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# Trajectory-Based Anycast Routing Protocol with MDRUs Assistance in Disaster Response Network

Zhijie Fan[1], Yueheng Liu[2], Mansi Zhang[1], Yue Cao[1*], Yinglong He[3], Kezhi Wang[4]
[1]School of Cyber Science and Engineering, Wuhan University, China. yue.cao@whu.edu.cn
[2] Wuhan Cyber Security Association, China. liuyueheng@whcsa.org.cn
[3] School of Mechanical Engineering Sciences, University of Surrey, UK. yinglong.he@surrey.ac.uk
[4] Computer Science, Brunel University, UK. kezhi.wang@brunel.ac.uk

***Abstract*—Modern rescue operations rely on wireless communications for safety reporting, area monitoring, and rescue coordination. However, natural disasters severely damage ground infrastructure, creating significant challenges for emergency rescue and recovery efforts. This paper establishes a disaster response network using Movable and Deployable Resource Units (MDRUs) in disaster-affected areas, to provide timely and reliable message transmission services. Firstly, to ensure a timely and efficient disaster response, we design a post-disaster emergency vehicle network architecture. Secondly, we propose a three-phase emergency relief model to dynamically deploy MDRUs, aiming to maximize their service coverage. Finally, we propose a Trajectory-Based Anycast Routing (TBAR) protocol, which enhances message transmission efficiency by optimizing route selection. Specifically, by facilitating the flexibility of anycast in delivering messages to any one of the reachable MDRUs, TBAR utilizes multiple copies of messages to reduce end-to-end latency and increase the delivery ratio. Moreover, TBAR adaptively evaluates the message delivery capability of candidate vehicles using a multi-attribute decision-making algorithm, considering link quality, trajectory similarity, and distance cost. Extensive simulation results show that TBAR significantly outperforms other baseline algorithms in multiple aspects.**

***Index Terms*—Disaster Response Network, Anycasting, MDRU, Trajectory-Based, Vehicular Ad-hoc Network (VANET).**

## I. Introduction

During natural disasters or emergencies, sudden and widespread breakdown of the terrestrial communication infrastructure can have significant impacts. This disruption hampers rescue coordination, delays aid delivery, and impedes communication among emergency responders. In disaster-affected areas, Base Stations (BSs) are likely to be partially or completely disabled due to physical damage and power disruption. This indicates that disaster-affected areas often lack the necessary communication facilities, severely impacting emergency response and rescue operations.

Movable and Deployable Resource Unit (MDRU) [1] is a vehicle resource unit equipped with wireless communication devices, satellite communication terminals, and power supply equipment. It is designed to provide reliable communication when network infrastructure is destroyed in disaster scenarios. It can operate on battery for more than 5 days and is easily deployed in disaster areas. Therefore, a disaster response network can be established quickly and efficiently by MDRUs.

Work [2] deployed MDRUs in disaster areas to restore communication within a Wireless Mesh Network (WMN), but WMN often lacks self-organization and adaptability to environmental changes. To improve flexibility, work [3] proposed a disaster response network combining MDRUs with user equipment. However, MDRUs have a limited communication range of about 500 meters. To expand coverage, work [4] proposed a disaster-resilient framework for heterogeneous vehicular networks, which mounts MDRUs on buses and integrates a resilient mesh network with traditional networks.

Designing an effective routing for emergency messages in the Vehicular Ad-hoc Network (VANET) is challenging. Generally, due to the random mobility of vehicles, messages may not be delivered to their destinations within Time-To-Live (TTL). Although several studies rely on geographic information, such as location and movement direction [5], [6], they often neglect complex and dynamic network topology. Additionally, relying solely on node mobility for message forwarding can cause local optimization issues. In VANETs, emergency message dissemination primarily relies on broadcast or unicast, but broadcasting can cause storms, congestion, and bandwidth consumption, while frequent topology changes hinder stable unicast transmission. Thus, achieving low-latency, high-delivery transmission remains challenging.

