Requirement Analysis for Building Practical Accident Warning Systems based on Vehicular Ad-hoc Networks

Niaz Morshed Chowdhury, Lewis Mackenzie and Colin Perkins
School of Computing Science
University of Glasgow
Glasgow, United Kingdom
n.chowdhury.1@research.gla.ac.uk, lewis.mackenzie@gla.ac.uk, csp@csperkins.org

***Abstract*—An Accident Warning System (AWS) is a safety application that provides collision avoidance notifications for next generation vehicles whilst Vehicular Ad-hoc Networks (VANETs) provide the communication functionality to exchange these notifications. Despite much previous research, there is little agreement on the requirements for accident warning systems. In order to build a practical warning system, it is important to ascertain the system requirements, information to be exchanged, and protocols needed for communication between vehicles. This paper presents a practical model of an accident warning system by stipulating the requirements in a realistic manner and thoroughly reviewing previous proposals with a view to identify gaps in this area.**

***Keywords*–**Accident Warning System, Vehicular Ad-hoc Network, Collision Avoidance, Safe Driving.

I. Introduction

Accident Warning Systems (AWSs) are used in Vehicular Ad-hoc Networks (VANETs) to avoid potential collisions and spread safety notifications amongst neighbouring vehicles [1]. The problem of designing efficient and effective warning systems has been widely studied. This involves design of warning systems that are capable of acting proactively before an accident takes place, or spreading post-crash messages for avoiding further collisions, or both [2].

In order to achieve the goals of a warning system, it is important to understand the requirements for building the system and the existing research gaps in this area. An in-depth requirement analysis, along with a review on existing proposals identifying their strength and weakness, should be proved helpful for future studies. To the best of our knowledge no such initiative has been undertaken in relation to AWSs, therefore the importance of having such a study remains high.

In this paper, we present a practical AWS model based on a detailed requirements analysis and a comprehensive survey of previous proposals. The contributions of this study are three-fold: first, we identify the preliminaries required to build a warning system and review existing systems described in the literature; second, we conduct the requirement analysis and identify gaps in existing research; finally, we present a practical model that an AWS should look like.

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The remainder of the paper is structured as follows: section II provides preliminaries, section III presents the review of existing systems, section IV discusses the requirement analysis, section V presents a practical model of AWSs and finally the paper concludes in section VI with a plan for future work.

II. Preliminaries

The problem of building automated accident warning systems for next generated vehicles has been widely studied. Despite the fact that a number of proposals have been described in the literature, there are still many areas that require clarification. Many proposals assume that vehicles will exchange their location in real-time, but is the Global Positioning System (GPS) accurate enough to provide location with sufficient precision? Other proposals talk about emergency braking, but how does a vehicle detect that another driver has stopped abruptly? Further how does a driver give input to the system that he/she has witnessed an incident? It would be inappropriate to move on without some answers to these issues. As our goal is to analyze requirements for a practical and realistic warning system, it is imperative that we look for clarification of these areas first. The following section presents a brief discussion concerning the background technologies underpinning accident warning systems.

A. The Network

Vehicular Ad-hoc Networks (VANETs) are considered suitable for AWS deployment mainly because of their infrastructure-less decentralized nature and dedicated car-to-car communication spectrum. A VANET is a type of wireless network that is specially designed for intelligent transportation system. It uses short-range wireless communication protocol IEEE 802.11p and operates in the 5.9 GHz band that the Federal Communication Commission (FCC) allocated for *Licensed Dedicated Short Range (LDSR)* communication in the United States [3] and the European Telecommunications Standards Institute allocated for *Intelligent Transportation System* in Europe [4]. The *p* version of the 802.11 MAC protocol is particularly designed with a view to reduce latency and enhance bandwidth of networks operating in a vehicular environment compared to other versions of the protocol. Unlike infrastructure based networks, such as cellular networks, a

Year	Accident Warning Systems
2005	SAVN [8], IWS [6]
2007	VSPCA [2]
2009	RBSM [14], OppCast [15]
2010	AICC [9], CRCA [16], WMPIV [17], ESBR [18], ESMD [11], EABS [19]
2011	SBIRC [10], ODEM [20], RVSS [21], ICWS [7]
2012	Geo-Diss [22], OAWS [23], CarSpeak [24]

TABLE I. AVAILABLE AWSS IN LITERATURE.

VANET is very flexible and can be formed on-the-fly. It also does not require expensive equipment apart from the wireless connectivity that is likely to be standard in next generation vehicles [5].

In this model an accident warning system is an application of VANETs that is responsible for warning vehicles before collisions take place. AWSs and VANETs have a complex relationship that varies depending on the architecture of the system. Some AWSs operate at the application layer and remain completely independent of the network layer [6], [7]. Such systems see the VANET as the network that provides communication functionality. However, AWSs can also be found at the network [2], [8] and link layers [9], [10]. In the former, the system usually acts as the main network protocol for a dedicated device whilst, in the latter, the AWS is integrated into the modified MAC protocol. Nevertheless, it is still a matter of debate at which layer warning system might be best fitted [11], [9].

