Edge-based V2X Efficient Traffic Emergency Responding Protocol*

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ABSTRACT

Traffic accidents considerably hinder transportation in urban centres, bringing high socio-economic costs. More importantly, an accident can severely compromise the health and lives of individuals. Minimizing the access time of an emergency response vehicle (ERV) to an accident site reduces damages, losses, and costs considerably. Traffic management systems (TMS) solutions ease the traffic congestion levels through recommended alternative re-routed paths. However, even though TMS might positively and indirectly aid ERV access, there is no focus on efficiently reducing ERV access time. Thus, a VANET-based approach is proposed to facilitate the timely arrival of an ERV to a destination. The approach uses multi-hop, ad-hoc messages between ordinary connected vehicles, the network edge, and ERVs to communicate details on an accident and coordinate a response. Results show that accident resolution can outperform congestion mitigation methods and demonstrate that ERV selection based on proximity reduces response time.

CCS CONCEPTS

• **Networks** → **Location based services**; **Network simulations**; • **Computing methodologies** → *Model development and analysis.*

KEYWORDS

VANET, Vehicular Cloud Computing, Accident Management

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1 INTRODUCTION

Traffic accidents are the cause of significant personal and economic damages. According to the WHO [18], annually, more than 1.3 million deaths are reported worldwide due to traffic accidents. In 2018, traffic accidents accounted for 1,922 fatalities and 152,847 injuries [4] in Canada, a 3.6% increase compared to 2017. Additionally, the total cost of traffic accidentsis estimated to be 4.2 million dollars [7] - 2.1% of Canada's GDP in 2018. The statistics have shown that decreasing traffic accidents is a socio-economic priority.

Tackling road risks requires coordinated efforts from governments, industry, and agencies [3]. Drivers, passengers, and pedestrians also play essential roles in improving road safety. Advancements in the automotive industry have allowed the design of more efficient and safer vehicles. Support technologies, such as obstacle and lane detection, can significantly decrease accidents [17]. Post-accident assistance is also crucial in reducing accident fatalities and severity [11]. Reducing the medical response time by 10 minutes can decrease the probability of death by one-third [11].

Post-accident assistance, as traffic accident warning/rescue, currently require human intervention, which poses several issues [2]. Reporting an accident may be delayed because a driver or passenger needs to react to report it. Also, people involved in a crash may forget to report it or be unable to do so due to injury, which reduces the chance that an emergency service receives an alert.

Automatic accident reporting and management systems powered by Vehicular Ad hoc Networks (VANETs) have gained attention [19]. VANETs can help to automatically report accidents and dangerous events [13]. The automatic reporting alerts surrounding vehicles of an accident and its severity. From these alerts, further accidents and costs can be avoided by having vehicles avoid roads where an accident occurred [2]. Using a VANET protocol to report accidents helps Emergency Response Vehicles (ERVs) react to the accidents faster. However, this scenario requires specific communication protocols, synchronization, and decision-making.

Given the shortcomings of existing accident reporting and rescue systems, we present a novel traffic emergency rescue protocol, relies on underlying Vehicular-to-Everything (V2X) communication opportunities. In our approach, vehicles communicate with other vehicles or the network edge, either directly or indirectly, through multiple hops. Vehicles collect and exchange information with the closest edge and make informed decisions based on these communications. Traffic accidents and dangerous areas can be identified as part of this information. Vehicles automatically detect and report accidents to the surrounding vehicles and the network edge, decreasing the chance of a report not being sent and reducing the message's delay in reaching surrounding vehicles and ERVs.

The paper is structured as follows. Section 2 presents a brief literature review in accident management. Section 3 presents the problem statement. Section 4 describes our system. Section 5 presents the simulation analysis conducted to evaluate our system's performance. Section 6 concludes the paper and discusses future works.

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2 RELATED WORKS

Many works have recently proposed road accident management algorithms and techniques powered by computational technologies and VANETs. These safety-related applications commonly address accident management tasks [5], including accident detection [9, 14], notification [2], post-accident traffic management [3, 16], optimization of ERV allocation and rescue [1, 10], etc. Since accidents trigger multiple events, some of the applications discuss multiple tasks.

Models for automatic detection of vehicle collisions have been widely explored in the literature using Intelligent Transportation Systems (ITS). An adaptive video-based algorithm has been proposed for accident detection on highways [9]. Using Closed-circuit television (CCTV), the algorithm monitors highway traffic flow through live video capture, which assists in detecting when vehicles' velocities sharply change. Another work [14] proposed using smartphones' onboard sensors to detect the large accelerations caused by accidents. A smartphone works as a portable "black box", seeing traffic accidents and recording data related to them. Upon an accident, the algorithm automatically transmits the accident-related data via the Web to dispatch rescue.

Previous research shows that the reporting of accidents in VANETs can reduce the occurrence of further accidents [2], where for every ten accidents, one of them is a secondary accident [1]. A delay optimal distributed algorithm has been proposed for the broadcast of safety messages in VANETs [2]. The algorithm consists of choosing the best-spanning relay, which is a vehicle that maximizes the message range and minimizes transmission. The algorithm, with a slight delay, is capable of notifying emergency services, and helps surrounding vehicles avoid new accidents.

