Context-Aware Cooperative Collision Avoidance Vehicle Braking Alert System for VANET

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ABSTRACT
Cooperative safety and infotainment were the key motivating factors behind the advent of vehicular communication architecture. In this paper, the Context-aware cooperative collision avoidance braking system is proposed. The vehicles moving in the same lane, closer than the safety distance (SD) are prompted to reduce their speed or increase the inter-vehicular distance. The SD is set according to the available parameters and road infrastructure, and is further tuned with the help of context-aware SD adjustment system. The system proposed is self-learning and alert messages are directed to only pertinent vehicles with the help of clustering. The hardware system is implemented in vehicle on highway for SD calculation.

Keywords
Collision avoidance, braking system, collision avoidance warning system, Cooperative collision avoidance, VANETs

1. INTRODUCTION
Accidents on the highways have taken the lives of many human beings since the advent of vehicles. Studies show that 60% of the accidents could have been succumbed, if the driver have been alerted a few fraction of a second in advance about the possible collision [1]. Moreover, on highways with large number of vehicles with high speeds, the damage of collision is enormous as in case of chain collisions. Vehicular Ad Hoc Network (VANET) is a special type of Mobile Ad Hoc Network (MANET) due to its unique features of no battery constraint and rapid mobility. Communication in VANETs is governed by Wireless Access in Vehicular Environment (WAVE) architecture [2]. One of the key motivation to develop WAVE architecture was to provide safety messages (such as accident alerts) and other time sensitive data services in a timely manner in order to reduce the number of possible casualties and fatalities. Wave Short Message (WSM) Protocol is used specifically for prioritizing the time-sensitive information data. A separate channel has been dedicated to the delivery of safety messages in a timely manner in the IEEE 802.11p protocol [3].

Studies have shown that the reaction time of a driver between collision detection event and application of brakes varies from 0.7s to 1.5s [2]. Many researchers have come with host of warning systems to alert the driver about the possible collision well ahead of the event [5, 6, 7]. Given the number of inputs, the On-board unit can determine the SD between the two adjacent vehicles. This SD is compared with the instantaneous distance of the vehicles in-line. Both the vehicles in front and behind, are monitored. In case, the instantaneous distance becomes less than the SD the front vehicle is alerted about the incoming vehicle. This kind of alert system is installed in the vehicle and can be used as a collision avoidance system on highway roads, where accidents due to driver fatigue and misjudgment of speed is a norm [8, 9].

Cooperative collision avoidance (CCA) is an application of inter-vehicular communication (IVC) protocol to reduce the rates of accidents. Implementation of CCA reduces the chain accident rates on highway platoons by 90% [10]. It is essential that such alert systems should be aware of the type of vehicles involved in the operation in a particular highway road as SD for various vehicles may vary. We use this technique amongst various types of vehicle in order to alert the drivers about the precise time to change the speed as per the situation. Packet dissemination in traditional mobile networks is usually achieved through topology based routing [11], but for CCA, it is more pertinent to use position-based routing [12] [13] due to the presence of Global Positioning Systems (GPS) in such nodes.

2. RELATED WORK
Collision avoidance has been achieved by many context-based models. In [6] two context models have been proposed. In the first model, Information such as Vehicle ID, physical dimensions, GPS coordinates, direction, speed, acceleration, time stamps and type of vehicle is used for computing the collision probability. The second model is an extension of the first model, in which details such as visibility, street view, rain intensity and temperature are obtained to get a better insight of context based decisions. For example, in dark, foggy condition collision warning will be sent substantially earlier than in clear daylight condition. In [14] two scalable cluster-based context-aware protocols were proposed for time sensitive and location based services to achieve better delivery rate and bandwidth utilization. Extensive research work has been done to make the vehicular communication more context-aware; adapting to change in density, speed, congestion, energy, connectivity and spatial mapping of vehicles. In [15], three parameters such as the distance to destination, traffic load of the corresponding road segment and real time vehicle density were used for the sequential selection of different junctions to build the route for increasing the packet delivery ratio and minimizing the average end-to-end delay. Movement prediction and real time traffic density information were utilized for selecting the route for data transfer based on selecting dynamically the junctions that should be used by the packets to pass through [16] and then, it uses an improved greedy strategy for forwarding packets between the two junctions. In [17], the congestion aware routing protocol is presented for VANETs. The throughput of a shared channel is limited by the channel capacity and transmissions in the nearby nodes. The proposed routing protocol restricts the transmissions in the congested nodes. MAC overhead, date rate and link quality were used for computing the

