HERO: Hybrid Emergency Route-Opening Protocol

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***Abstract*—This paper presents an ad-hoc vehicular protocol to support the logistics of first responders. First responders often travel several kilometers to reach an area impacted by an accident or other emergency. The street-path between an emergency responder and an operational field often includes densely populated areas with busy vehicular traffic. It is key that emergency vehicles are able to traverse them safely and as quickly as possible. Vehicular communications is essential for supporting this traversal. Traditionally, this communication is accomplished through intense sirens and lights. Our protocol improves upon traditional techniques by forwarding a first responder's current location and estimated path over an ad-hoc vehicular network. Vehicles lying along this path receive packets and take appropriate actions giving way to an emergency vehicle. Our protocol improves over traditional methods in two ways. First, packets propagated over a vehicular network affords a more timely notification withoug congesting the network. In addition, notifications supply vehicles with a first responders GPS location and intended path traversal. These two improvements allow vehicles to safely and efficiently clear pathways long before an emergency vehicle's arrival.**

***Keywords*-Mobile Computing; Ad Hoc Networks; Pervasive Opportunistic Communications**

I. Introduction

Effective and efficient emergency response is one of the primary challenges to man-made and natural disasters. Recent events such as the twin towers attack and hurricanes Katrina highlighted the importance of quick emergency response to large scale disasters. Similarly, in the case of personal emergencies, such as house fires, automobile accidents, health emergencies, etc., the speed of the first responder's arrival often make the difference between life or death. For example, consider the case of a routine 911 call for a head-on collision. The dispatched emergency vehicle often needs to race through rush hour traffic, ignoring traffic lights, stop signs, and speed limits, in an effort to ship the injured to the nearest hospital before it is too late. For the first responders, every second counts.

Most emergency vehicles utilize a 100W RMS siren to alert drivers of their presence. Unfortunately, the acoustic alarm alone is not sufficient to guarantee a safe and clear way for first responders. Studies performed in Australia [1] show that 1 in 100 crashes involve emergency vehicles on duty. It is estimated that first responders are at a 50% greater risk of being involved in a crash while on duty [2]. To help open up a clear and safe way for the emergency vehicles, consequently reduce the accident rate as well as improving the efficiency of emergency response, we propose a novel ad-hoc communication protocol, known as Hybrid Emergency Route-Opening Protocol (HERO), in this paper.

HERO is a broadcast-based communication protocol designed to timely and precisely inform pedestrians and drivers of the location, speed, and path of an emergency vehicle. HERO disseminates information over an opportunistic network among smartphones and other WiFi-capable portable devices. In order to reduce network congestion, HERO applies Geo Routing techniques to effectively route and filter messages. HERO's performance was evaluated through both simulation and a prototype implemented on a US campus's Vehicular Testbed. Both simulation and testbed results showed a timely arrival of notifications. These notification provided more than adequate time for an vehicle to safely give way to an emergency vehicle.

The reminder of this paper is organized as follows: in section II we describe the protocol in detail; section III analyzes Hero's performances and implementation issues. The related work is described in section III-C while section IV concludes this paper.

II. Protocol

Two types of nodes participate in HERO's protocol. First, the Emergency Vehicles (EVs) act as the sources. Collateral Vehicles (CVs) make up the second group of participating vehicles. These vehicles act as both destinations and forwarders. We assume that all vehicles (CVs and EVs) are equipped with devices, such as mobile phones or portable computers, that have GPS and an 802.11 radio with ad-hoc support. EVs are assumed to be equipped with navigation system that pre-calculates routes.