Post-accident approaches aim to manage the flow of vehicles in the accident region by decreasing traffic jams and cleaning the rescue routes for ERV. Next Road Rerouting (NRR) [16] is a vehicle rerouting system to aid drivers and avoid unexpected congestions. NRR relies on a centralized communication architecture that supports information exchanging between vehicles, city infrastructure, such as induction loops and intelligent Traffic Lights (iTLs), and the central server. Induction loops connected to the iTLs perform the detection of traffic events, allowing a central server to suggest new next road choices to affected vehicles.

A Multi-layer and Vanet-based Approach to Accident Management in Smart Cities (ALIVE) [3] aims to provide a distributed TMS designed to minimize traffic jams caused by en-route events. ALIVE performs its execution in a three-module system. It monitors and connects vehicles with city infrastructure to detect en-route events. ALIVE is also responsible for accident detection and management by disseminating warning messages in multiple hops. Finally, ALIVE assists vehicles in sharing traffic information locally, improving traffic efficiency by avoiding congested roads.

Machine learning techniques have been used to classify and predict the severity of accidents considering real accident data [1]. Through accident severity classification, the allocation of emergency services can be optimized, which contributes to reducing accident impacts. Five accident classification algorithms (Random Forests, Naive Bayes, Decision Tree, K Nearest Neighbor, and Logistic Regression) predict the traffic accident's severity. Given the accident class, they accurately predict the number of ERVs needed.

FTAR [10] explores communication characteristics of fog-enabled Vehicular Software Defined Networks (VSDNs) to ensure a fast accident response. The approach uses remote video analysis to classify accident severity. FTAR can select and send the corresponding rescue service based on the accident's severity. Fogs near the accident define a congestion avoidance area. Therefore, vehicles in the area receive periodical warnings to avoid the accident path, which is a rescue vehicle's prioritized route.

This previous research shows that there are multiple methods to reduce further damages from traffic accidents. These include alerting surrounding drivers of the accident, alerting vehicles in the path of an emergency that ERVs are approaching, and ensuring that communications used by ERVs are secure. This work differs from the previous literature approaches by implementing a V2X fast accident rescue system that considers accident region traffic flow and geographic position of ERVs for selecting the fastest ERVs. The selected ERV calculates its rescue route, which other vehicles should avoid. Vehicles traveling in the accident region help by broadcasting warning messages and in cleaning the rescue route.

3 PROBLEM STATEMENT

Accidents are reasonably unpredictable events. In an urban traffic network, vehicles constantly move around and are subject to traffic accidents. In the most basic way, an accident is a collision that disrupts the normal flow of traffic at an unexpected location and time, forcing one or more vehicles to stop.

Traffic congestion. As a result of an accident, traffic congestion can occur. A vehicular collision usually causes road obstructions. In such a scenario, vehicles heading to the accident road must be alerted, changing their routes, and traveling around the accident.

Late rescue. An ERV must reach the location of the accident promptly to assist victims and reduce the chances of fatality. However, due to the flow of vehicles surrounding the accident region, the rescue time can be delayed significantly. As a late rescue is a cause of concern in traffic accident management, an ERV must have a prioritized rescue path. Consequently, vehicles along the rescue routes must be re-routed to decrease the chances of rescue delays.

These two issues have driven the design of our approach, using accident reports from vehicles involved in a traffic accident with an Approaching Emergency Vehicle Alert. The alert notifies ERVs of an accident, allows vehicles to move out of an ERV's path, and enables vehicles to travel around accident areas. As in Figure 1, the related scenario includes the assumptions outlined below:

(1) The scenario consists of an urban area where vehicles move independently along a topology of road segments. Each vehicle has its own trip destination. Vehicles may be in any position within the urban area when an accident occurs.
(2) Data exchange can happen over V2X, but in a more restricted scenario, vehicles process information and communicate with other vehicles (Vehicle-to-Vehicle (V2V)) and Roadside Units (Vehicle-to-Infrastructure (V2I)) across multiple hops (up to 3 in our scenarios). Such exchanges include the lengths of roads and the shortest distance for a vehicle to reach its destination.
(3) Traffic accidents/emergencies may occur unpredictably in any location of the urban area.
(4) ERVs are present in the urban center in unknown positions, and at least one ERV is available to respond to the accident.

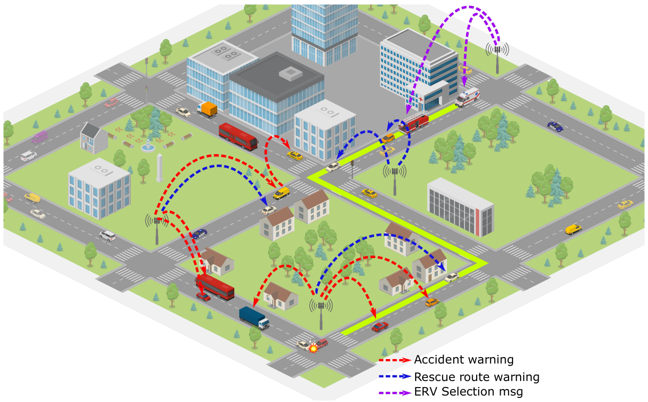


Figure 1: Emergency vehicle reaching the accident site.