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congestion probability of each node. The routing metric of the proposed protocol is based on the congestion probability. The proposed routing protocol results in reduction of the control overhead, link stability and throughput improvement. A context aware and energy driven route optimization technique is developed for Fully Electric Vehicles (FEV) in [18]. Vehicle to Vehicle communication has been used to realize context awareness. Linearly combined Cost Optimization (LCO) and Energy-Constrained Optimization (ECO) optimality formulations were used to address the energy-driven aspect. Greedy forwarding in a vehicular environment can lead to topology holes (when a packet cannot be further forwarded due to absence of neighboring nodes) -which stresses the need of the spatial view of environment [19]. To counter the topology holes, the optimal global route towards the destination is obtained using the Dijkstra's algorithm rather than the optimal local view. The optimal global view is obtained by layering the map from abstract details to minute details. Due to the rapid topological changes, incorrect density collection, buildings in between; shortest path in geographic routing might have shorter life because of disconnections. The remedy is to divide the road into segments of size equal to that of an average car. The safe distance between the vehicles were computed using there action time, comfort brake factor, average velocity and the length of the cell [20]. Probability of vehicles turning towards a particle road and the number of nodes turning to a particular road is evaluated using the number of vehicles that may turn on other roads of the intersection vehicles stopping at the intersection forms cluster and becomes normal after resuming their motion. Many hardware systems have been patented for collision avoidance and SD calculations. In [21], the SD between vehicles in a straight line is checked and a warning is associated if the vehicles come closer than the SD. But in [21], the SD, only varies from person to person, not as per the capability of car's braking capacity. In [22], driving method of various drivers were observed and SD was determined accordingly to reduce the number of accidents as safe distance set for various speeds without considering driver's driving might be frustrating for some drivers. The driver manually enters his reaction time in [22], which might be doubtful in many instances. Reaction time is adapted over time by considering its maximum and minimum limit. Factors like driver's indication light, reaction time, acceleration and braking the pedal are used to determine the SD.

3. COLLISION AVOIDANCE BRAKING ALERT SYSTEM

In this paper, a simple highway scenario consisting of three cars going in the fast lane in a straight line on a certain highway is considered as shown in Figure 1. The driver of the middle car having fatigue might head on and collide with the car ahead. Eventually, the vehicle # 1 might also collide due to instant breaking by the two vehicles in front thus causing chain collision of the substantial damage. We have designed a cooperative collision avoidance braking alert system (CCABAS) which avoids such situation. Before dwelling into the algorithm that governs the CCABAS, the following assumptions are made:

- All the nodes are equipped with On-board unit, digital maps and GPS module.
- All the vehicles are assumed to calculate the relative velocity, the relative distance and direction of the vehicle in front and behind them using GPS.

The SD is first set as per the input parameters available. If the instantaneous distance between two vehicles becomes less than the SD, then the vehicles are alerted to increase the distance. The braking alert system is self- configuring and context aware; as SD for vehicle with traditional and advance braking systems (Anti-lock Braking System) is different. Thus, the CCABAS compute the vehicles braking capacities by exchanging the information using inter-vehicular communication (IVC).

Information about the braking capacity is exchanged between all the vehicles in a spatial environment. However, the alert messages are only delivered to the vehicles in a straight line. For instance, the critical information about safety is irrelevant for vehicle#4 in the particular scenario (see Figure 1). Thus, only vehicles travelling in a straight line should be alerted by the system. This is achieved by velocity, GPS coordinates and direction comparison. Thus, after performing the comparison of the three vehicles (that forms the cluster), the message is received by the members of the cluster only. The alert message contains the Vehicle ID, direction, current speed, cluster table (containing member vehicle IDs) and GPS coordinates of the vehicle. The relative velocity and distances computed using GPS coordinates and direction. If there is a change in vehicle lane, the information about these vehicles removed from the cluster table.

