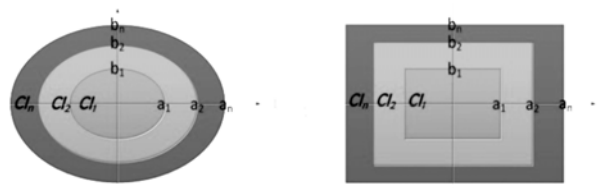

Figure 2. Ellipse is approximately substituted by rectangular.

We take ellipse which centrals in the focus of the earthquake as area that needs relief. The major and minor axes are ai and bi (i=1…n) respectively. After a real earthquake, we assume that elliptic intensity region cause by earthquake can be substituted by rectangular and CI values are equal in the same intensity region.

With the determinations of CI values and numbers of first responders, this paper discusses mobility model of responders to achieve the optimal rescue results: The most affected areas should be relieved first and whole rescue process should cost as short time as possible.

IV. MOBILITY MODEL IN EARTHQUAKE EMERGENCY RESCUE SCENARIO

We adopt the grid models that proposed in [1, 18] for earthquake emergency rescue scenario as is shown in Fig.3. In this model, squares with head portraits denote busy squares. White squares denote cleared squares. Shaded squares denote un-cleared squares. We assign corresponding CI values to all squares in order to calculate the degree of catastrophic intensity.

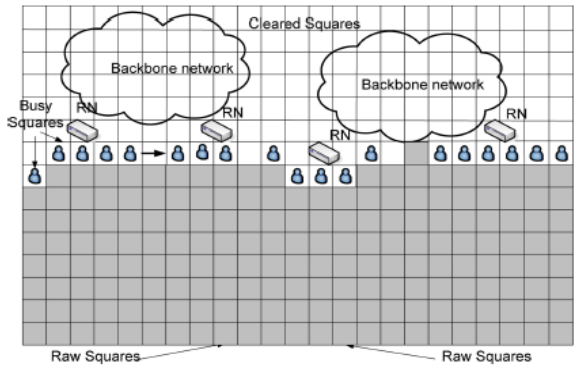

Figure 3. Grid-based disaster areas.

Faced with a mission of relieving a large scale disaster area, first responders ought to start from a few squares on the boundary of the disaster area. In this section, we put forward the catastrophic intensity-based rescue mobility model (CIBRMM) to achieve the optimal rescue results that presented in the end of section 3. The mobility model is shown in Fig.4.

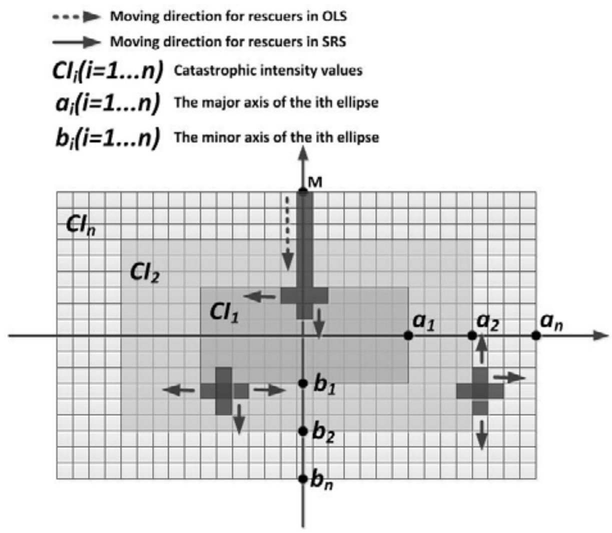

Figure 4. CIBRMM for rescuers.