4 EDGE-BASED EMERGENCY RESPONSE

The proposed approach aims at effectively enabling an emergency response to a traffic accident with the help of the Cloud Edge (CE), deployed together with roadside units (RSUs), as illustrated in Figure 1. Since the response to an emergency event is entirely reactive, it necessarily relies on constant environment monitoring, reacting to accident events, as summarized in Algorithm 1. This protocol is designed to work in a fully V2X scenario, where multiple network devices cooperate. For instance, pedestrians (Vehicle-to-Pedestrians (V2P)) and cyclists, when aware of the possible risks of accident regions, can effectively avoid them. However, this paper presented a more stringent scenario where communication occurs between vehicles (V2V) and the cloud edges (V2I). Inevitably, an accident produces traffic congestion starting from a road segment. The detection thus takes a collaborative, distributed strategy where the vehicle involved with the accident, or surrounding vehicles, identifies the emergency event. This detection procedure is represented in Line 2 of Algorithm 1 where an accident event stops the vehicle, blocking the road. We assume that the detection of an emergency is realized correctly and immediately after the accident occurs. Accident detection can be conducted manually or automatically, through collision detection methods [9]. After the detection, the resolution procedure is then initiated, organized into five steps: accident dissemination, discovery of ERVs, selection of an ERV, dissemination of the emergency route, and accident resolution.

4.1 Event / Accident Dissemination

Any vehicle involved with the accident sends a message, reporting it, represented by Line 5 of Algorithm 1. Each of these reporting messages is identified with a unique accident ID. The vehicle that generates the accident ID adds the time of the emergency event. These messages also contain the geographical position of the accident so that ERVs can be sent to the location. This work uses the ID of the road segment where the accident occurs as the geographical position of the accident. The position of the accident allows nearby vehicles to avoid the respective road segment. As vehicles receive the accident dissemination message, they can modify their current route to prevent congestion in the accident area - a simplified strategy comparable to previous congestion avoidance features [10].

The accident is then propagated to the Cloud network edge (CE). Vehicles, upon receiving the emergency message, forward it, as described in Lines 8-11 of Algorithm 1. To ensure reliable delivery, the issuing vehicle retransmits the message in set intervals (a_{bd}), represented in Lines 18-19 of Algorithm 1. The retransmissions suspend when a Cloud Edge Node (CEN) responds to the message, described in Lines 16-17 of Algorithm 1.

Algorithm 1: Accident Resolution in Vehicle

Input: ID: ID of vehicle; t: current time; r: current road;
p: current path of vehicle; p_v: path of ERV;
s: state of vehicle;
e: event($moving$, $alert_v()$, $alert_{nv}()$, $alert_{ar}()$, $alert_{CEN}$, $onsite_v$)

1 **if** $s == moving$ **then**
2 **if** $e == accident$ **then**
3 $s = stopped$;
4 $r = blocked$;
5 $alert_{acc}(ID, t, r, \text{"}accident\text{"})$;
6 **else if** $e == alert_v(ID_v, p_v)$ **then**
7 $p = reroute(p, p_v)$;
8 **else if** $e == alert_{nv}(ID_a, t_a, r_a, \text{"}accident\text{"})$ **then**
9 $r_f = blocked$;
10 $p = reroute(p, r_a)$;
11 $alert_{acc}(ID_a, t_a, r_a, \text{"}accident\text{"})$;
12 **else if** $e == alert_{ar}(ID_v, r, t)$ **then**
13 $r = unblocked$;
14 $p = reroute()$;
15 **else if** $s == stopped$ **then**
16 **if** $e == alert_{CEN}$ **then**
17 $a_{bd} = \infty$;
18 **else if** $e == timer(a_{bd})$ *and* $!alert_{CEN}$ **then**
19 $alert_{acc}(ID, t, r, \text{"}accident\text{"})$;
20 **else if** $e == onsite_v$ **then**
21 $s = moving$;
22 $r = unblocked$;
23 $p = reroute()$;

Algorithm 2: Accident Resolution in Edge

Input: P: set of ongoing accident resolutions; ERV: set of ERVs;
r: accident road; t: accident time;
ID_{acc}: ID of accident vehicle; ID_v: ID of ERV;
e: event($alert_{acc}()$,$rep_v()$,$timer()$,$ack_v()$,$alert_{ar}()$)

1 $P = \varnothing$;
2 **if** $e == alert_{acc}(ID_v, t, r, \text{"}accident\text{"})$ **then**
3 **if** $\nexists (ID_v, t, r) \in P$ **then**
4 $P \cup (ID, t, r)$;
5 $ERV = \varnothing$;
6 $req_v(rsu_{ID}, ID_v, r, t)$;
7 $timer(ID_v, t, r) = start(\phi)$;
8 **else if** $e == rep_v(ID_v, r, t)$ **then**
9 $ERV \cup (ID_v, r, t)$;
10 **else if** $e == timer(ID_{acc}, t, r)$ **then**
11 **if** $|ERV| >= 1$ **then**
12 $fr = pick_{min}(ERV, d(r))$;
13 $ERV - \{fr\}$;
14 $select_v(rsu_{ID}, r, t)$;
15 $timer(ID_{acc}, t, r) = restart(\lambda)$;
16 **else**
17 $req_v(rsu_{ID}, ID_v, r, t)$;
18 $timer(ID_v, t, r) = start(\phi)$;
19 **else if** $e == ack_v(rsu_{ID}, r, t)$ **then**
20 $timer(ID_{acc}, t, r) = \infty$;
21 **else if** $e == alert_{ar}(ID_{acc}, r, t)$ **then**
22 $P - \{(ID_{acc}, r, t)\}$;
23 $(ID_{acc}, r, t) = \text{"}resolved\text{"}$;