B. Global Positioning Systems (GPS)

The Global Positioning Systems (GPS) is a space-based navigation system that can provide the geographic location of a suitable receiver anywhere on Earth. A GPS-aware AWS obtains vehicle location through GPS and uses this information in its warning. The accuracy of the GPS reading is particularly important because other vehicles act depending on this information. Though military systems are more accurate, at the moment, the US Government is providing 7.8 meter accuracy at the worst case with 95% confidence for public GPS. However, the actual accuracy that users attain depends on various other factors including atmospheric effects and receiver quality. The Federal Aviation Administration (FAA) of the United States government showed using real-life data that on average accuracy is usually 3 meter and can be further improved in combination with other augmentation systems [12].

The GPS modernization program is an ongoing research that has high priority in the United States. The US government has policies to meet the growing demand for enhanced performance. The first next-generation GPS satellite was launched in 2005 and by 2016 GPS III will be in operation. This phase is expected to be fully functional within 2020 [13]. By this time warning systems for vehicles should be at a mature stage and we may expect that these technologies in combination will help achieving safe and accident-free road transportation systems in future.

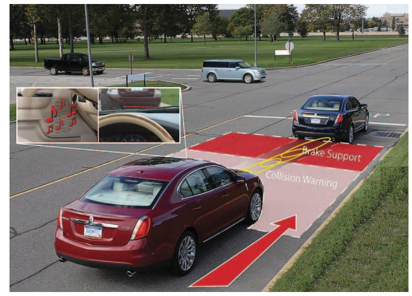

Fig. 1. Collision Warning with Brake Support. Image provided by the Ford Motor Company, USA under Creative Commons Attribution 2.0 Generic license.

C. Supplementary Sensors

There are several sensors that detect problems and inform drivers accordingly [25]. For instance, *Lane Departure Warning System (LDWS)* are responsible for identifying unintentional lane changes. Mercedes has developed a LDWS called *Lane Keeping Assist* that detects unplanned lane changes and informs the driver accordingly [26]. An AWS can then transfer this warning to the vehicles who might be endangered because of this event. An *Emergency Braking System (EBS)* is a type of sensor that detects sudden braking and generates warnings. There is another type of sensor commonly known as *Frontal Collision Detection System (FCDS)* that detects obstacles in front of a car using infrared or radar. With the combination of these sensors, rapid warnings for a wide range of collisions can be produced.

D. On Board Unit (OBU)

An *On Board Unit (OBU)* is a device available in vehicles that is usually equipped with GPS and communication facilities. It has provision to take input from drivers on an on-demand basis. Such devices are currently used for collecting tolls and navigating digital maps but can easily be adapted to work with an AWS too [27]. Given such a scenario, a driver would be able to generate warnings should he/she witnesses an incident.

III. EXISTING AWS REVIEW

Although researchers have been actively involved in designing accident warning systems for vehicles for several years, no initiative has ever been undertaken to accumulate system requirements for a practical warning system. We examined 18 proposals in the literature that have been used to build accident warning systems between 2005 and 2012. Table I presented these proposals in order of their publication year. These proposals independently analyzed the problem and came up with different solutions. However, as these solutions lack a proper requirement analysis, some important aspects have tended to be overlooked. In this section, we review these proposals and identify their advantages and disadvantages. Later we will use our findings in requirement and research gap analysis.

A. Flooding-based Schemes

SAVN [8] is one of the earliest attempts at building accident warning system that covers a broad range of collision avoidance approaches. This system divides warning messages into different categories and assigns priorities. IWS [6] and ICWS [7] are two other simple systems that only address intersection hazards and trigger collision avoidance notifications when a vehicle approaches a junction. Nonetheless, VSPCA [2] is more sophisticated in terms of both coverage and data dissemination. It follows the footsteps of SAVN and generates warnings for a diverse range of scenarios that include collision avoidance messages and event-driven post-incident warnings. One of the key contributions of this latter work is to separate messages based on creator and forwarder. A message created by a source vehicle holds the highest priority and any forwarder subsequently downgrades its priority to normal.

The main problem of the above four systems is their data dissemination scheme. They use flooding to spread warnings among vehicles. This scheme effectively distributes warnings without having to know the network at all; however, it by definition, floods the network with redundant data and risks generating a broadcast storm in high traffic density scenarios.

B. Non-flooding Schemes

RBSM [14] is arguably the first proposal that shows much concern about *reach-ability*. It tries to bring a tradeoff between the importance of reach-ability of a warning and the consequences the network suffers due to flooding. It introduces two key elements in the design of warning systems: firstly, it tries to control flooding by using a parameter that keeps track of the maximum number of time a message can be forwarded. Secondly, it makes use of beacon messages to allow any given vehicle to learn about its neighbourhood. The former approach is taken to allow senders to control the scope of a particular warning; in this paper we will call such schemes *limited-scope-broadcast*. The latter approach is particularly helpful because beacon message can help sending data along with control information. OppCast [15] is another warning system that closely imitates the functionality available in RBSM except for the fact that its forwarding is based on an opportunistic algorithm, and to limit the coverage of the warning it uses specific length of roads. Nevertheless, it splits the responsibility for delivering potential collision avoidance warnings and event-driven warnings between beacon message and limited-scope-broadcast respectively. ESBR [18] and Geo-Diss [22] also follow the principle followed by RBSM.