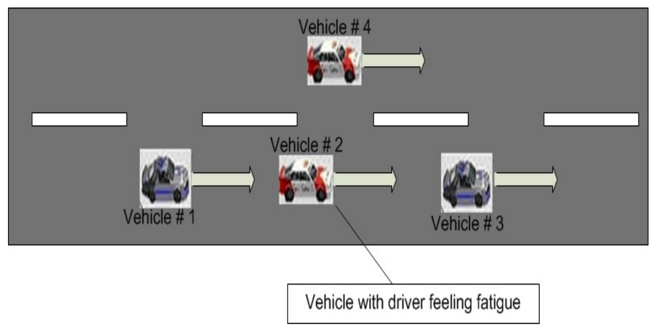

Figure 1. Highway scenario with potential collision situation

4. SD CALCULATION

We have computed the SD based on the number of the available input parameters and the type of terrain. Referring to Figure 1, if Vehicle# 2 is the reference vehicle, vehicle#1and vehicle#2 are moving ahead and behind the reference vehicle.] Generalizing the concept, If Ven is the vehicle under consideration, then we can assume that the vehicle in front is denoted by Ven+1 and the vehicle immediately behind is denoted by Ven-1. The following notations were used for computing the SD.

Vn: Speed of the considered vehicle Ven

F: Vehicles in front of the considered vehicle Ven-1

B:Vehicles behind of the considered vehicle Ven+1

a: Acceleration of the considered vehicle Ven

be: Brakes applied by the considered vehicle Ven in emergency situation

bn:Brakes applied by the considered vehicle Ven in normal situation

β:Tolerence factor

δ: Reaction time of driver.

The SD between two adjacent vehicles can be computed as follows [5]:

$$SD = \beta \times (Ve_{n-1} \times \delta + \frac{Ve_{n-1}^2}{2b_n} + \frac{Ve_n^2}{2a_e}) \quad (1)$$

Thus, first product term of the equation (2) is the personal space that seems unsafe to the driver, while the second term is related to relative speed and breaking response time of the driver. Third and fourth term corresponds to deceleration and breaking capacity of the vehicle.

Now considering the braking capabilities of the vehicles, we calculate the SD by [21]:

$$SD = VR \times TIMEK - VRR \times TIMEN + \left(\frac{(VRR)^2}{2 \times GR}\right) - \alpha G \times GA \quad (2)$$

Where:

VR = velocity of the vehicle

TIMEK = Uncomfortable distance between the vehicles for the driver

VRR= Relative speed between the vehicles

TIMEN = Response time of the driver

GR = Braking deceleration factor

αG = Acceleration of vehicle ahead

GA = Depressing capacity of the preceding vehicle

If the highway under consideration is on a slope, then considering other pertinent factors, SD is calculated as [23]:

$$SD = \left[\frac{W}{2gC_{ae}}\right] \times \ln(1 + C_{ae} V^2 / (\eta\mu W + f_r W \cos\theta + W \sin\theta)) \quad (3)$$

Where:

W=Weight of the vehicle

g= gravity pull

η=Efficiency of the brake

μ= Friction factor

fr=Rolling factor

θ= Slope of the road

Cae= (ρ×A_f×C_d)/2 (4)

ρ= Air density

Af= Projection area

Cd=Air drag factor

Equation (4) can be applied to any vehicle having "W" weight moving at an inclined road with slope θ, moving with some amount of rolling and friction factor having break efficiency of η

Depending upon the set of available parameters and type of terrain any equation from Equations (1) to (3) can be used to set up the initial value of the SD. The braking capacity of each vehicle is considered and then, the value of SD is adjusted as per the system output using the following system design (Figure 2).