Motivated by above research gap, we design a disaster response network, and propose a trajectory-based anycast routing protocol for emergency message dissemination. The main contributions can be summarized as follows:

- Previous work on disaster response networks deployed MDRUs statically, unable to adapt to the dynamic changes in disaster areas. To provide timely and reliable communication, we utilize MDRUs as mobile BSs and expand communication coverage via VANET. Additionally, we propose a three-phase emergency relief model to dynamically deploy MDRUs, meeting the specific communication requirements of different relief phases.
- Considering the vehicle state and message forwarding direction, we propose a Trajectory-Based Anycast Routing (TBAR) protocol. TBAR employs a trajectory-based approach to control message forwarding direction, reducing the hops of messages. Additionally, compared to traditional broadcasting and unicasting, anycasting significantly reduces end-to-end latency while maintaining a high transmission rate.

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## II. Related Work

### A. MDRU-based Network Architecture

Most MDRU-based architectures are designed to rebuild networks after a disaster. Zhou et al. [7] reconstructed the post-disaster network by deploying MDRUs and relay units at the edge. To study the wireless access control problem in edge-aided disaster response networks, they proposed a learning-based wireless access control method for edge disaster response networks. Safety confirmation is an important application of disaster-resilient networking based on MDRUs. However, in a network with multiple MDRUs, the image search time for safety confirmation can increase due to the distributed image database and network capacity limitations. Ngo et al. [8] proposed a method to ensure minimal search time for users in the safety confirmation process. The above studies have utilized MDRUs to establish disaster response networks, however, their deployment is static. Moreover, their research primarily focuses on access control and security confirmation, without examining routing strategies.

### B. Emergency Message Routing

Researchers have proposed various solutions to enhance the efficiency and reliability of emergency message dissemination. Ullah et al. [6] proposed a reliable relay selection approach for Emergency Message Routing in Intermittently Connected Networks (EMR-ICN). EMR-ICN utilized location prediction and various mobility metrics to select relay vehicles, ensuring a stable routing path. Liu et al. [9] proposed a novel Temporary Warning Network (TWN) for secure message dissemination in urban traffic environments. Specifically, TWN was constructed through relay vehicle selection based on spatio-temporal correlations of vehicle trajectories, enabling rapid dissemination of safety messages within Regions of Interest (RoIs). To maintain TWN during incidents, a reselection mechanism was also proposed, the system allows newly arriving vehicles in the RoI to receive messages promptly. However, both methods suffer from high overhead due to frequent relay operations.

## III. System Model

### A. Network Architecture

The post-disaster emergency vehicle network architecture is shown in Fig. 1, it consists of two main components, i.e., MDRUs and vehicles. They are equipped with wireless communication devices, which enable them to communicate with each other. In addition, other facilities such as aerial platform and Emergency Response Center (ERC) are involved.

**MDRUs:** MDRUs serve as temporary BSs, connecting the aerial platform to VANET and enabling mobile communication during critical incidents. MDRUs provide signal transmission for rescuers and survivors while caching vital information. Through VANET links, MDRUs send navigation as well as dispatch decisions to rescuers and vehicles.

**Vehicles:** The primary role of vehicles is to collect disaster information, store and forward messages. Using sensors and communication equipment, they collect emergency information about disaster areas and road damage conditions, forwarding it to other vehicles or MDRUs via the TBAR protocol.

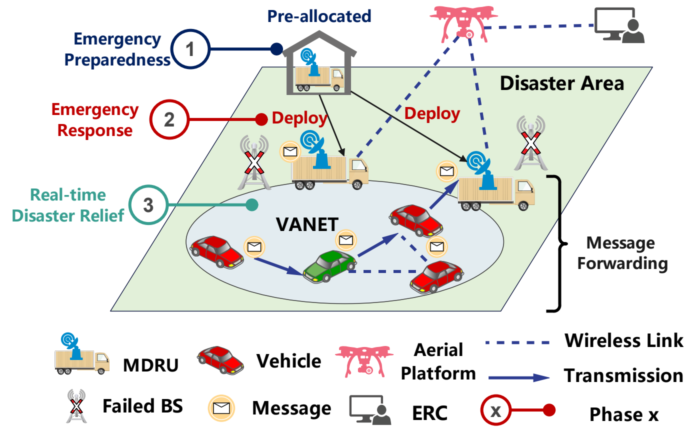


Fig. 1: Network architecture.

**Aerial Platform:** The aerial platform, composed of unmanned aerial vehicles, provides aerial views, collects real-time messages from disaster areas, and acts as a relay to transmit messages between MDRUs and ERC.