Packets are inserted into HERO's ad-hoc network by an EV. These packets contain an emergency vehicle's path from its current position to its destination. An EV continuously broadcasts packets while en route to an emergency. The sending rate of an EV is configurable and defined by B_{period}. On receipt of a packet, a CV calculates the packet's relevance to its current position. Relevance is determined

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by calculating the distance of the receiving node to the path of an EV. If this distance lies below a pre-configured threshold, $W_{dilation}$, the receiving vehicle queues the packet for rebroadcast. A packet's queued time, Q_{time}, defines the time a packet is queued before rebroadcasting. Q_{time} is inversely proportional to the distance between the sender and receiver such that receivers farthest from a sender resend packets quicker than those closest to the sender. While packets are queued, CVs listen for additional messages. CVs drop queued packets under two conditions: a) The CV receives a duplicate of the currently queued packet, and b) The CV receives a packet newer than the queued packet.

We assume that a duplicate packet is the result of another node's rebroadcast. Since nodes farthest from the sender propagate faster, nodes closest to the sender is prevented from rebroadcasting. Forwarding packets in this manor ensures a low hop count and minimal congestion.

1) Packet Format: A packet from HERO consists of a time to live, timestamp, unique ID, the EV's latitude and longitude, the last senders latitude and longitude, and a concatenation of all GPS points in a route. Vehicles acquire timestamps through their respective GPS units. GPS attained timestamps guarantee that all vehicles are synchronized.

Vehicles keep a cache of recent packets to avoid resending old packets. We implemented this cache as a hash table. Packets are hashed by their unique IDs (such as a MAC address or ESN) and store the most recent packet's timestamps. When a vehicle receives a packet, it retrieves the unique ID's timestamp from the hash table. If the entry does not exist, the new ID is added with the packet's timestamp. If an entry does exist, but the stored timestamp is older than the new packet's, that timestamp is replaced. If the timestamp is newer (or equal) than that of a new packet, the new packet is dropped and the hash table is left unchanged.

Our cache does require flushing. However, this is done lazily. For example, a cache can be flushed on the first collision (two MAC addresses hash to the same key), or when the cache reaches a predefined threshold. For our implementation, we flushed the cache at a predefined threshold. However, the number of EVs encountered by a DV is quite small resulting in an extremely small cache.

A. Path Relevance

A collateral vehicle must verify its relevance to an EV's route. If a CV is too far from a route it should drop the respective packet. To calculate a CV's distance from a route, the CV must walk through the list of GPS points that define the route. These points construct a series of connected line segments. CVs can calculate its distance from each line segment to find the closest segment.

Once the closest edge is found, the CV can check if its distance from the closest edge falls within $W_{dialation}$. We refer to this distance as path dilation. Path dilation is the maximum distance packets deviate from a first responder's path. CVs forward packets if they fall within the path dilation. Before forwarding, CVs replaces the previous sender's latitude and longitude with their own.

B. Relay Selection Algorithm

Only nodes farthest from the sender should forward packets. We determine this node by implementing a timer with its expiration period dictated by the distance to the sender. The following equation is used to calculate a node's forwarding timer

$$(D_{max} - S_{dist}) * Q_{min}$$

D_{max} is determined by the medium. S_{dist} is the distance (in meters) from a receiving node to a sending node. We multiply the difference between D_{max} and S_{dist} by Q_{min}. Q_{min} is the number of milliseconds a node should wait for each meter. This value must be great enough so that very few cars will attempt to rebroadcast at the same time. If vehicles attempt to rebroadcast at the same time, we'll experience collisions resulting in packet loss. If this value is too large, then messages would not propagate fast enough and cars may not receive enough warning. We used a default value of $10\nu s$ for our experiments.

C. Determining the Radio's Range

During experimentation, we observed a radio range of up to 430m. However, the signal was extremely weak and required a direct line of sight. During our testbed, the number of packets traversing more than 300m was extremely small. Our testbed revealed that 99.95% of all packets travelled less than 300m in an individual hop. As we increased our radio range, the longest delay also increases and slows the delivery of packets. Due to the sparsity of packets over 300m and a desire for fast propagation, we chose to limit the range to 300m. Any packets traversing more than 300m were rebroadcasted immediately.

III. EVALUATION

HERO was assessed by both simulations and a live testbed. Simulations provided results for large scale deployments, while the testbed provided real world data to support our simulations.