As we mentioned earlier AWS can be found in the link layer too. The AICC protocol [9] is an example of this type of system. The key contribution of AICC is rate-based warning dissemination. Unlike the previously described systems, AICC does not send warnings at a constant rate, but rather tries to assess the nature of the situation and adjusts the rate of warning based on that assessment. In addition, it also increases or reduces transmission power to alter the coverage around the source vehicle. The former technique determines how frequently warnings should be disseminated and the latter how far a warning should travel in one transmission. SBIRC [10] is another link layer accident warning system. SBIRC makes the use of raptor codes for warning message dissemination. It also prioritizes its warnings based on importance.

There are some event specific systems that trigger warnings if they encounter predefined events. For example, CRCA [16] is a limited-scope-broadcast based warning systems that only generates warnings in the event of emergency brake and potential intersection collisions that it identifies in advance using a prediction-based algorithm. ODEM [20] is another road-safety system that gets activated when an accident takes place. It uses opportunistic propagation of accident information to hospitals, police stations and fire stations

Fig. 2. City intersections are the most complex scenarios that involve both vehicles and human. Image provided by the ScientificAmerican.com under fair use policy of the Creative Commons (CC) license.

Although limited-scope-broadcast reduces the wastage of network capacity compared to flooding-based schemes, it does not stop the flooding of the immediate locale of the source. It has the basic properties of a stochastic broadcast scheme and is also capable of creating a broadcast storm in regions of high traffic density.

C. Other Schemes

WMPIV [17] is a unique proposal that introduces *relay-based* forwarding. Its collision detection is limited to forward and lane-change collisions but it significantly reduces number of transmissions while using limited-scope-broadcast. It selects suitable relay vehicles which carry warnings as those vehicles move on. EABS [19], RVSS [21] and OAWS [23] are other proposals that use the relay-vehicle and follow similar concept. One of the major limitations of relay-based system is that it cannot ensure reach-ability and often covers only a narrow range of possible scenarios.

ESMD [11] is an attempt to bring in session-oriented data dissemination in the form of a tree-based multicast. It transforms the multicast routing problem into a delay-constrained minimum Steiner tree problem with a view to connect all nodes together. It also uses beacon messages to communicate with one-hop neighbours and covers all possible collision scenarios. CarSpeak [24], a publish/subscription based content-centric warning systems introduces an approach that stores information in an *Octree* [28] and later distributes it on-demand. One of the major drawbacks that these schemes exhibit is poor latency. AWSs are extremely time sensitive and give any data dissemination protocol little time to discover routing path for fetching data from the network.

IV. Requirement Analysis

In this section, our intention is to assess the bigger picture. We start from possible scenarios, identify potential collisions,

AWS	FUC	PUC	IntC	FrdC	LCC	VOC	VBC
SAVN	✓	✓	✓	✓	✓	×	×
IWS	×	×	✓	×	✓	×	×
VSPCA	×	×	✓	✓	✓	×	×
RBSM	×	×	✓	✓	✓	×	×
OppCast	✓	✓	✓	✓	✓	×	×
AICC	✓	✓	✓	✓	✓	×	×
CRCA	✓	✓	✓	×	×	×	×
WMPIV	×	×	×	✓	✓	×	×
ESBR	✓	✓	✓	✓	✓	×	×
ESMD	✓	✓	✓	✓	✓	×	×
EABS	×	×	✓	✓	✓	×	×
SBIRC	✓	✓	✓	✓	✓	×	×
ODEM	×	✓	×	×	×	×	×
RVSS	×	✓	×	×	×	×	×
Geo-Diss	✓	✓	✓	✓	✓	×	×
OAWS	✓	✓	✓	✓	✓	×	×
ICWS	×	×	✓	✓	✓	×	×
CarSpeak	✓	✓	✓	✓	✓	×	×

TABLE II. COLLISIONS THAT PREVIOUS PROPOSALS ADDRESSED.

look into types of messages that AWSs typically exchange and then talk about suitable data dissemination approaches.

A. Possible Scenarios

The first requirement is to identify driving scenarios. There are many such scenarios but, for simplicity, we can group them into three broad categories according to basic road layout: intersections, single carriageway and dual carriageway. Besides, these road types look different in a city proper and on highways connecting cities and towns. In summary, we consider city and highway scenario separately and divide each into the three categories stated.

Of the three categories, intersections are the most complex in terms of response time and involved entity. It is likely that a city intersection would include pedestrians and cyclists in addition to vehicles whilst only vehicles are usually present on highway intersection. However, highway intersections are more likely to involve a variety of vehicle types. A realistic AWS design must take these features into account.

Single carriageways can be found cities and also in rural settings. Fast vehicles moving in opposite directions may here collide with each other head on. An AWS in such a scenario may have little time to detect and warn a driver about a potential collision unless the transmission power of the wireless transmission is set to cover a relatively larger area. Because of the presence of the central reservation divider, most dual carriageways do not have the same threat of head on collision. Nevertheless, as they have multiple lanes and vehicles often moving at high speeds, suddenly lane changes or braking manoeuvres can result in collisions. In order to try to prevent these kind of accidents on both single and dual carriageways, we need to classify collision types.