**ERC:** ERC handles the deployment and control of the disaster response network, aggregates and processes messages from disaster areas, as well as sends control messages to the aerial platform and VANET.

### B. Three-phase Emergency Relief Model

When a disaster occurs, the aerial platform first detects the situation and transmits emergency information to ERC, which then deploys MDRUs to restore communication. The emergency relief model consists of the following three phases:

**Emergency Preparedness Phase.** Using historical damage information and disaster forecasts, the government's emergency response department predicts the regional risk index and pre-allocates MDRUs to regional ERCs.

**Emergency Response Phase.** After the disaster, extensive damage to BSs disrupts message transmission, delaying emergency communications. During this phase, MDRUs are deployed near the damaged BSs to restore communication quickly. TBAR routes emergency messages efficiently through the deployed MDRUs, ensuring rapid and reliable message dissemination in affected areas.

**Real-time Disaster Relief Phase.** Based on the disaster messages from the emergency response phase, the ERC evaluates the situation. Then, ERC uses the Particle Swarm Optimization (PSO) algorithm to optimize MDRU deployment according to the actual conditions. Meanwhile, the TBAR protocol continues to be used for routing emergency messages, enhancing network coverage and transmission efficiency.

### C. Message Forwarding Model

*1) Reference Trajectory Generation:* The message forwarding model generates events and triggers the vehicle to generate

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messages. At the same time, it computes the reference trajectory for the message. The definition of the reference trajectory is as follows.

We denote a road network as a graph $G = (V, E)$, where $V$ is the set of road points, and $E$ is the set of road segments.

*Definition (Trajectory):* A trajectory can be represented as $\mathcal{T} = \langle p_1, p_2, ...., p_n \rangle$, where $p_i = (x_i, y_i) \in V$ is the position of road point, and $(p_i, p_{i+1})$ represents the road segment between consecutive points. We utilize $\mathcal{T}$ to describe the reference trajectory of a message or the mobility of a vehicle.

*Definition (Reference Trajectory):* The reference trajectory, denoted by $\mathcal{T}_r$, starts at the location of source that generates the message and ends at the message destination. $\mathcal{T}_r$ is computed based on a pre-stored digital map about the network, following the shortest path determined by the Dijkstra algorithm [10].

Once the reference trajectory is generated, it is embedded in the message. It serves as a reference when selecting message relays, aiding in the delivery to the destination.

*2) Message Relaying:* The vehicle carrying the message (or a copy) evaluates potential relays when encountering other vehicles. The main task is to determine if an intermediate vehicle would be a better choice for relaying the message. Detailed selection criteria are provided in Section IV-B.

*3) Message Management:* Message management is based on anycasting, which focuses on efficiently routing emergency messages to MDRUs. The process works as follows:

**Destination Selection:** The destination for the message is all MDRUs in the network. When generating a message, the system calculates the reference trajectory to each MDRU, forming a set of reference trajectories.

**Message Transmission:** TBAR protocol, based on anycasting, enhances the delivery rate of emergency messages. This is because multiple copies of each message exist within the network. Even if one path fails, other paths are available, thereby increasing the reliability of message transmission.

**Delivery Confirmation:** A message is considered successfully delivered once it reaches any MDRU. Upon successful delivery, the copies of the message within the network are deleted, reducing network load. The MDRU will then forward the message to the ERC, where further decisions will be made.

## IV. Proposed Method

### A. Optimal Deployment of MDRUs

The objective of optimal deployment problem for MDRUs is to maximize the coverage range of MDRUs. This ensures that more vehicles are served.

We define Road Topology Segments (RTS) to represent normal road sections within a specific area. Using RTS as the basic unit, the objective function can be expressed as follows:

$$\min \sum \left[\alpha \left(L_{\mathcal{R}_{sum}} - L_{\mathcal{R}_{cover}}\right) + \beta L_{\mathcal{R}_{repeat}}\right]$$
$$s.t. \begin{cases} C1 : 0 \le L_{\mathcal{R}_{repeat}} \le L_{\mathcal{R}_{cover}} \le L_{\mathcal{R}_{sum}} \\ C2 : \alpha + \beta = 1 \end{cases}, \tag{1}$$

where $L_{\mathcal{R}}$ is the total length of segments within RTS $\mathcal{R}$. $\mathcal{R}_{sum}$ represents the RTS in disaster areas, $\mathcal{R}_{cover}$ describes the RTS within the coverage of MDRUs. Additionally, $\mathcal{R}_{repeat}$ denotes the RTS that are overlapped by MDRUs, i.e., the RTS that are covered by more than one MDRUs. Thus, the objective function minimizes uncovered and overlapped RTS, with $\alpha$ and $\beta$ serving as the weight coefficients.