The accident report dissemination consists of sending and forwarding messages from one vehicle to multiple surrounding vehicles, propagated over multiple hops. To mitigate the issues from broadcast storms, we have adopted an extended dissemination method where the furthest vehicles from the origin of the arriving message re-transmit the message. This method may reduce the

Algorithm 3: Accident Resolution in ERV

```
Input: ID: ID of vehicle; g: current task; c: current road; r: accident road;
       t: accident time; p_v: current path of ERV; e: event(req_v(),select_v())
1  g = ∅;
2  if e == req_v(rsu_ID, r, t) then
3      if g == ∅ then
4          rep_v(ID, r, t);
5  if e == select_v(rsu_ID, r, t) then
6      g = (r, t);
7      p_v = path(fr, r);
8      ack_v(rsu_ID, r, t);
9      while g != ∅ AND timer(r, t) do
10         alert_v(ID, p_v);
11         if c == r then
12             alert_ar(ID, r, t);
13             g = ∅;
14         timer(r, t) = restart(ω);
```

number of hops required to reach the destination (network edge) or cover the entire network. Also, repeated messages are not retransmitted. This dissemination strategy thus reduces congestion while still maintaining maximum range [6].

4.2 ERV Discovery

Upon receiving an accident message (accident report), the network edge builds a list of ERVs, as summarized in Algorithm 2, where Line 2 represents the arrival of the accident report message. Based on the dissemination strategy, the CEN closest to the accident receives the accident report message first. From this list, an ERV is selected to travel to the accident site. As soon as the CEN is notified, it verifies if this accident is ongoing through the accident ID (time and location), as in Line 3. A new accident resolution process initiates by creating an empty list of ERVs, Line 5. The CENs then broadcast a message requesting the position of ERVs, as described in Lines 6-7 of Algorithm 2. An available ERV responds to the CEN request with its position and vehicle ID, as described in Lines 2-4 of Algorithm 3. An ERV is considered available when not being already assigned to another accident resolution task; the decision about availability is entirely local to the ERV.

A CEN adds the received ID of an ERV to a list for further analysis and selection, as described in Lines 8-9 of Algorithm 2. The list is assembled on-demand; proactively building the list of vehicles probably introduces several inconsistencies related to the availability and position of the ERVs, defying the purpose of reaching the accident site in time.

The CEN waits for a predefined amount of time ϕ to collect responses from ERVs, as shown in Line 10 of Algorithm 2. If there is no response, the CEN repeats its request for ERVs. If there is more than one available ERV, the CEN selects only one of them to resolve the accident. ϕ is necessary but deterministically adds a delay to resolving an accident incident.

4.3 ERV Selection

As summarized in Lines 10-15 of Algorithm 2, the CEN selects an ERV from its list of free ERVs after the discovery time (ϕ) expires. The selection of the ERV can be conducted depending on different criteria ($d(r)$). In this work, the proposed resolution method can consider either the shortest or fastest path to the destination road. The *shortest path* represents the route with the minimum distance following the traffic topology between the current position of the ERV and the accident site. The *fastest path* represents the route with the minimum amount of time to traverse following the traffic topology between the current position of the ERV and the accident site, considering the current traffic congestion level. The CEN then sends a message addressed to the selected ERV. The message contains the time, road ID of the accident, and the path that the CEN generated.

As described in Lines 5-12 of Algorithm 3, on the receipt of the selection message, the ERV marks itself busy. After selection, the ERV begins traveling to the accident road using the path to the accident it calculates. Similar to the ranking of ERVs, the calculated path can follow different criteria: shortest path or fastest path.

The vehicle also sends an acknowledgement of its dispatch for the CEN, as indicated in Line 8 of Algorithm 3. If the CEN does not receive this acknowledgement within a period (λ), as indicated in Line 15 of Algorithm 2, it sends the next closest ERV in its list. If the CEN receives the confirmation from the selected ERV, it terminates the respective timer. The CEN restarts the discovery of ERVs in case no ERV is available, as indicated in Line 17-18 of Algorithm 2.

4.4 ERV Route Dissemination

While moving to accident, the selected ERV disseminates its route at set intervals, as in Lines 9-14 of Algorithm 3. This dissemination is issued periodically (ω) over 3 hops. The route to the accident site that the ERV computes is a list of road segments for nearby vehicles to avoid. The dissemination allows vehicles to vacate the ERV's path, as described in Lines 6-7 of Algorithm 1. Any vehicle which receives such messages recomputes its current route by avoiding any road in the list shared in the message.

4.5 Accident Resolution

At the accident, the ERV transmits a message to the network edge, informing that it has arrived. The arrival of an ERV ($c == r$) is represented in Lines 11-13 of Algorithm 3. The vehicles involved in the accident also receive the message and stop transmitting their periodic accident reports. In the current design, as an ERV reaches the accident, it marks its status as *free*, making itself available again.