B. Potential Collisions

For our purposes we will consider the following categories which cover most real-world scenarios.

1) Follow-Up Collisions (FUC): These occur when a vehicle slows or halts in the middle of a free-flowing highway because of a technical problem, loss of control on a slippery or damaged road surface or even a primary collision. The successor vehicle following behind the one affected may crash into the back of it.

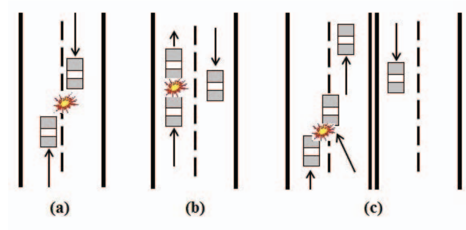

Fig. 3. Collisions occur on a free-flowing road among bidirectional traffic (a) or traffic moving on the same direction (b and c).

2) Pile-Up Collisions (PUC): Sometime referred to as a *Multiple Vehicle Collision*, this is a type of road accident that can easily develop out from a two vehicle follow-up collision, if further following vehicles become involved.

3) Intersection Collisions (IntC): These occur at road intersections and roundabouts when drivers fail to notice a vehicle coming from another direction. Intersection collisions are especially common in busy urban areas. Directions of vehicles are also diverse in intersections and any AWS will require to take account of this.

4) Forward Collisions (FC): These occurs when two vehicles coming from opposite direction collide and crash into each other. This kind of collision is generally only possible where a road divider is not present.

5) Lane-Change Collisions (LCC): These occur mostly on dual carriageways when drivers try to change lane but fail to notice vehicles coming from behind. Sometime an AWS can predict an LCC hazard based on the movement of nearby vehicles.

6) Vehicle-to-Object Collision (VOC): It occurs when a vehicle hits a stationary object. The object itself can be a part of the traffic infrastructure such as a barrier or some sort of obstacle accidentally or deliberately moved onto road. Such a collision can only be avoided if the vehicle at risk is equipped with appropriate sensors; however, an AWS can effectively prevent follow-up and pile-up collisions that might occur as a consequence of a VOC by taking appropriate measures immediately.

7) Vehicle-to-Body Collision (VBC): This type of collision occurs when a vehicle impacts a human or animal who happens to be on the road for whatever reason. A VBC is somewhat different from a VOC because in this collision the non-vehicular party is mobile and may try to avoid the incident by moving randomly and abruptly. Avoiding this kind of collision also requires appropriate sensors and but again, an AWS can prevent follow-up and pile-up collision developing out of the incident.

Table II shows that among the 18 proposals we reviewed only 9 addressed the first five of those possible seven collisions. VOC and VBC are not covered at all by any of the previous proposals.

C. Warning Message

Because collisions differ in nature, the warnings and safety notifications generated by accident warning systems also differ.

AWS	EDM	PWM	RCN	ECU
SAVN	✓	✓	✓	✓
IWS	×	✓	×	×
VSPCA	×	✓	×	×
RBSM	×	✓	×	×
OppCast	✓	✓	×	×
AICC	✓	✓	×	×
CRCA	✓	✓	×	×
WMPIV	×	✓	×	×
ESBR	✓	✓	✓	✓
ESMD	✓	✓	×	×
EABS	×	✓	×	×
SBIRC	✓	✓	×	×
ODEM	×	×	×	✓
RVSS	✓	×	×	×
Geo-Diss	✓	✓	✓	×
OAWS	✓	✓	×	×
ICWS	×	✓	×	×
CarSpeak	✓	✓	✓	×

TABLE III. MESSAGES THAT PREVIOUS PROPOSALS ADDRESSED.

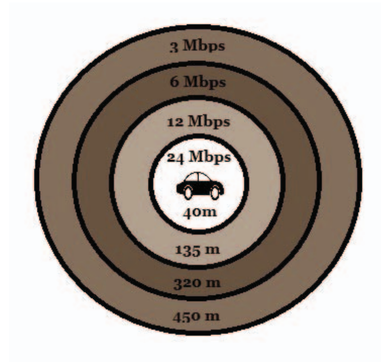

Fig. 4. IEEE 802.11p Data Rate vs Coverage [30].

When and how frequently these message be sent is an important another concern. The following section briefly addresses the different message types and dissemination approaches used in previous proposals.

1) Message Type: Event Driven Messages (EDM) are found in most AWSs. Table III shows that among the 18 systems we reviewed, 11 use this type. Such messages are reactive and sent in response to specific events. Incidents such as encountering an accident, emergency braking, careless driving, witnessing an incident and so on may result in such a message being transmitted. In fact there are two types of EDM - active and passive. Active EDM's are generated by the vehicle involved in an incident whilst passive EDM's are generated by vehicles who witness that incident. Active EDMs are more delay sensitive than passive EDMs as they aim to inform immediate neighbours about the incident.

Periodic Warning Message (PWM), on the other hand, are present in almost every AWSs, with 16 out of the 18 reviewed using this type of warning. The primary objective of this type of message is to warn nearby vehicles about a potential collision in advance. Dissemination of PWMs needs to be conducted carefully as it may cause contention for channel access in the network.