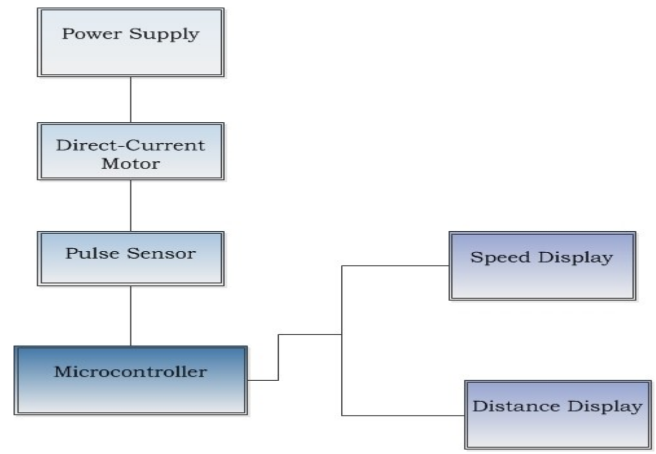

Figure 2. Context-Aware SD adjustment System

The above hardware system calculates the time taken by the individual vehicle to apply brakes and distance covered to reach the rest speed. The learnt data are then used to adjust the evaluated value of SD. The SD is then used for comparison with instantaneous distance between vehicles and drivers are alerted if the instantaneous distance is less than the SD.

5. STRUCTURE OF THE COMPLETE SYSTEM

The structure of the complete system is explained by the flow diagram depicted in Figure 3. The input parameters are gathered as per the road infrastructure, slope of the road and environment. The initial value of the SD is set with the help of equations (1) to (3), then the SD adjustment were made as per the braking capacity of the individual vehicle. System learns about the braking capacity of the individual vehicle and driver by observing his braking time to get the car to rest. It is updated with each pattern learned. The information about the SD is broadcasted. Same line vehicles are detected by the use of GPS, velocity and direction of motion. Same lane vehicles form a cluster. Intervehicle distance of the vehicles belonging to the same cluster is constantly observed. In case of potential collision, the alert safety messages are sent to only those vehicles that are in the same lane (multicasted to cluster members).

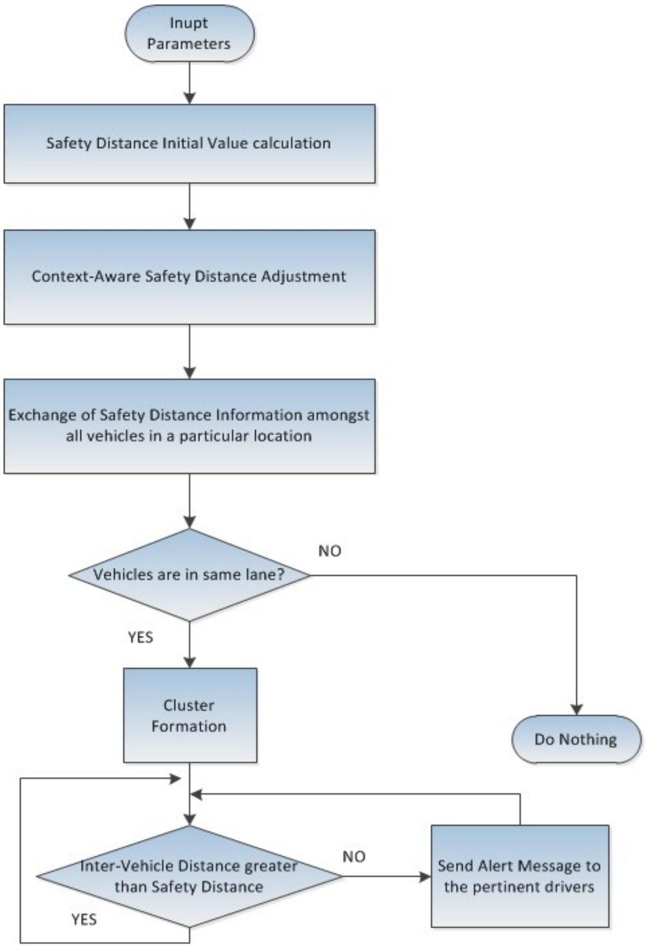

Figure 3. Flow Diagram of the context-aware CCABA System

6. HARDWARE SYSTEM EVALUATION RESULT

The hardware system was implemented on a highway (Motorway – Peshawar to Islamabad) in Pakistan for the speed ranges from 50km/hr up to 170km/hr. The distance and time taken by the application of brakes were recorded and then, the SD was adjusted. Figure 4a and 4b shows distance travelled and time taken after applying the brakes to make the vehicle rest to zero speed respectively. By comparing the values of distances covered from Figure 4a with the evaluated SD, the SD is adjusted.