A. Simulation Design

For our simulation scenarios, a 4000x4000 km^2 map of an area in Los Angeles (see Figure 1) was imported from US Census Bureau TIGER/Line database [3]. As indicated in the map, EV started from a hospital and finished in the South East corner where the accident was assumed to have taken place. The path has a length of 6.5 km and is constructed using Google Map's routing suggestion.

Our simulations were based on QualNet 4.0 and VanetMobiSim 1.1[4]. VanetMobiSim is an extension to the CANU Mobility Simulation Environment [5] with VANET-specific

Figure 1. The map of the simulated area with the route of EV highlighted in bold.

additions such as realistic mobility models and multi-lane supports. The parameters used for each simulator are listed in Table I. These parameters were carefully chosen to simulate a realistic urban setting and are kept constant throughout all simulations.

We focused our study on the effect of $W_{dilation}$ and fix other parameters to values deemed reasonable as listed in Table II. Three path dilation scenarios, *Narrow*, *Medium*, and *Wide*, were setup based on the $W_{dilation}$ shown in Table III. It is also desirable to evaluate HERO's performance under different traffic conditions. As indicated in Table IV, three type of scenarios, *Light*, *Moderate*, and *Heavy*, each with different number of CV, were constructed. The average distance between the nearest neighboring vehicles, which was computed during simulation, for each traffic condition is also listed in the table. The placement and mobility of the traffic were generated randomly in VanetMobiSim according the model specified in Table I. Hence, there are nine simulation scenarios for HERO when combing different $W_{dilation}$ and traffic conditions. Each scenario was simulated 20 times with different random seeds to reach a grand total of 180 simulations.

Since HERO is a rather unique protocol, it is fairly difficult to find a similar data dissemination protocol to compare against. As a result, flooding, i.e. unintelligent forwarding, was chosen as a competing protocol as it is the most effective, but also most traffic-intensive, way to disseminate information in ad-hoc networks. In order for a fair comparison, flooding was restricted to a maximum distance of 600m from EV. The value was chosen to give adequate amount of time ($>$ 30s) for the driver of CV to respond without flooding an exceedingly large area. Furthermore, a random delay of 100-300ms was applied when forwarding the packet to avoid collisions. The flooding protocol was also simulated under the three traffic scenarios 20 times, producing a total of 60 simulations.

Table I
PARAMETERS FOR QUALNET AND VANETMOBISIM

QualNet	
Pathloss model	Two-Ray
Fading model	Rayleigh fading
Phy model	802.11b
Antenna model	Omnidirectional
MAC protocol	IEEE 802.11
Radio range	100m
Warm-up period	10s
VanetMobiSim	
Position Generator	RandomInitialPositionGenerator
Trip Generator	RandomTripGenerator minstay=5s maxstay=30s
Driver model	IDM_LC minspeed=8m/s maxspeed=20m/s

Table II
LIST OF PARAMETERS FOR HERO AND VALUES USED IN SIMULATION

Parameter	Value
B_{period}	4s
TTL	15s
D_{max}	300m
Q_{min}	2.5ms
$W_{dilation}$	Variable (see Table III)

B. Simulation Results

Flooding is well know for causing a large amount of packets in the network [6]. Figure 2 shows the number of packets sent for HERO, normalized to that generated by flooding, in different scenarios. In general, the traffic conditions have smaller effect on the number of packets sent. On the other hand, $W_{dilation}$ plays an important factor in determining the amount of packets in the network. For the smallest $W_{dilation}$, i.e. the *Narrow* scenario, HERO generates 65 to 75% less packets than flooding on average. For the *Wide* scenario, HERO is only capable of cutting the packets by around 30%. This is because the coverage area of HERO grows with larger $W_{dilation}$. In the worst case scenario, the area can easily outgrow that covered by the flooding protocol, which is confined by a fixed radius.

The relay selection algorithm helps to suppress a sig-

Table III
SIMULATED PATH DILATION SCENARIOS SETTINGS.