Once the network edge receives a message of an accident resolution, it clears its reference of the ERV responding to the accident, as described in Lines 21-22 of Algorithm 2. The respective accident is removed from the set of ongoing accidents. Also, the accident ID is marked as resolved, preventing lingering, expired accident reports.

An ERV, when moving towards an accident, periodically checks its progress. If the ERV detects that it stopped moving due to traffic, it requests the CEN to send an additional ERV, increasing the reliability in assisting accident incidents. Even though implemented, this feature was not included in the performance evaluation.

5 PERFORMANCE ANALYSIS

We have evaluated the performance of the proposed emergency response approaches through simulation analyses using Veins [12] (OMNet++ [15] and SUMO [8]). The analyses observed the ERV's access time and traffic flow affected by accidents.

5.1 Simulation Scenario

The simulation scenarios consisted of a $6.8km^2$ region of downtown Toronto. The map was obtained using the online OpenStreetMap

Figure 2: Downtown Toronto region. **(Golden circles mark locations of CENs. In the partitioned scenario, the blue square on the left half of the map denotes the region in which ERVs are initially confined, and the red circles mark potential accident roads.)**

tool[1]. Figure 2 illustrates the region for both the open and partitioned scenarios. The simulations ran across the two different scenarios, both using the same Toronto region:

- **Open Map.** Vehicles (including ERVs) are placed on the map in random positions, traveling to random destinations. Exactly one accident occurs 10 seconds after the simulation starts. The road the accident takes place on is the busiest road in the simulation.
- **Partitioned Map.** Non-ERV vehicles are placed on the map in random positions, traveling to random destinations. ERVs are placed in the left half of the map, traveling to a random destination, which is also on the left half of the map. Exactly one accident occurs 10 seconds after the simulation starts. The road the accident takes place on is a random selection from six pre-defined roads on the right side of the map. This scenario segregates the ERVs from the accident road by the time the accident occurs.

Vehicles in this map operated at speeds defined by the map's roads: the highest maximum speed of any road is ($100km/h$), the mean speed is ($33.7km/h$), and the standard deviation of speeds is ($18.2km/h$), as in Table 1. In simulations, any vehicle positioned on an accident road or in a cluster with another vehicle involved in the accident is rendered immobile and part of the accident.

5.2 Simulation Parameters

The experiments were ran at seven different vehicle densities: 50, 100, 150, 200, 250, 300, and 350 $vehicles/km^2$. These densities correspond to seven total numbers of vehicles 340, 680, 1020, 1360, 1700, 2040, and 2380 vehicles, respectively, as listed in Table 1.

In each experiment, NICs used a transmission power of $20mW$, with a noise floor of $-98dBm$. To increase the range of communications, messages would be repeated for up to 3 hops. The four RSUs, acting as CENs, have a communication range of $1km$. After extensive simulation analyses, the algorithm parameters were set to values in Table 1.

5.3 Compared Algorithms

Simulations were tested with six differing levels of complexity within the accident response algorithm. The details of these simulation types are listed below:

- **Full Responsive Approach (FRA).** The full design, with all features listed in Section 4.

[1]Open Street Map Foundation at https://www.openstreetmap.org

Table 1: Simulation Parameter Settings.

Parameter	Value Range
Vehicle Density	340 - 2380
RSU Density	4
Average Vehicle Speed	9.3 m/s
Transmission Power	20mW
RSU comm. range	1000m
ϕ, λ, ω	4s, 3s, 15s
Map	Toronto, Canada

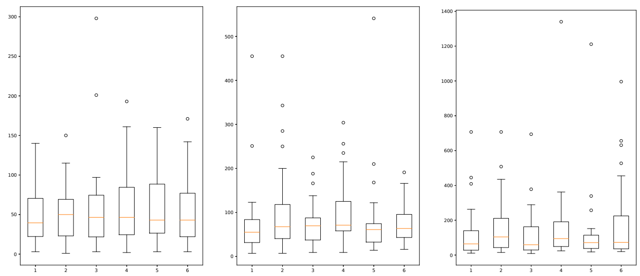
- **Random Selection (RS).** A design wherein the CEN does not select ERVs based on their distance to the accident, but instead picks the first ERV which responded to the CEN.
- **No Broadcast (NB).** A design wherein the ERV does not broadcast its intended path to the accident, so cars do not clear a path for the ERV.
- **Random Selection, No Broadcast (RS-NB).** A design wherein the CEN selects the first ERV that replies and ERVs do not broadcast their intended paths.
- **Full Responsive Approach + (FRA+).** FRA but with ERV selection based on the fastest route to accident considering the congestion of the roads.
- **No Broadcast + (NB+).** NB but with ERV selection based the on fastest route to accident considering the congestion of the roads.

Additionally, the performance analyses considered **Next Road Rerouting (NRR)** to compare its performance in mitigating traffic under the situation of accidents. The focus of our proposed algorithm, as well as variants, is to minimize ERV access time, but also has consequences in reducing traffic congestion.