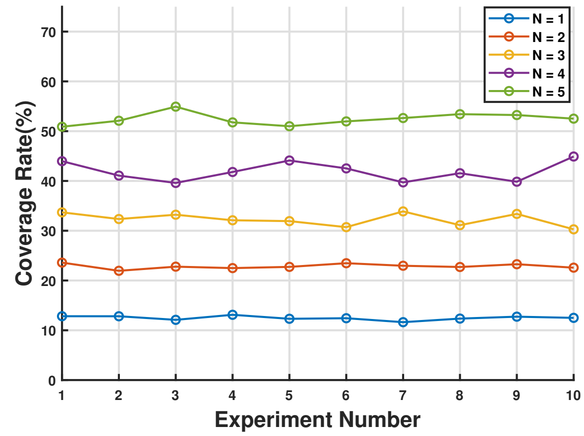


Fig. 2: Coverage rate for different numbers of MDRUs.

Similar to the problem discussed in literature [11], the MDRUs deployment problem is also NP-hard. Therefore, we utilize PSO algorithm to solve the optimal deployment problem of MDRUs. On the simulation map mentioned in section V-A, we consider deploying 1 to 5 MDRUs sequentially. Each case is tested several times with 1000 iterations. Fig. 2 shows the obtained road coverage, $N$ is the number of MDRUs.

According to the work [11], 25% coverage would serve more than 70% of vehicles, which is the most cost-effective option. Therefore, we choose to deploy three MDRUs in disaster areas to build a disaster response network.

### B. Relay selection in TBAR Protocol

*1) Link Quality:* During message forwarding, link quality is a criterion for selecting relay vehicles. The evaluation indexes of link quality include expected link survival time and link reliability, defined as follows.

*Definition (Expected Link Survival Time):* It indicates how long the link is expected to remain connected between two vehicles. According to the definition in work [12], the method for calculating expected link survival time is outlined below.

For any two vehicles $i$ and $j$ on the road, denoted as $C_i$ and $C_j$ respectively. Their respective positions and speeds are $p_i = (x_i, y_i)$, $\mathbf{v_i} = (v_{x_i}, v_{y_i})$, and $p_j = (x_j, y_j)$, $\mathbf{v_j} = (v_{x_j}, v_{y_j})$. The distance between $C_i$ and $C_j$, denoted by $\mathbf{\Delta D}_{i,j}$, is $(x_j - x_i, y_j - y_i)$. Similarly, the speed difference between $C_i$ and $C_j$, denoted by $\mathbf{\Delta V}_{i,j}$, is $(v_{x_j} - v_{x_i}, v_{y_j} - v_{y_i})$. The distance between $C_i$ and $C_j$ changes over time is given as follows:

$$D_{i,j}(t)^2 = [x_j(t) - x_i(t)]^2 + [y_j(t) - y_i(t)]^2 . \tag{2}$$

We assume the communication radius of vehicles is $R$. If $D_{i,j}(t) \le R$, $C_i$ and $C_j$ can communicate at time $t$. When the initial distance $D_{i,j}(t_0) \le R$, the communication duration for $C_i$ and $C_j$ is denoted as $T_{i,j}$, calculated by the formula:

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$$T_{i,j} = \begin{cases} 0 & |\mathbf{\Delta D}_{i,j}| = R,\ \cos\theta \geq 0 \\ \infty & \mathbf{\Delta V}_{i,j} = 0 \\ \frac{-B+\sqrt{B^2-4\times A\times C}}{2\times A} & \text{otherwise,} \end{cases} \tag{3}$$

where $A = |\mathbf{\Delta V}_{i,j}|^2$, $B = 2\mathbf{\Delta D}_{i,j}\mathbf{\Delta V}_{i,j}$, $C = |\mathbf{\Delta D}_{i,j}|^2 - R^2$, and $\cos\theta = cos(\mathbf{\Delta D}_{i,j}, \mathbf{\Delta V}_{i,j})$.