Definition: Taking the origin of coordinates as the center, the rectangular area is s_{a_i,b_i}($1\leq i\leq n$), Δs_i=s_{a_i,b_i}-$s_{a_{i-1},b_{i-1}}$,specially, $a_0=b_0=0$,$s_{a_0,b_0}=0$,so Δs_1= s_{a_1,b_1}.Obviously, the severely afflicted areas can be reached as soon as possible if responders start their works from the midpoint of length to the focus area. Rescuers move from the midpoint M of rectangular to the focus area Δs_1 directly. Then, rescuers move downward, leftward or rightward under the mobility model presented in [1, 18] to fulfill their tasks. When rescuers meet the boundary of Δs_1 or CS area, they change to any other directions except boundaries of Δs_1 or the way they come here. Rescuers do their works directly if their following destination is RS area. They joined together with other rescue teams if their following destination is BS area. All rescue teams repeat this process until area Δs_1 is cleared. We assume that all rescue teams converged at the point X of area Δs_1. Then rescue teams repeat above process in area Δs_2 until this area is cleared. In the end, all affected areas are cleared. The procedure is shown in Fig.5.

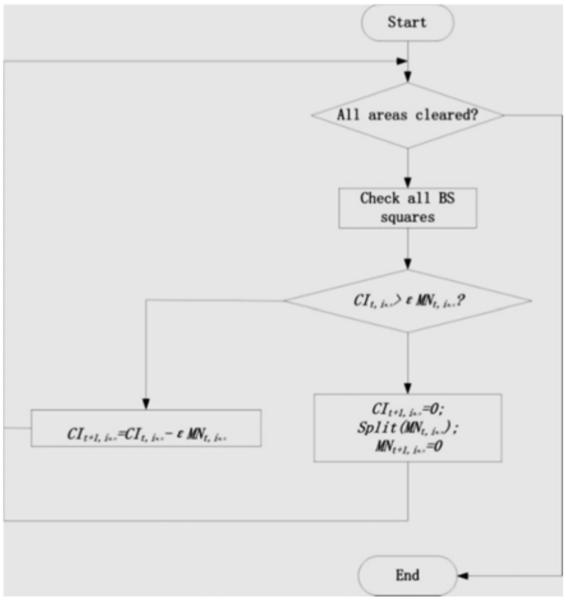

Figure 5. Trends of CI values in each affected squares.

It can be seen from the CIBRMM that the whole rescue procedure can be divided into two stages. We call the first stage Opening Lifeline Stage (OLS), in which responders move from midpoint M to focus area Δs_1. It takes time T_1 to fulfill all tasks. We call the second stage Spreading Rescue Stage (SRS), which takes time T_2 to fulfill all tasks. Thus, it will take time $T(T=T_1+T_2)$ to fulfill all tasks affected in disaster areas.

$$T_1 = \sum_{i=1}^{n-1} \frac{CI_{i+1}}{\varepsilon \cdot C_{MN}} \cdot \frac{a_{i+1}-a_i}{a} \tag{1}$$

$$T_2 = \sum_{i=1}^{n} \frac{\Delta s_i}{a^2} \cdot \frac{CI_i}{\varepsilon \cdot C_{MN}} \tag{2}$$

$$T = \sum_{i=1}^{n-1} \frac{CI_{i+1}}{\varepsilon \cdot C_{MN}} \cdot \frac{a_{i+1}-a_i}{a} + \sum_{i=1}^{n} \frac{\Delta s_i}{a^2} \cdot \frac{CI_i}{\varepsilon \cdot C_{MN}} \tag{3}$$

Fig.5 shows CI value trends of each disaster area in the whole rescue process. In SRS, responders check CI values of adjacent areas after relief of current areas. Without loss of generality, they probably move upward, downward, leftward or rightward. However, responders have to fulfill all tasks in one RW area before moving to the next, so the CI value should be zero in one of the four adjacent areas. Thus, responders can move to three other directions only. Also, we should take into account two particular cases. Firstly, rescuers cannot move to the area in which CI value equals zero. Secondly, rescuers cannot move outside boundary of current area before all areas with the same seismic intensity cleared. CIBRMM algorithm is shown in Table II.