Scenario	$W_{dilation}$
Narrow	100m
Medium	200m
Wide	400m

Table IV
SIMULATED TRAFFIC SCENARIOS SETTINGS.

Scenario	Num. of CV	Avg. distance to nearest CV
Light	400	68m
Moderate	800	43m
Heavy	1600	28m

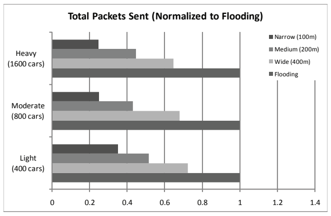


Figure 2. The total number of packets sent, normalized to flooding, for each traffic condition and path dilation scenarios.

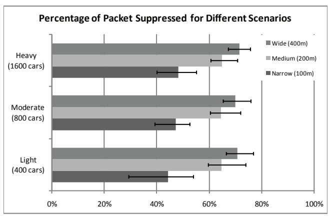


Figure 3. The average percentage of packet suppressed due to the relay selection algorithm in different scenarios.

nificant portion of the packets as shown in Figure 3. The suppression ratio stays relatively constant despite of different traffic conditions while around 45%, 65%, and 70% of received packets are suppressed in the *Narrow*, *Medium*, and *Wide* scenarios respectively. When combined with path relevance check, less than one out of ten received packets is actually retransmitted (Figure 4) in *Heavy* traffic scenarios. The retransmission ratios are higher, albeit still respectable, for less busier traffic–around one-eighth for *Moderate* and one-fifth for *Light*. In summary, HERO produces significantly less traffic and is more scalable with increased traffic than flooding.

The second part of the results evaluate the effectiveness of HERO against flooding. Figure 5 shows the percentage of packets travels up to a particular distance, with a granularity of 100 meters, for each traffic scenario. According to [7], emergency vehicles should be highly visible from at least 200 meters. This in turns suggest that an emergency packet should travel more than 200 meters to make it effective when there is a clear line of sight to EV. It can be seen from the figure that when $W_{dilation}$ is set to *Medium* and *Wide*, around the same percentage of packets traveling over 200m as flooding for *Light* and *Moderate* traffic conditions. However, for *Heavy* scenario, flooding outperforms HERO by sending near 100% of packets over 200m. This result is not surprising as flooding is non-selective broadcasting, as long as there is a relay node within range, which is highly likely in denser traffic, the packet will be propagated to the furthest place possible. In the case of HERO, a packet is propagated only if it is deemed appropriate based on path relevance.

Next, we measured the available response time afforded

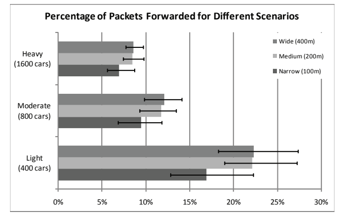


Figure 4. The average percentage of packets received by CV that is forwarded in different scenarios.