*Definition (Link Reliability):* According to the definition of link reliability in the work [13], link reliability is the probability that a link between vehicles will remain continuously available for a specified period. The method for calculating link reliability is detailed below.

The probability density function of the communication duration $T$, denoted by $f(T)$, is calculated as follows:

$$f(T) = \frac{2R}{\sigma\sqrt{2\pi}} \frac{1}{T^2} e^{-\frac{(\frac{R}{T}-\mu)^2}{2\sigma^2}}, T \geq 0, \tag{4}$$

where $\mu$ and $\sigma$ denote the expectation and variance of $\mathbf{\Delta V}_{i,j}$, respectively. Then, the link reliability $r_t(l_{i,j})$ at time $t$ is:

$$r_t(l_{i,j}) = \begin{cases} \int_t^{t+T_{i,j}} f(T_{i,j})dT & T_{i,j} > 0 \\ 0 & otherwise. \end{cases} \tag{5}$$

Therefore, the link quality can be expressed as:

$$LQ_{i,j} = r_t(l_{i,j}) \times T_{i,j}. \tag{6}$$

*2) Trajectory Similarity:* We define the trajectory similarity as $TS$, which is calculated as follows:

*Definition (Trajectory Similarity):* It is the proximity of vehicle's moving trajectory to the message's reference trajectory.

As shown in Fig. 3, $\mathcal{T}_m$ represents the current moving trajectory of the candidate vehicle $C_i$, while $\mathcal{T}_r$ represents the reference trajectory of message. We define local sliding windows $\mathcal{W}_m$ and $\mathcal{W}_r$, illustrated in Fig. 3. Considering the case where $C_i$ is on the $(p_{\alpha-1}, p_\alpha)$ road segment, the sliding window $\mathcal{W}_m$ is $\langle p_\alpha, p_{\alpha+1}, p_{\alpha+2}\rangle$. Meanwhile, other sliding window $\mathcal{W}_r$ is given by $\langle p_\beta, p_{\beta+1}, p_{\beta+2}\rangle$, where $p_\beta$ ($p_\beta \in \mathcal{W}_r$) is the closest trajectory point to $p_\alpha$ ($p_\alpha \in \mathcal{W}_m$). Then, $\mathcal{W}_m$ and $\mathcal{W}_r$ are utilized to calculate the similarity of two trajectories $\mathcal{T}_m$ and $\mathcal{T}_r$.

The distance $D(p, \mathcal{W}_r)$ from a point $p$ to a trajectory $\mathcal{W}_r$ is defined as follows, where $ED(p, r)$ denotes the Euclidean distance between two trajectory points $p$ and $r$.

$$D(p, \mathcal{W}_r) = \min_{r\in\mathcal{W}_r} ED(p, r). \tag{7}$$

$TS$ measures the average minimum distance from each point in a trajectory to another trajectory. The distance from each point in $\mathcal{W}_m$ to $\mathcal{W}_r$ is not necessarily equal to the distance from each point in $\mathcal{W}_r$ to $\mathcal{W}_m$, i.e., $TS(\mathcal{W}_m \rightarrow \mathcal{W}_r) \neq TS(\mathcal{W}_r \rightarrow \mathcal{W}_m)$. Therefore, $TS(\mathcal{W}_m, \mathcal{W}_r)$ is asymmetric and can be computed by:

$$TS(\mathcal{W}_m \rightarrow \mathcal{W}_r) = \frac{1}{|\mathcal{W}_m|}\sum\nolimits_{m\in\mathcal{W}_m} e^{-D(m,\mathcal{W}_r)}. \tag{8}$$

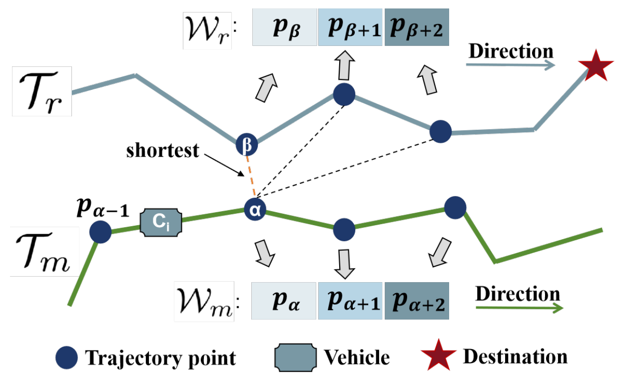

Fig. 3: An example of trajectory similarity.