There are two other message types that can be found in some warning systems. These are Road Condition Notification (RCN) and Emergency Call-Up (ECU). RCN can be used to let other vehicles know about traffic and weather conditions. However, rapid growth in smartphone apps development makes it possible to receive such information from alternative sources. ECU might be helpful for post-crash call-up to hospitals and police stations but again that can be achieved by other means. Therefore, we do not consider these types further in this paper.

2) Frequency: The number of message sent per second is closely related to overall performance of the AWS. As PWMs are sent regularly, they can become the primary contributors to the frequency count. A dynamic counter-based frequency controller could play an important role in controlling the volume of such messages [29].

3) Priority: Prioritizing message is an approach towards establishing control over data dissemination though it has not been widely implemented. Only a few proposals have considered prioritization of AWS messages though this has the potential to partition overall bandwidth intelligently for different requirements [2].

4) Coverage: Coverage is of obvious importance, yet has not been widely considered. Out of the 18 reviewed proposals, only one addressed altering coverage dynamically. Figure 4 shows how IEEE 802.11p coverage has a clear relation to data rate: an increase in coverage, decreases data rate and vice versa [30]. In a highly dense traffic environment coverage can be reduced whilst on highways with less traffic, an AWS can increase coverage to reach vehicles at a greater distance.

D. Data Dissemination Schemes

An important challenge that has to be addressed in VANET-based AWSs is how to distribute warning messages among vehicles. So far we have examined possible scenarios, potential collisions, required message types to avoid those collisions and message frequency to potential receivers. The next issue is to consider what type of dissemination scheme should be used for these messages and why.

There are two different data dissemination models: pull and push [5]. The following section discusses the suitability of those two models in An AWS context.

1) Pull Model: Data dissemination schemes that are designed based on a pull model bring information from the sender on demand. It is completely at the receiver's discretion from where and when data will be fetched. As AWSs are based on VANETs, the pull model often suffers from long latency. Previous investigation reveals that unicast paths in VANETs have very short lifetimes [31], [32] and vehicles frequently change trajectory [33]. As a result, it is difficult to keep tracking a sender for a continuous supply of data.

A recently popular pull approach is the publish/subscribe scheme where one or more node acts as the source of information, i.e. the publisher, and are followers who subscribe to access the information [24]. This approach might work well even in a wireless network where movement of the nodes is relatively slow, but not in most VANET scenarios.

Core and cluster multicast are two ideal examples of pull model [34]. At first sight these schemes might fit in the problem we are discussing. Since vehicles often move in a group on roads, formation of a core or cluster might provide the basis of group communication where a vehicle could talk to the core or cluster head and share its location while collecting neighbours information. However, this system breaks down when core node or cluster head leaves the network, as might happen at any intersection. Detection of the sudden disappearance of the core or cluster head followed by a compensatory election would potentially render the group inactive for a while and make it vulnerable.

2) Push Model: In the push model, the source sends data to receivers whenever it wishes. It injects data into the network without necessarily knowing who the receivers will be and it therefore does not have to track them. Because of the problematic mobility behaviour of the nodes, many VANET routing protocols use the push model for data forwarding [35] and indeed it has been almost universally used in previous proposals. However, the push model has its own drawbacks that are described later in this section and is not an ideal fit for data dissemination in AWSs.

Flooding is the simplest push scheme in AWS operation. Vehicles send data to their neighbours and their neighbours re-send received data to their neighbours and so on so that a warning can be propagated quickly to every vehicle. In order to reduce network load, *opportunistic forwarding* is sometime used [15]. This is a probabilistic data dissemination method that tries to send data at best effort; however, it does not guarantee successful delivery of all messages to its entire targeted audience. On the other hand, though relay-based scheme has been one of the latest approaches being tried in accident warning systems, it is not a standalone method. It requires an auxiliary data dissemination scheme to keep it active in absence of sufficient vehicles to relay data.

Limited-scope-broadcast (LSB) is the most popular push model. Instead of flooding the whole network, this aims to limit data dissemination to a specific geographical scope. Though limited-scope-broadcast does not flood the entire network by sending packets, it does flood the locale of the sender. It uses stochastic broadcast scheme and can generate a local broadcast storm.

A broadcast storm occurs when a node broadcasts a packet to its one-hop neighbours, who usually effectively receive it at the same time. If each neighbour then tries to rebroadcast immediately they will all try to get simultaneous channel access resulting in packet collision and delay. In order to avoid such situation, stochastic broadcast protocols in ad-hoc network deliberately insert a small but random jitter called a Random Assessment Delay (RAD) in the scheduling of data delivery from the network to link layer so that neighbouring nodes rebroadcast data at different times. However, when the number of rebroadcasts significantly increases, contention for channel access becomes fierce and the RAD can become overwhelmed. If the network continues to experience such behaviour, a storm will ensue.