5.4 Performance Metrics

Following the two simulation scenarios, a range of vehicle densities, and 32 randomly distributed simulation seeds, these experiments yielded averages with 95% confidence intervals in several performance metrics:

- **Average Speed:** Mean speed of all vehicles in the scenario (m/s).
- **Time Loss.** The time difference (s) between a vehicle's actual traversal time and its expected traversal time at its maximum speed. A high measure of time loss indicates higher congestion.
- **Travel Time.** The amount of time (s) a car takes to reach its destination; a lower number indicates a lesser level of congestion.
- **ERV Response Time.** The measure of time (s) starting from the ERV hearing about an accident and ending at the point where the accident is solved.
- **Travel Index (TI).** A measure (s/m) that represents the performance of an ERV reaching an accident based on the route distance. A high value indicates poor response time.
- **Total Access Time.** The total time (s) since an accident incident occurs until it is resolved.
- **Sent Packets.** The control overhead imposed by each approach in terms of number of sent packets per vehicle. A higher number of packets indicates more overhead. Because of redundancy mitigation measures for broadcasting in this work, this metric shows lower values in scenarios with a higher vehicle density.



(a) 340 **(b) 1360** **(c) 2380**

Figure 3: Dispersion sample analysis: total accident time (s).

5.5 Results

The simulation results have confirmed assumptions defined for the two scenarios and approach variants. Even though more realistic, the Open Scenario rendered a high variability in the results while the Partitioned Scenario conditioned ERV trips between two well-defined regions in the map. The high result variability in several metrics was caused due to fortunate coincidences in which accidents occurred very close to a network edge or an ERV. This variability rendered statistically inconclusive analyses even for variants that are expected to underperform. Figure 3 illustrates the high variability for Total Accident Time (TAT), where outliers condition averages and intervals considerably.

5.5.1 Congestion Management Analysis. The focus of the proposed approach consists of minimizing the ERV's access time to the accident site. However, resolving an accident indirectly contributes in mitigating traffic congestion. As result, we have compared the proposed variants against NRR, a recent centralized traffic congestion solution especially designed in the context of traffic accidents.

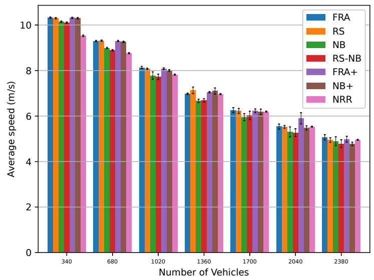
As depicted in Figures 4 and 5, NRR showed similar Average Speed to FRA and FRA+, especially in highly dense scenarios. On the other hand, NRR presented slightly lower Average Speeds in low-density scenarios. NRR mitigates congestion by re-routing vehicles through alternative paths around the accident region. In lower-density scenarios, the resolution of an accident allows the traffic to converge to normal flow speeds. In the end, resolving an accident saves time in the long run because vehicles were stopped or travelling at very low speeds in a congested area for some time. All variants show similar average speeds overall.

In terms of Time Loss, shown in both 4b and 5b, NRR outperforms the proposed emergency resolution protocols for medium densities (1020-1700) in both scenarios; for low and high densities (340-680, 2040-2380), it underperforms. In general and on average for the open scenario, NRR shows 222s of Time Loss while FRA and FRA+ presents 1̃98s of Time Loss. From the figures, we can observe that Time Loss for NRR grows linearly with density. At high densities, NRR has less room to route traffic through alternative paths, whereas resolving an accident compensates for the time lost waiting for the arrival of an ERV. At low densities, NRR has more opportunities for finding alternative paths, but accident resolution occurs earlier with faster ERV access to the accident site, reducing the negative effect of the time vehicles wait. Among the variants, we can observe small discrepancies in Time Loss; NB and RS-NB perform worse with medium density where there is room for FRA and FRA+ to implement procedures for reducing ERV access time.

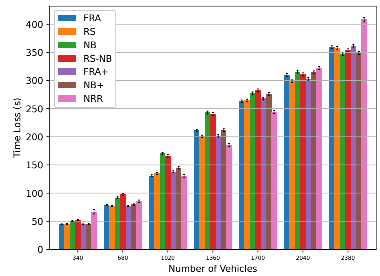
According to Figures 4c and 5c, NRR showed a higher average Travel Time in the Open Scenario (3̃08s) when compared to FRA and FRA+ (3̃71s). NRR only underperformed in low densities (340-1020), where resolving an accident allowed vehicles to continue on their original paths without being affected by any further delays. In higher densities, resolving an accident has not helped improve the overall Travel Time, where re-routing allowed vehicles to circumvent the congestion area. NB and RS-NB performed the worst among the variants, which was evident in the Open Scenario with medium to high densities. Across all simulations in the open scenario, NB and RS-NB yielded average Travel Times of 4̃11s and 4̃07s, respectively, compared to the grand average of Open Scenario Travel Times, which was 3̃85s. The lack of ERV route broadcasting limited the access of ERVs to the accident site by not prompting vehicles to find alternative paths. It is worth noticing that NRR performed fairly well in Travel Time, but it drastically underperformed in terms of Time Loss. This outcome is produced by NRR's focus on generating overall better travel times. The algorithm selected routes that presented the shortest path, but vehicles inevitably traversed those paths longer than expected. Coincidentally, the time losses in NRR have not impacted the travel times.