$$TS(\mathcal{W}_r \rightarrow \mathcal{W}_m) = \frac{1}{|\mathcal{W}_r|}\sum\nolimits_{r\in\mathcal{W}_r} e^{-D(r,\mathcal{W}_m)}. \tag{9}$$

$$TS(\mathcal{W}_m, \mathcal{W}_r) = \frac{1}{2}\left[TS(\mathcal{W}_m \rightarrow \mathcal{W}_r) + TS(\mathcal{W}_r \rightarrow \mathcal{W}_m)\right]. \tag{10}$$

*3) Shortest Distance Cost:* As shown in Fig. 3, the message $m$ is transmitted to its destination using $C_i$ as a relay vehicle. The shortest distance cost, denoted by $DC_i$, is calculated as:

$$DC_i = d_{i,\alpha} + d_{\alpha,\beta} + d_{\beta,dest}, \tag{11}$$

where $d_{i,\alpha}$ represent the distance from the current position of $C_i$ to $p_\alpha$, while $d_{\alpha,\beta}$ describes the distance of from $p_\alpha$ to $p_\beta$. Additionally, $d_{\beta,dest}$ denotes the distance from $p_\beta$ to the destination along the reference trajectory $\mathcal{T}_r$.

*4) Adaptive Weighted Multi-Attribute Utility Function:* Multi-attribute decision-making is utilized to solve the optimal solution selection considering multiple attributes. We select link quality $LQ$, trajectory similarity $TS$ and shortest distance cost $DC$ as decision attributes, design a multi-attribute utility function for selecting candidate relay vehicles based on these attributes. The utility function of the candidate vehicle $C_i$, denoted by $U_i$, is calculated as:

$$U_i = U_i(l)^{w_l^i} \times U_i(t)^{w_t^i} \times U_i(d)^{w_d^i}, \tag{12}$$

where $U_i(l)$, $U_i(t)$, and $U_i(d)$ denote $LQ$, $TS$ and $DC$, respectively. The weights for these attributes are denoted by $w_l^i$, $w_t^i$, and $w_d^i$, with $w_l^i + w_t^i + w_d^i = 1$. Before calculating the utility function $U_i$, $U_i(\cdot)$ is normalised to $[0-1]$. Therefore, the closer $U_i(\cdot)$ of a vehicle is to 1, the more likely it is to be selected as a relay vehicle. If any attribute value of a vehicle is 0, its utility function value is 0.

According to the formula in the work [14], an adaptive maximum deviation algorithm determines the weight of each attribute for candidate relay vehicles. Then the weight value of the $m^{th}$ attribute of $C_i$, denoted by $w_m^i$, is calculated as:

$$w_m^i = \frac{\sum_{i=1}^{n}\sum_{k=1,k\neq i}^{n}|u_{im} - u_{km}|}{\sum_{m=1}^{3}\sum_{i=1}^{n}\sum_{k=1,k\neq i}^{n}|u_{im} - u_{km}|}, \tag{13}$$

where $u_{im}$ represents the normalised value of the $m^{th}$ attribute

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of $C_i$, and $n$ is the number of candidate relay vehicles.

*5) TBAR Message Forwarding:* TBAR scores the candidate vehicle set and judges their potential for transmitting messages. Algorithm 1 details the scoring process for candidate relays and returns a set of candidate vehicles sorted by utility.