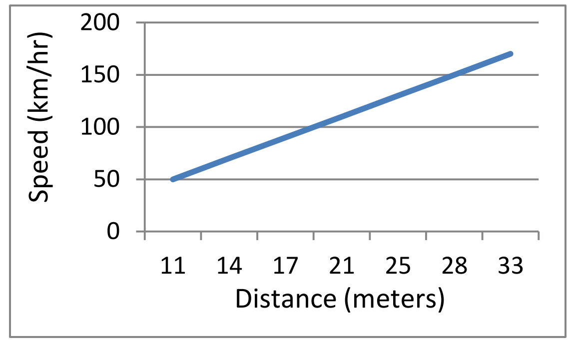

Figure 2a. Distance covered to decrease the speed to zero

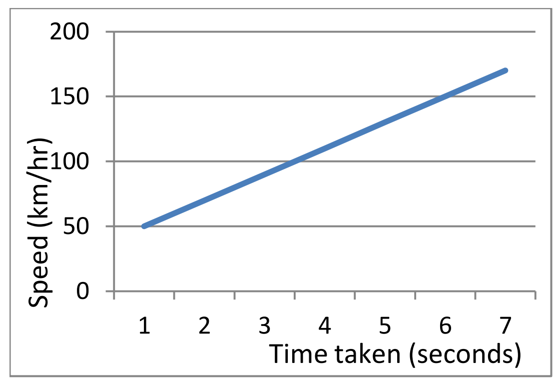

Figure 4b.Time taken to decrease the speed to zero

7. CONCLUSIONS & FUTURE WORK

We have designed and implemented a Context-aware cooperative collision avoidance braking alert system. The SD is set to alert the drivers if they are moving too close to the vehicle in front and behind. The alert safety message is multicasted rather than broadcasted to avoid irritation and disturbance to other drivers. The system learns about the braking capacity of vehicles and SD is set accordingly. The system is of great use to avoid collisions due to common highway problems such as driver's fatigue.

In future we intend to automate braking system with the alert system in order to save lives and damages more efficiently.

8. REFERENCES

[1] C. D. Wang and J. P. Thompson.Apparatus and method for motion detection and tracking of objects in a region for collision avoidance utilizing a real-time adaptive probabilistic neural network, 1997. US.Patent No. 5,613,039.

[2] Uzcategui, R.; Acosta-Marum, G.; , "Wave: A tutorial," Communications Magazine, IEEE , vol.47, no.5, pp.126-133, May 2009

[3] IEEE P802.11p/D3.0, "Draft Amendment to Standard for Information Technology-Telecommunications and Information Exchange between Systems – Local and Metropolitan Area Networks-Specific Requirements — Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications-Amendment 7: Wireless Access in Vehicular Environment," 2007

[4] M. Green. "How Long Does It Take to Stop?" Methodological Analysis of Driver Perception-Brake Times. Transportation Human Factors, 2(3):195–216, 2000.

[5] Taleb, T.; Ooi, K.; Hashimoto, K., "An Efficient Collision Avoidance Strategy for ITS systems," Wireless Communications and Networking Conference, 2008.WCNC 2008.IEEE , vol., no., pp.2212,2217, March 31 2008-April 3 2008

[6] Eigner, R.; Lutz, G., "Collision Avoidance in VANETs - An Application for Ontological Context Models," Pervasive Computing and Communications, 2008.PerCom 2008. Sixth Annual IEEE International Conference on , vol., no., pp.412,416, 17-21 March 2008

[7] Tatchikou, R.; Biswas, S.; Dion, F., "Cooperative vehicle collision avoidance using inter-vehicle packet forwarding," Global Telecommunications Conference, 2005.GLOBECOM '05.IEEE , vol.5, no., pp.5 pp.,2766, 2-2 Dec. 2005

[8] Sagberg, Fridulv."Road accidents caused by drivers falling asleep." Accident Analysis & Prevention 31, no. 6 (1999): 639-649.