Through numerical analysis [36] shows how a broadcast storm is generated in IEEE 802.11 multi-hop wireless networks and argues that as the number of neighbouring nodes increases, throughput performance falls. Two other works, [37], [38], investigate the problem from an ad-hoc network perspective and identify that rebroadcast plays the key role in creating a storm that leads to redundancy, contention and collision in the network. [39], [40] reinvestigate the issue from the VANET's perspective and conclude that i) high link load causes high contention in the network resulting in packet loss and ii) low packet penetration causes long delay. As a result, though limited-scope-broadcast increases the packet reach-ability ratio, it also increases the end-to-end delay.

Data Dissemination Schemes	**Accident Warning Systems**
Push Model	
Flooding	SAVN, IWS, ICWS, VSPCA
LSB at Network Layer	RBSM, OppCast, ESBR, Geo-Dess, CRCA, ODEM
LSB at Link Layer	AICC, SBIRC
Relay	WMPIV, EABS, RVSS, OAWS
Pull Model	
Multicast	ESMD
Publish/Subscribe	CarSpeak

TABLE IV. DISSEMINATION SCHEMES OF EXISTING AWS.

Table IV lists all surveyed AWSs along with the data dissemination schemes they employ. It is clear that limited-scope-broadcast from the push model is the most popular scheme, used 12 times in total. In contrast, the pull model is not popular, because of its relative incompatibility with a highly mobile network like a VANET.

It seems clear therefore that the push model is the better data dissemination model for time-sensitive warning systems. However, given the drawbacks of the schemes considered so far, none of them is ideally suited for the demands of an AWS environment

V. A Practical Model

In previous sections we have reviewed existing warning systems and identified advantages and disadvantages. We have also undertaken a requirement analysis with a view to discerning where and how an AWS should operate. It is now time to summarize the outcomes of these deliberations as they impact the design of an ideal practical warning system.

We propose that an AWS should be accompanied by at least three sensors: Lane Departure Warning Systems (LDWS), Emergency Braking System (EBS) and a Frontal Collision Detection System (FCDS). The vehicle should also be equipped with an On Board Unit (OBU) with GPS functionality. These components assist the AWS in covering possible collision scenarios discussed earlier.

In terms of transmission, the AWS should follow a push model. Though limited-scope-broadcast is a good data dissemination scheme for reaching the maximum number of relevant receivers in the minimum time, some modification is needed to optimize its transmission. Otherwise, in dense traffic environment broadcast storm will potentially render the system ineffective. As mentioned earlier in section IV(C), a cross layer interaction between network and link layer is likely to enhance performance by allowing co-access to parameters from both layers such as hop count, transmit power etc.

The warning system should be capable of sending two types of message: Event Driven Message (EDM) and Periodic Warning Message (PWM). EDMs should in turn be of two types: active, generated by a vehicle involved in an incident, and passive, generated by a vehicle witnessing who learns of an incident indirectly. As described in section IV, message should

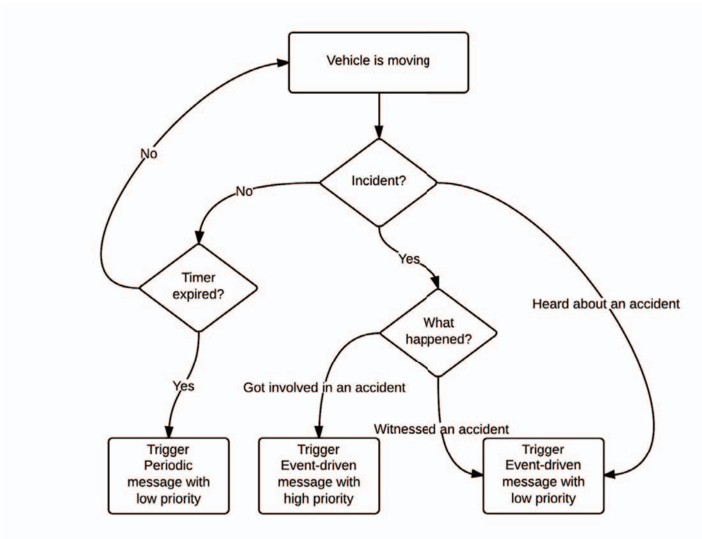

Fig. 5. Message Forwarding in a Practical Warning System

be prioritized: all active EDMs should have higher priority; passive EDMs on the other hand will have lower priority. The context of EDM messages (i.e. colliding with another vehicle, emergency braking, hitting a pedestrian etc.) can be distinguished based on a message code. We do not recommend sending road condition or traffic notification as those issues can be covered more effectively by other technologies. However, exceptional and potentially dangerous circumstance such as icy, slippery or damaged roads can be accommodated using EDMs with a special code.

We propose that PWMs issued by a source vehicle should have high priority but a forwarding vehicle should downgrade this. Underlying argument behind this design choice is that a vehicle that sends a warning generated by itself would create higher threat to the vehicles around it compared to those vehicles that forward others' PWMs. The frequency of the PWM should be controlled by a dynamic counter. There should be another control parameter to adjust coverage area. With the help of these two parameters, number of warning can be controlled by sensing the environment around the native vehicle. Figure 5 summarizes how we propose the warnings to be treated by accident warning systems.