5.5.2 ERV Access Analysis. As shown in Figure 6 and 7, all results are statistically similar. There is a high variability in the observed metrics in both scenarios. In the Open Scenario, the positions of accidents and ERVs were uncontrolled, allowing for more realistic simulations but generating very high discrepancies in the results. Some runs coincidentally presented a better selection of available ERVs, accidents happening closer to CENs and ERVs, and low congestion levels in the accident region. In the Partitioned Scenario, there was some level of control of accidents and ERVs, which led to lower variability – narrower confidence intervals, but large discrepancies still remained. Moreover, some results showed 0 ERV Response Times; ERVs were coincidentally already near the accident site, so theoretically, less efficient variants benefited.

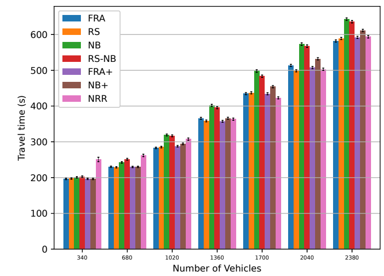
Looking at averages can allow us to drive conclusions on overall tendencies as the density of vehicles increases. As presented in Figures 6a and 7a, FRA and FRA+ showed better general performance across different vehicle densities. The RS and RS-NB variants, on the other hand, presented the highest ERV Response Time. Intelligently selecting ERVs that are closer or more susceptible to arrive faster to the destination allowed an overall shorter ERV Response Time. Moreover, when comparing results between scenarios, the Open Scenario was more erratic. All results contained larger confidence intervals when compared against the respective results (variant and vehicle density) in the Partitioned Scenario. Controlling the scenario limited the overall distance between ERVs and accidents, reducing the number of fortunate coincidences. FRA and FRA+ demonstrated overall ERV Response Times even smaller than the other variants in the Partitioned Scenario. FRA presented average access times that grew moderately with increasing densities - except for the highest density (2380). In the Partitioned Scenario, ERV response time grew by 42% when vehicle density increased from 340 to 2040. In contrast, ERV response time grew by 84% when increasing the vehicle density from 340 to 2380. Please note that FRA+ and NB+ employed the fastest path instead shortest path for ERV selection and ERV route definition. The fastest path method has not significantly enhanced FRA and NB variants, debunking



(a) Average Speed

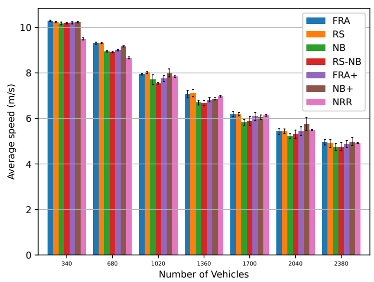


(b) Time Loss

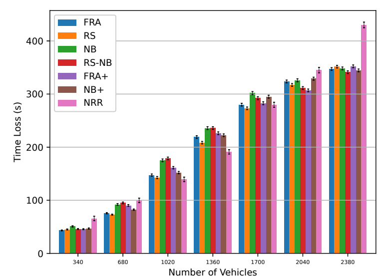


(c) Travel Time

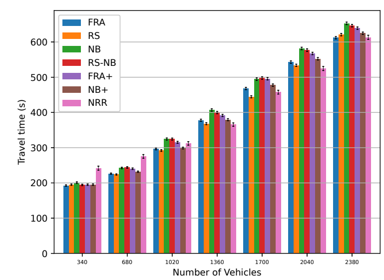
Figure 4: Traffic congestion analysis of open scenario.



(a) Average Speed

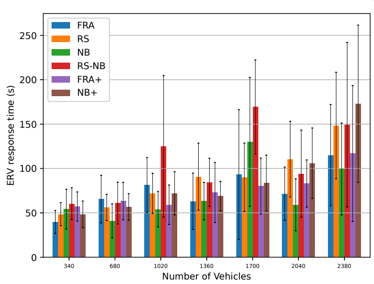


(b) Time Loss

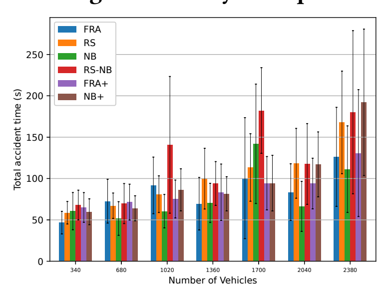


(c) Travel Time

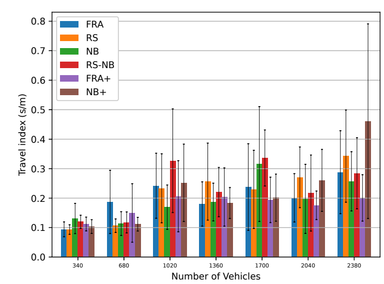
Figure 5: Traffic congestion analysis of partitioned scenario.