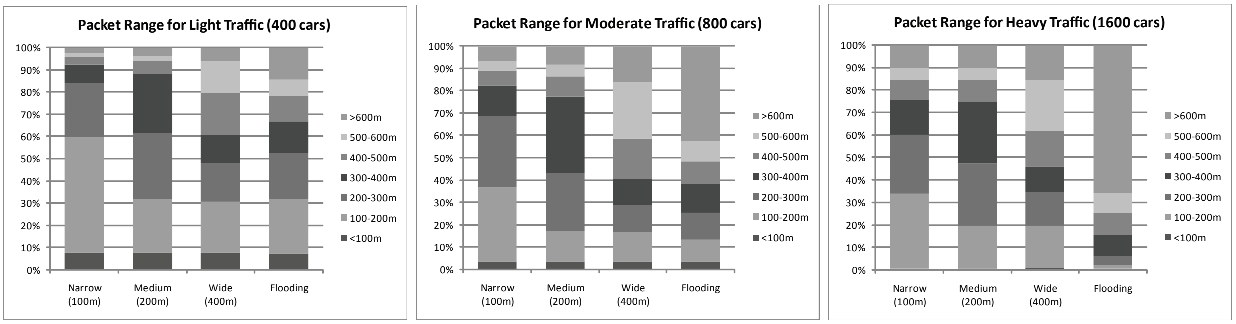
to a CV. This is measured by the time it takes from a CV receiving the first emergency packet to first encountering the EV. An encounter is defined as coming within 100m radius of EV. As indicated by the results in Figure 6(a), for the *Light* scenario around 70% of CV running HERO, regardless of $W_{dilation}$, has less than 10 seconds of response time, which is unlikely to be adequate for the drivers to react and pull over. This may appear to be unsatisfactory at first; however, after comparing to the flooding protocol, where 40% of CV has less than 10 seconds, and 70% of CV has less than 20 seconds of response time, it becomes apparent that the poor results are largely due to the sparseness of the traffic. In other words, there is not enough of traffic to sustain a long chain of ad-hoc relays along the path EV travels on. The picture improves dramatically in Figure 6(b) for the *Moderate* scenario. For all $W_{dilation}$, at least 50% of CV running HERO has more than 30 seconds of response time, which is considered sufficient for drivers to slow down and give way to the EV. The overall response time decreases further with a larger $W_{dilation}$. Finally, HERO shows its real strength with 1600 cars in the *Heavy* scenario. Even with a *Narrow* $W_{dilation}$, over 82% of CV has more than 30 seconds of response time before encountering EV. The percentage grows to 95% in the *Wide* scenario, which is less than 0.2% fewer than in the case of flooding, despite sending 30% fewer packets as shown previously.

C. Testbed

Our testbed consisted of 6 cars. One car acted as the EV while the remaining 5 cars acted as CV. Each car was fitted with a Linux or Mac laptop with a Holux GPS unit. The HERO prototype was written in C using standard UDP sockets over an ad-hoc network. Each vehicle drove serially down a 1.5 kilometer path with two right turns. The EV followed in the rear while continually broadcasting emergency packets. The testbed took place near UCLA campus. Figure 7 displays a satellite view of our test bed.

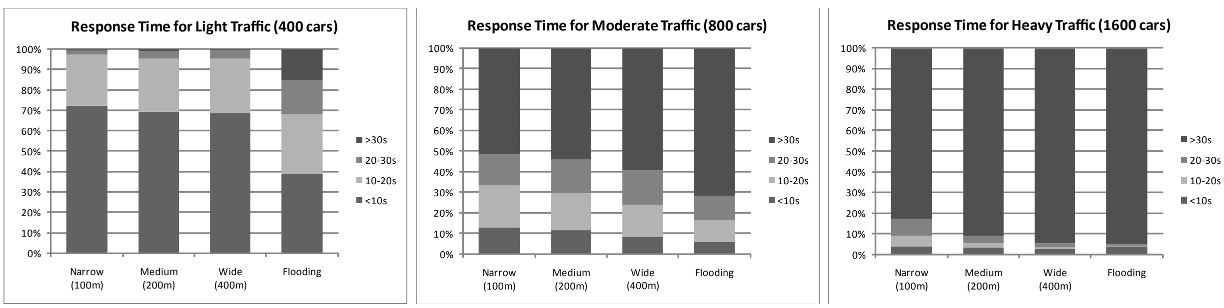
The testbed was run 5 times and took an average time of 2 min 43 seconds. The test bed took place just after rush hour traffic providing us with a light to moderate amount of traffic. Distances between each car ranged from 5m to 110m. Cars drove at an average speed of 28.4 km/hr.

We first analyzed the feasibility of implementing HERO



(a) (b) (c)

Figure 5. Percentage breakdowns of the maximum range each packet travels when the traffic is (a) light (b) moderate, and (c) heavy for the three different path dilations scenarios in comparison with flooding.



(a) (b) (c)

Figure 6. Percentage breakdowns of the response time each NV has before coming within 100m of EV when the traffic is (a) light (b) moderate, and (c) heavy for the three different path dilations scenarios in comparison with flooding.