VI. Conclusion and Future Study

This paper presents a detailed requirement analysis for building warning systems for next generation vehicles and proposes a realistic model for future development. The main contribution of this paper can be summarized as: identifying preliminaries and key requirements that is necessary to build an AWS and having reviewed existing proposals, presenting a practical model that fits with the requirements.

In future, we have three plans to accomplish step-by-step: we are going to design a realistic obstacle and mobility model to simulate warning systems that will be later used to investigate the impact and consequence of broadcast storm in this domain and finally, explore the the possibility of having a data dissemination scheme that follows push model but avoid creating broadcast storms in the network as well as mitigates other shortcomings that limited-scope-broadcast demonstrates while working with AWSs.

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References

[1] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, "A comprehensive survey on vehicular Ad Hoc network," *Journal of Network and Computer Applications*, pp. 1–13, 2013.

[2] F. J. Martinez, J.-C. Cano, C. T. Calafate, and P. Manzoni, "A VANET Solution to Prevent Car Accident," in *Proceedings of Jornadas de Paralelismo*, (Spain), 2007.

[3] "FCC Allocates Spectrum in 5.9 GHz Range for Intelligent Transportation System Uses." Published as a News Release by Federal Communications Commission, Washington, D.C. 20554., 1999.

[4] "Cars Talking and Hearing in Harmony' - a Smart Move for ETSI! Newly published ETSI Harmonized Standard enables market placement of radio equipment for road safety and traffic management." Published as a Press Release by European Telecommunications Standards Institute (ETSI), Sophia Antipolis, France., 2008.

[5] T. Nadeem, P. Shankar, and L. Iftode, "A Comparative Study of Data Dissemination Models for VANETs," in *Proceedings of IEEE Third Annual International Conference on Mobile and Ubiquitous Systems: Networking & Services*, (San Jose, CA, USA), pp. 1–10, 2006.

[6] Y. Liu, U. Ozguner, and E. Ekici, "Performance Evaluation of Intersection Warning System using a Vehicle Traffic and Wireless Simulator," in *Proceedings of IEEE Intelligent Vehicles Symposium*, (Las Vegas, NV, USA), pp. 171–176, June 2005.

[7] J. Yang, J. Wang, and B. Liu, "An Intersection Collision Warning System Using Wi-Fi Smartphones in VANET," in *Proceedings of IEEE Global Telecommunications Conference*, (Houston, TX, USA), pp. 1–5, December 2011.

[8] C. J. Merlin and W. B. Heinzelman, "A study of Safety Applications in Vehicular Networks," in *Proceedings of IEEE International Conference on Mobile Adhoc and Sensor Systems*, (Washington, DC, USA), November 2005.

[9] C.-L. Huang, Y. P. Fallah, R. Sengupta, and H. Krishnan, "Adaptive Intervehicle Communication Control for Cooperative Safety Systems," *IEEE Networks*, vol. Vol. 24, Issue 1, pp. 20–25, January-February 2010.

[10] N. F. Abdullah, A. Doufexi, and R. J. Piechocki, "Car-to-Car Safety Broadcast with Interference using Raptor Codes," in *Proceedings of IEEE 73rd Vehicular Technology Conference*, (Budapest, Hungary), May 2011.

[11] A. Sebastian, M. Tang, Y. Feng, and M. Looi, "A Multicast Routing Scheme for Efficient Safety Message Dissemination," in *Proceedings of IEEE Wireless Communication and Networking Conference (WCNC)*, (Sydney, Australia), 2010.

[12] NOAA, "GPS Accuracy," tech. rep., National Coordination Office for Space-Based Positioning, Navigation, and Timing, URL: http://www.gps.gov/systems/gps/performance/accuracy, 2013.

[13] NOAA, "GPS Modernization," tech. rep., National Coordination Office for Space-Based Positioning, Navigation, and Timing, URL: http://www.gps.gov/systems/gps/modernization, 2013.

[14] L. Yang, J. Guo, and Y. Wu, "Piggyback Cooperative Repetition for Reliable Broadcasting of Safety Messages in VANETs," in *Proceedings of 6th IEEE Consumer Communications and Networking Conference*, (Las Vegas, NV, USA), 2009.

[15] M. Li, W. Lou, and K. Zeng, "OppCast: Opportunistic Broadcast of Warning Messages in VANETs with Unreliable Links," in *Proceedings of IEEE 6th International Conference on Mobile Adhoc and Sensor Systems*, pp. 534–543, October 2009.

[16] J. J. Haas and Y.-C. Hu, "Communication Requirements for Crash Avoidance," in *Proceedings of 7th ACM International Workshop on VehiculAr InterNETworking (ACM VANET)*, (Chicago, IL, USA), pp. 1–10, September 2010.

[17] Q. Yu and D. Liu, "Disseminate Warning Message in VANETs Based on Predicting the Interval of Vehicles," in *Proceedings of 5th International Conference on Frontier of Computer Science and Technology*, (Changchun, China), pp. 559–564, 2010.

[18] F. Martinez, M. Fogue, M. Coll, J.-C. Cano, C. Calafate, and P. Manzoni, "Evaluating the Impact of a Novel Warning Message Dissemination Scheme for VANETs Using Real City Maps," in *Proceedings of International IFIP TC 6 Networking Conference*, (Chennai, India), pp. 265–276, May 2010.