TABLE II. CIBRMM ALGORITHM

D=0; // counter initialization
$F_l=F_r=F_u=F_d=0$; // adjacent *CI* value initialization
IF ($CI_{t,i_{m-1,n}}\neq 0$) {F_u=1,D++;} //calculation for adjacent *CI* value, counter and *CI* value reset
END IF
IF ($CI_{t,i_{m+1,n}}\neq 0$) {F_d=1,D++;}
END IF
IF ($CI_{t,i_{m,n-1}}\neq 0$) {F_l=1,D++;}
END IF
IF ($CI_{t,i_{m,n+1}}\neq 0$) {F_r=1,D++;}
END IF
IF (F_u=1) $MN_{t+1,i_{m-1,n}}=MN_{t,i_{m-1,n}}+MN_{t,i_{m,n}}$/D; //determination for moving direction according to adjacent *CI* value
END IF
IF (F_d=1) $MN_{t+1,i_{m+1,n}}=MN_{t,i_{m+1,n}}+MN_{t,i_{m,n}}$/D;
END IF
IF (F_l=1) $MN_{t+1,i_{m,n-1}}=MN_{t,i_{m,n-1}}+MN_{t,i_{m,n}}$/D;
END IF
IF (F_r=1) $MN_{t+1,i_{m,n+1}}=MN_{t,i_{m,n+1}}+MN_{t,i_{m,n}}$/D;
END IF
IF ($F_l=F_r=F_u=F_d=0$) MoveRandom($MN_{t,i_{m,n}}$); //Random moving if all adjacent *CI* values are zero
END IF
RETURN($MN_{t+1,i_{m-1,n}}$, $MN_{t+1,i_{m+1,n}}$, $MN_{t+1,i_{m,n-1}}$, $MN_{t+1,i_{m,n+1}}$)

V. SIMULATIONS AND RESULTS ANALYSIS

We carried out simulation experiments through MATLAB to evaluate the performance of the proposed mobility model. We compared CIBRMM with traditional mobility model (TMM) which was presented in [1, 18]. Parameters are listed in Table 3.

TABLE III. PARAMETERS USED IN SIMULATIONS

Parameters Descriptions	Values
Number of mobile nodes	100
Dimensions	20×20
CI_1	30
CI_2	20
CI_3	10
Time needed for one responder to reduce one unit of CI	1

Fig.6 shows the earthquake scenario we assumed in our experiments.

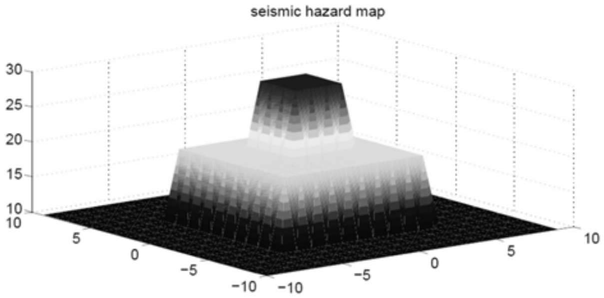

Figure 6. Earthquake simulation scenario.

A. Relationship analysis between rescue time and numbers of severely afflicted areas

After an earthquake, the focus areas suffer the most. First responders should save lives as soon as possible in these areas as were shown in Fig.6 with CI1. The rescue efficiency is inversely proportional to the rescue time. Fig.7 shows relationship between rescue time and numbers of severely afflicted areas.

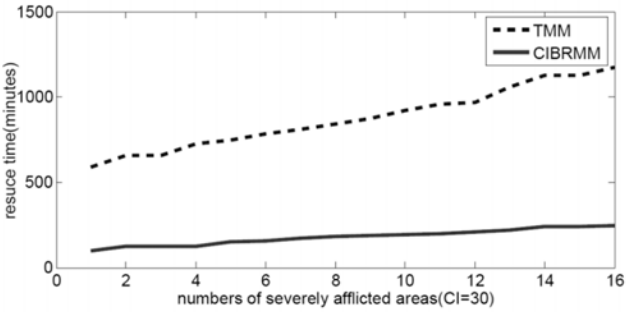

Figure 7. Relationship between rescue time and numbers of severely afflicted areas.