(a) ERV Response Time

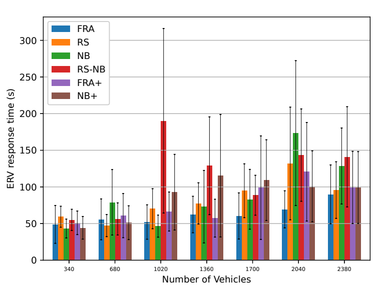


(b) Total Accident Time

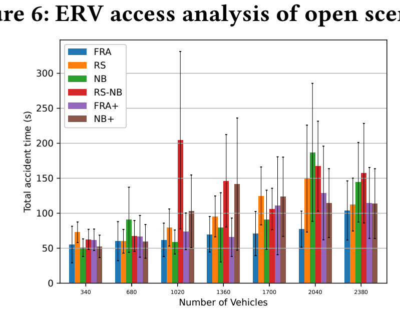


(c) Travel Index

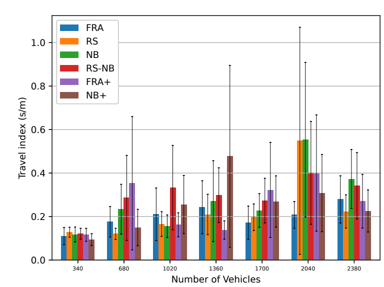
Figure 6: ERV access analysis of open scenario.



(a) ERV Response Time



(b) Total Accident Time



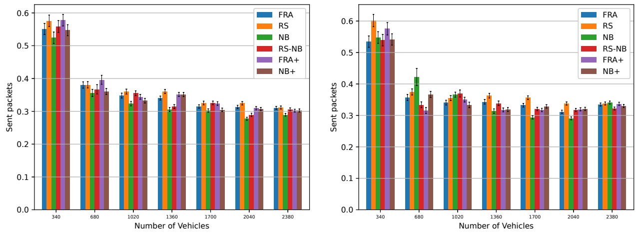
(c) Travel Index

Figure 7: ERV access analysis of partitioned scenario.

initial expectations. In the Partitioned Scenario, FRA showed lower averages than FRA+ did – except for 1360 vehicles – while NB showed expressive higher averages than NB+ did only in high densities (2040-2380). Finally, an ERV periodically disseminating its route showed marginal or no improvement on ERV access time. NB and NB+ showed overall equivalent performance to FRA and FRA+ in the Open Scenario. In the Partitioned Scenario, FRA presented an overall shorter ERV Response Time than NB and NB+ did.

When observing Total Accident Time in Figures 6b and 7b, close similarities in the metric ERV Response Time can be noticed. In other words, analysis shows that the TAT fundamentally consists of adding an invariant time proportional to the density of vehicles on ERV Response Time. The additional time corresponds to the accident alert dissemination and ERV discovery across the network.

Figures 6c and 7c summarize the results related to the Travel Index analysis in both scenarios. Travel Index – inverse of ERV



(a) Open scenario **(b) Partitioned scenario**

Figure 8: Overhead analysis (sent packets) in both scenarios.

average speed – represents the time needed to cover the selected route to the accident. FRA+ and NB+, which make use of fastest route, do not show significant improvement in avoiding congestion to reach the accident site. Also, the ERV periodically advertising its route to vehicles for them to change their paths has not significantly improved ERV access times. Though quite erratic, FRA and FRA+ present values that indicate slight improvement in TI. However, no apparent trend can be derived from the results as densities increase or between the Open and Partitioned Scenarios. This high variability is a consequence of the highly mobile environment. (i) Fastest paths become stale relatively quickly. (ii) There are only narrow windows of opportunity for vehicles to clear the ERV route.

5.5.3 Overhead analysis. All proposed variants rely heavily on V2X communication across the urban environment, containing control messages to enable the dissemination of routes and accident incidents. Figures 8a and 8b show the control overhead that the variants impose on the underlying communication system. Except for an outlier, NRR in the Partitioned Scenario, all variants present similar overhead. There is no difference between the scenarios because the accident and route dissemination are constrained according to the position of accidents, ERVs, and network Edges. We can observe that more packets per vehicle are sent at a low density (340). The amount of packets per vehicle sent do not change in medium to high densities of vehicles since nodes are close to each other and listening to neighbour transmissions, which prevents a transmission. On the other hand, sparse environments introduce a low probability of listening to neighbour transmissions and require more packet forwards to cover the region.

6 CONCLUSION

Given the high cost of accidents, it is vital to ensure TMS can quickly address an accident and help those involved to reduce both human and socio-economical costs. We have presented a reliable V2X-based method to respond to accidents. Assisted by a network edge, our protocol contacts ERVs to solve accident incidents. In particular, the protocol uses Cloud Edge nodes to select ERVs based on their proximity to the accident as a policy to reduce ERV response time. Additionally, ERVs broadcast their intended paths to prevent ordinary vehicles from overcrowding the ERV's route to the accident. Results have demonstrated that the proposed protocol had an overall positive effect on traffic flow, outperforming a recent, centralized TMS approach that mitigates congestion caused by accidents. The results also showed a trending improvement in ERV access time through smart selections and route avoidance strategies even though the large mobility variability caused high variance in the results.

Future studies may improve this algorithm in selecting ERVs and broadcasting ERV routes more effectively, coping with the highly dynamic topology. Given that other factors, such as time loss and network overhead, do not vary based on different studied protocol variants, it indicates that ERV response time should be targeted instead of other factors, such as overhead. Furthermore, the ability for ERVs to re-route multiple times to avoid congestion may also improve the algorithm's efficiency, especially in situations with very high vehicle densities.

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