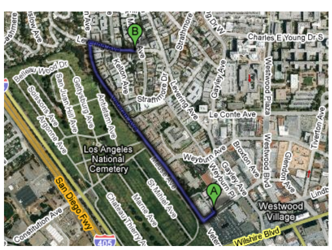


Figure 7. Each vehicle started at point A and ended at point B.

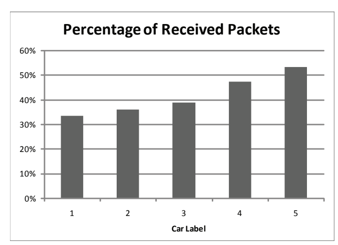


Figure 8. Displays the percentage of packets received by a vehicle. Vehicles labelled with the smallest number are farthest away from the ambulance.

over an ad-hoc wireless network. Surprisingly, WiFi turned out to be an extremely reliable medium for HERO. Figure 8 displays the percentage of received packets. Vehicles are labelled from 1 to 5. 1 being the vehicle farthest from the EV. Cars received between 33% and 52% of all packets broadcasted by the EV. As expected, the number of packets received lowered for vehicles farthest from the source. Packets often travel from EV to farthest CV under a second.

Packets were broadcasted 1 time per second by the EV. At a speed of approximately 30km/hr in an urban environment, the EV will travel 8 to 9 meters between each broadcast. With packets traveling over 500m in under a second (with propagation), HERO affords more than adequate time for vehicles to detect EV and safely pull to the side of the road. In our scenario, it would take over 70 seconds for the EV to traverse over 500m. To note, we expect far larger time intervals in real world deployments. Due to the limited number of cars and moderate level of traffic we were unable to spread vehicles more than 500m. However, the numbers from our testbed are extremely promising and show a large scale deployment to be both feasible and effective.

We did find a serious limitation to WiFi in an urban environment. Our testbed was run near dormitories of UCLA campus with a high number of WiFi networks. During our analysis, we found the packet delivery rate fell to 10%-20%. The worst location from our experiments was the second right hand turn displayed in Figure 7. However, an overall worst case delivery rate of 33% is rather promising.

IV. Related Work

HERO was most influenced by geo routing protocols such as Geo Random Forwarding (GeRaf) [8]. GeRaf finds the best route (by least distance traveled) to the destination. Packets are broadcasted from a source to all nodes within hearing distance. Upon receiving a packet, nodes wait a variable amount of time before forwarding the packet. Nodes closest to the destination wait less time then other nodes. This method gives priority to those located closest to the destination. Nodes drop packets when a node closer to the destination broadcasts first. HERO uses a very similar methodology to GeRaf. However, packets are propagated along a predefined route defined by an emergency vehicle. Also, packets are not required to reach the destination. Authors in [9], [10], [11] provide a similar geo broadcasting technique for vehicular networks. However, propagation does not follow predefined paths as does HERO.

Authors in [12] proposed a multi-hop vehicular broadcast protocol (UMB) similar to HERO. UMB divided an upcoming road into segments. The vehicle lying in the farthest segment is assigned to rebroadcast packets. To avoid collisions, UMB utilized a handshake mechanism similar to that discussed in [13]. A similar protocol can be found in [14] where a zone-of-relevance is staked out to prevent flooding. From our simulations and testbed, we felt the need for more stringent forwarding mechanisms was unnecessary.

V. Conclusion

This paper presented HERO, a geo-routing protocol for clearing pathways of emergency vehicles. HERO improves upon traditional techniques (such as sirens and lights) by forwarding a first responder's current location and estimated path over an ad-hoc vehicular network. Vehicles lying along this path receive packets and take appropriate actions giving way to an emergency vehicle. This method provides both timely and informative messages to drivers.

Most importantly, HERO has the potential of being far more effective than traditional sirens and lights. Our simulations and testbed showed a more timely arrival of notifications while adding contextual data on the speed, direction, and path of an emergency vehicle. With this information, vehicles can safely clear routes for emergency vehicles. We hope that HERO will one day help save lives and improve vehicle safety.

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