In Fig.7, rescue time needed for TMM is more than that needed for CIBRMM in severely afflicted areas. That is because under TMM, rescuers start their tasks from the least afflicted areas step by step, while under CIBRMM, rescuers move directly to the severely afflicted areas by opening lifeline, then they spread within these areas until all severely afflicted areas are cleared. Rescue time is increasing with the increasing numbers of the severely afflicted areas under both mobility models, which is in line with the actual rescue process, as rescue time increases with the increasing number of disaster areas.

B. Relationship analysis between rescue time and numbers of affected areas

Fig.8 shows relationship between rescue time and numbers of affected areas.

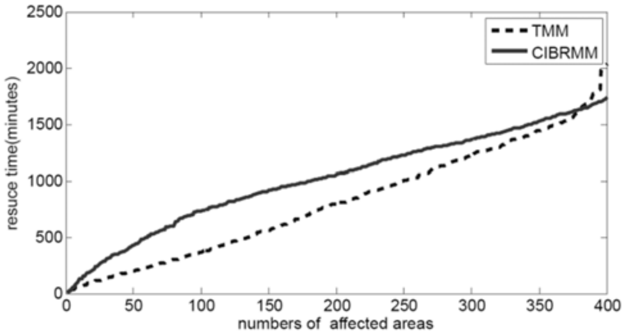

Figure 8. Relationship between rescue time and numbers of affected areas.

We can see from Fig.8 that rescue time increases with increasing number of affected areas under both mobility models. Rescue time needed for TMM is less than that needed for CIBRMM before 380 squares are cleared. That is because under the same rescue efficiency, responders start their work from areas with small CI value in TMM, while in CIBRMM, responders head to areas with big CI value. When the number of squares is over 380, rescue time needed for CIBRMM is a little less than that needed for TMM. That is because the mass motion of responders in the late CIBRMM makes rescue time shorter, while the scattered motion of responders in the late TMM makes rescue time longer.

C. Relationship analysis between rescue time and CI value

Fig.9 shows relationship between rescue time and CI value.

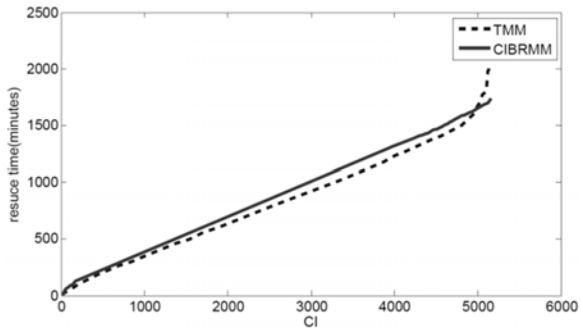

Figure 9. Relationship between rescue time and CI value.

From Fig. 9 we can see that with the increase of CI value, rescue time is approximately increasing linearly under both models. Rescue time under CIBRMM is a little longer than that under TMM. This is because rescuers mainly start their tasks from the harder-hit areas, so it may take much time for them to get these areas cleaned. When CI value reaches 5000, rescue time under TMM exceeds that under CIBRMM, this is in accordance with the results in Fig. 8 as in the relatively concentrated mobility under CIBRMM decreases rescue time.

VI. Conclusions and Future Works

In this paper, we study the network topology as well as the mobility model in earthquake emergency rescue scenario. Firstly, we designed DAWN topology especially for earthquake scenarios. Secondly, we proposed a novel mobility model CIBRMM for rescuers in order to shorten rescue time in severely afflicted areas. We gave the algorithm for CIBRMM; meanwhile, we presented formulas to calculate rescue time in each rescue stage. Following such mobility model, more lives can be saved after an earthquake. We set earthquake scenario simulation to evaluate the performance of CIBRMM. We compared CIBRMM with TMM and results showed that rescue time needed for CIBRMM is less than that needed for TMM in severely afflicted areas. Although responders spent a little more time in CIBRMM, it is worthwhile for saving lives. We merely proposed a novel mobility model in this paper without considering routing protocols used during rescue process. Future efforts in this field and direction will be our tasks.

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