[19] H. Kim, "An Efficient Alert Broadcasting Scheme Considering Various Densities in VANET," in *Proceedings of Springer Communications in Computer and Information Science (CCIS) Conference*, pp. 631–638, 2010.

[20] R. Namritha and K. Karuppanan, "Opportunistic Dissemination of Emergency Message using VANET on Urban Roads," in *Proceedings of IEEE International Conference on Recent Trends in Information Technology*, (Chennai, India), pp. 172–177, June 2011.

[21] H.-S. Kim, S.-S. Jang, H.-C. Cha, and T.-Y. Byun, "A Relay Vehicle Selection Scheme for Delivery of Emergency Message Considering Density and Trajectory of Moving Vehicles for VANET," in *Proceedings of Springer Communications in Computer and Information Science (CCIS) Conference*, pp. 257–266, 2011.

[22] Y. Li and W. Wang, "Geo-Dissemination in Vehicular Ad Hoc Networks," in *Proceedings of IEEE Ad-hoc and Sensor Networking Symposium*, 2012.

[23] A. Amoroso, G. Marfia, M. Roccetti, and G. Pau, "To Live and Drive in L.A.: Measurements from a Real Intervehicular Accident Alert Test," in *Proceedings of IEEE Workshop on Wireless Vehicular Communications and Networks*, pp. 328–332, 2012.

[24] S. Kumar, L. Shi, N. Ahmed, S. Gil, D. Katabi, and D. Rus, "CarSpeak: A Content-Centric Network for Autonomous Driving," in *Proceedings of ACM SIGCOMM*, (Helsinki, Finland), pp. 259–270, August 2012.

[25] J. Laukkonen, "A collision avoidance system may reduce the likelihood of a serious accident," tech. rep., About.com (Car Tech), 2013.

[26] Leipzig, "Lane keeping assist: Steering wheel vibrates to warn the driver if the car leaves its lane unintentionally," tech. rep., Mercedes-Benz Cars, 2008.

[27] "LKW-MAUT Electronic Toll Collection System for Germany," 2013. URL: http://www.roadtraffic-technology.com/projects/lkw-maut/lkw-maut3.html.

[28] H. Samet, "Octree Approximation and Compression Methods," in *Proceedings of the 1st International Symposium on 3D Data Processing Visualization and Transmission*, 2002.

[29] S. O. Al-Humoud, L. M. Mackenzie, and W. Vanderbauwhede, "Dynamic counter-based broadcast in MANETs," in *Proceedings of the 4th ACM workshop on Performance monitoring and measurement of heterogeneous wireless and wired networks*, (Canary Islands, Spain), pp. 84–88, 2009.

[30] C. Campolo and A. Molinaro, "Data Rate Selection in WBSS-based IEEE 802.11p/WAVE Vehicular Ad Hoc Networks," in *Proceedings of Nets4Cars*, pp. 412–416, 2010.

[31] S. Y. Wang, "Predicting the Lifetime of Repairable Unicast Routing Paths in Vehicle-Formed Mobile Ad Hoc Networks on Highways," in *Proceedings of the 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, (Barcelona, Spain), September 2004.

[32] S. Y. Wang, "On the intermittence of routing paths in vehicle-formed mobile ad hoc networks on highways," in *Proceedings of 7th International IEEE Conference on Intelligent Transportation Systems*, October 2004.

[33] J. Harri and C. Bonnet, "A Lower Bound for Vehicles Trajectory Duration," in *Proceedings of IEEE Vehicular Technology Conference*, 2006.

[34] P. Mohapatra, C. Ghu, and J. Li, "Group Communications in Mobile Ad Hoc Networks," *IEEE Computer*, vol. 37, pp. 52–59, February 2004.

[35] R. Chen, W. Jin, and A. Regan, "Broadcasting in Vehicular Networks: Issues and Approaches," *IEEE Networks*, vol. 24(1), pp. 20–25, January–February 2010.

[36] J.-M. Choi, J. So, and Y.-B. Ko, "Numerical Analysis of IEEE 802.11 Broadcast Scheme in Multihop Wireless Ad-hoc Networks," *Information Networking. Convergence in Broadband and Mobile Networking Lecture Notes in Computer Science*, vol. 3391, pp. 1–10, 2005.

[37] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad Hoc Network," in *Proceedings of ACM MOBICOM*, (Seattle, Washington, USA), pp. 151–162, 1999.

[38] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad-hoc Network," *Wireless Networks*, vol. 8, pp. 153–167, 2002.

[39] N. Wisitpongphan, O. K. Tonguz, J. S. Parikh, P. Mudalige, F. Bai, and V. Sadekar, "Broadcast Storm Mitigation Techniques in Vehicular Ad Hoc Networks," *IEEE Wireless Communications*, pp. 84–94, 2007.

[40] F. J. Martinez, C.-K. Toh, J.-C. Cano, and C. T. Calafate, "A Street Broadcast Reduction Scheme (SBR) to Mitigate the Broadcast Storm Problem in VANETs," in *Proceedings of Wirelss Pers. Communication*, 2011.