[9] Schmidt, Eike A., Michael Schrauf, Michael Simon, Martin Fritzsche, Axel Buchner, and Wilhelm E. Kincses."Drivers' misjudgement of vigilance state during prolongedmonotonous daytime driving." Accident Analysis & Prevention41, no. 5 (2009): 1087-1093.

[10] Tatchikou, R.; Biswas, S.; Dion, F., "Cooperative vehicle collision avoidance using inter-vehicle packet forwarding," Global Telecommunications Conference, 2005.GLOBECOM '05.IEEE , vol.5, no., pp.5 pp.,2766, 2-2 Dec. 2005

[11] Soujanya, B., T. Sitamahalakshmi, and C. H. Divakar."Study of Routing Protocols in Mobile Ad-Hoc Networks."International Journal of Engineering Science and Technology 3, no. 4 (2011).

[12] Mauve, M.; Widmer, J.; Hartenstein, H., "A survey on position-based routing in mobile ad hoc networks," Network, IEEE , vol.15, no.6, pp.30,39, Nov.-Dec. 2001

[13] Stojmenovic, I., "Position-based routing in ad hoc networks," Communications Magazine, IEEE , vol.40, no.7, pp.128,134, Jul 2002

[14] Abrougui, K.; Boukerche, A.; Pazzi, R.W.N., "Design and Evaluation of Context-Aware and Location-Based Service Discovery Protocols for Vehicular Networks," Intelligent Transportation Systems, IEEE Transactions on , vol.12, no.3, pp.717,735, Sept. 2011

[15] Chunchun Zhao; Changle Li; Lina Zhu; Hang Lin; Jiandong Li, "A vehicle density and load aware routing protocol for VANETs in city scenarios," Wireless Communications & Signal Processing (WCSP), 2012 International Conference on , vol., no., pp.1,6, 25-27 Oct. 2012

[16] Jerbi, M.; Senouci, S.-M.; Meraihi, R.; Ghamri-Doudane, Y., "An Improved Vehicular Ad Hoc Routing Protocol for City Environments," Communications, 2007.ICC '07. IEEE International Conference on , vol., no., pp.3972,3979, 24-28 June 2007

[17] Barba, C.T.; Mezher, A.M.; Igartua, M.A.; Guérin-Lassous, I.; Sarr, C., "Available Bandwidth-Aware Routing in Urban Vehicular Ad-Hoc Networks," Vehicular Technology Conference (VTC Fall), 2012 IEEE , vol., no., pp.1,5, 3-6 Sept. 2012

[18] Yan Wang; Jianmin Jiang; Tingting Mu, "Context-Aware and Energy-Driven Route Optimization for Fully Electric Vehicles via Crowdsourcing," Intelligent Transportation Systems, IEEE Transactions on , vol.14, no.3, pp.1331,1345, Sept. 2013

[19] Jing Tian; Lu Han; Rothermel, K., "Spatially aware packet routing for mobile ad hoc inter-vehicle radio networks," Intelligent Transportation Systems, 2003.Proceedings. 2003 IEEE , vol.2, no., pp.1546,1551 vol.2, 12-15 Oct. 2003

[20] Qing Yang; Lim, A.; Shuang Li; Jian Fang; Agrawal, P., "ACAR: Adaptive Connectivity Aware Routing Protocol for Vehicular Ad Hoc Networks," Computer Communications and Networks, 2008. ICCCN '08. Proceedings of 17th International Conference on , vol., no., pp.1,6, 3-7 Aug. 2008

[21] Hibino, Katsuhiko, Takao Nishimura, and Noriaki Shirai."Measuring apparatus for detecting distance between vehicles and related warning system." U.S. Patent 5,684,473, issued November 4, 1997.

[22] Nocker, Gerhard."Method for controlling the distance between moving motor vehicles." U.S. Patent No. 5,375,060. 20 Dec. 1994.

[23] Chen, Yuan-Lin, and Chong-An Wang. "Vehicle Safety Distance warning system: A novel algorithm for vehicle Safety Distance calculating between moving cars." In Vehicular Technology Conference, 2007.VTC2007-Spring. IEEE 65th, pp. 2570-2574. IEEE, 2007