**Algorithm 1** TBAR Message Forwarding

**Input:** Message $m$, Candidate Vehicle Set $CV$
**Output:** $CV_{sorted}$: $CV$ sorted by utility function
$LQ_m \longleftarrow$ Create a set for link quality.
$TS_m \longleftarrow$ Create a set for trajectory similarity.
$DC_m \longleftarrow$ Create a set for shortest distance cost.
$U \longleftarrow$ Create a set for utility function.
**for** $c_i$ in $CV$ **do**:
    Calculate $LQ_{m_i}$ using Eq.(6)
    $LQ_m \longleftarrow$ Add $LQ_{m_i}$
    Calculate $TS_{m_i}$ using Eq.(10)
    $TS_m \longleftarrow$ Add $TS_{m_i}$
    Calculate $DC_{m_i}$ using Eq.(11)
    $DC_m \longleftarrow$ Add $DC_{m_i}$
**end for**
Normalize $LQ_m$, $TS_m$, and $DC_m$, respectively.
**for** $c_i$ in $CV$ **do**:
    Calculate $w_1^i$, $w_2^i$, and $w_3^i$ using Eq.(13)
    $SCV \longleftarrow U_i = LQ_{m_i}^{w_1^i} \times TS_{m_i}^{w_2^i} \times DC_{m_i}^{w_3^i}$
**end for**
$CV_{sorted} \longleftarrow$ Sort $CV$ in descending order of $U$.
**return** $CV_{sorted}$

## V. Performance Evaluation

### A. Simulation Setup

The evaluations are based on Opportunistic Network Environment (ONE) [15]. Realistic road data from Helsinki city with a 4500m × 3400m area serves as the scenario for our simulation experiment. Vehicles travel at speeds ranging from 18 to 54 km/h, with a transmission range of 100 meters. They randomly generate 1 MB messages with a 10-minute TTL, and each message is replicated to 10% of the total vehicle count. We compare TBAR with the following routing protocols.

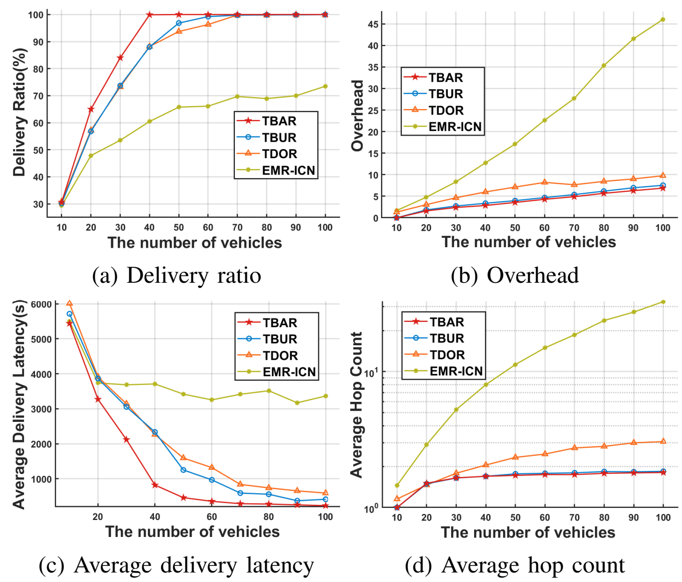
- **EMR-ICN** [6]: EMR-ICN is a unicast emergency message routing protocol. The vehicle adopts mobility metrics for relay selection to ensure a stable routing path.
- **TDOR** [10]: TDOR is a trajectory-driven routing protocol. The vehicle with the trajectory closest to the destination will be selected as the relay for forwarding.
- **TBUR**: TBUR changes the message transmission strategy of TBAR from anycast to unicast.

The performance of our work is evaluated based on the following key parameters:

- **Delivery Ratio:** The ratio of messages successfully delivered to the total number of messages generated.
- **Overhead Ratio:** The ratio between the number of relayed messages and the number of delivered messages.
- **Average Delivery Latency:** The average time for a message to be forwarded from source to destination.
- **Average Hop Count:** The number of vehicles that are needed to deliver a message.

### B. Influence of Network Density

In this section, we consider the influence of different numbers of vehicles (ranging from 10 to 100) on the efficiency of TBAR and benchmark methods. The message generation interval is fixed at 5 seconds.




(a) Delivery ratio (b) Overhead
(c) Average delivery latency (d) Average hop count

Fig. 4: Influence of network density.

As shown in Fig. 4a, the delivery ratio increases as the total number of vehicles rises. TBAR consistently achieves the highest delivery radio in all scenarios. Both TBUR and TDOR are trajectory-based, resulting in similar delivery rates. However, TBAR adopts anycasting based on TBUR, leading to a higher delivery rate than other baseline methods.

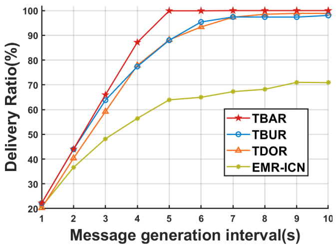
Fig. 4b shows how the overhead changes with different numbers of vehicles. As the number of vehicles increases, the overhead rises because more nodes complicate communication. TBAR, TBUR and TDOR have low overhead, with mean values of 3.84, 4.26, and 6.52, respectively. However, EMR-ICN's overhead is 5.67 times higher than TBAR's.

Fig. 4c demonstrates that average delivery latency decreases as the number of vehicles increases. It is worth noting that TBAR achieves the lowest average delivery delay, being at least 29.34% lower than TBUR, 35.84% lower than TDOR, and 63.25% lower than EMR-ICN.

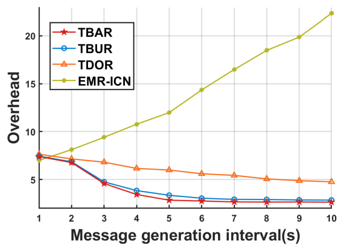
In Fig. 4d illustrates the impact of vehicle density on average hop count. As the number of vehicles increases, available relays rise, resulting in a higher hop count. The average hop count for TBUR is similar to that of TBAR. However, compared with TDOR and EMR-ICN, TBAR reduces the average hop count by 38.94% and 88.75%, respectively.

### C. Influence of Message Density

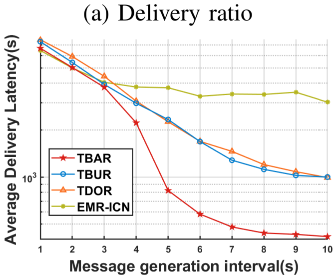
In this section, we consider the influence of different message densities on the efficiency of TBAR and benchmark methods. We set the message density by controlling the message generation interval (from $1s$ to $10s$), meaning the message volume ranges from 1.8k to 18k. The number of vehicles is fixed at 40, while other parameters are unchangeable.



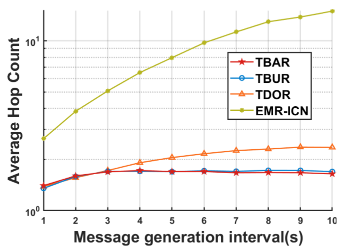

(a) Delivery ratio




(b) Overhead




(c) Average delivery latency




(d) Average hop count

Fig. 5: Influence of message density.

Fig. 5a shows the delivery ratio versus message generation interval. In all simulations, TBAR achieved the highest delivery rate, with nearly 100% delivery when the message generation interval exceeds 4 seconds. TBUR and TDOR have similar delivery ratios. In contrast, EMR-ICN ignores the destination's location, preventing optimal relay selection and thus performing the worst.

In Fig. 5b shows the impact of message density on overhead. TBAR, TBUR, and TDOR, exhibit a decreasing trend in overhead, with mean values of 3.85, 4.09, and 5.96, respectively. The overhead of EMR-ICN increases significantly because it does not limit the number of message copies, reaching a maximum overhead of 138.8.

Fig. 5c illustrates how the average delivery latency of the four methods varies with message density. Notably, TBAR has the lowest latency, at least 25.83% lower than TBUR, 29.70% lower than TDOR and 47.32% lower than EMR-ICN, highlighting its superiority in delivering emergency messages.

Fig. 5d shows the impact of message density on average hop count. The average hop count of EMR-ICN is much higher than TBAR's due to its relay selection strategy, which leads to frequent switching of relays. Compared with TDOR and EMR-ICN, TBAR reduces the average hop count by 17.95% and 81.41%, respectively.

## VI. Conclusion

This paper proposed a solution to quickly and efficiently restore communication services after a disaster. Specifically, we established a disaster response network by combining MDRUs with VANET. Firstly, to expand the service coverage, we applied the PSO algorithm to find the optimal deployment for MDRUs. Secondly, a trajectory-based anycast routing protocol was proposed, which considered link communication quality, trajectory similarity and distance cost. Finally, extensive simulations were conducted to evaluate the performance of our work. The simulation results showed that our work was effective in restoring communication in disaster areas, even when the basic communication facilities were damaged.

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