Adjacent Vehicle Collision Avoidance Protocol in Mitigating the Probability of Adjacent Vehicle Collision

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***Abstract*—This paper introduces a collision avoidance technique for Vehicular Ad hoc Networks (VANETs). An alarm is generated as a warning by the adjacent vehicle depending upon the active speed of impact (ASI) a vehicle expects to encounter after both the adjacent vehicles expect to apply brakes, while in full throttle exactly at the same time. A novel technique of measuring the vehicles' stopping time is introduced by manipulation of co-efficient of decreasing speed (CODS) by the receiving vehicle. Depending upon the received information of CODS, initial speed and other associated factors, the vehicle is given a pre-emptive signal to maintain a safety margin by decreasing or increasing the current vehicle speed. An efficient data packet protocol known as Adjacent Vehicle Collision Avoidance version 1.0 (AVCA ver 1) is introduced in order to update the receiving vehicle with minimum possible data-rate and the requisite amount of data.**

Keywords- V2V; VANE; co-efficient of decreasing speed

I. Introduction

Most of the time the vehicles are moving juxtapose with each other. There is always a possibility of a collision if the vehicles are moving very close to one another. A measure of a minimum threshold distance is therefore useful even if both the adjacent vehicles apply brakes at full throttle simultaneously. A collision can take place if the stopping distance D_{stop} and stopping time T_{stop} of the followed vehicle is less than that of following vehicle. Length of T_{stop} and D_{stop} depends upon the inertial property, initial speed of the vehicle V_i just before applying brakes, the gear of the vehicle at which it moves and braking system of the vehicle. It is mandatory for adjacent vehicles to share critical information among each other *a priori* to avoid any possibility of in-line collision in advance. The passive vehicle (one that receives the signal from adjacent vehicle) using inter-vehicular communication [7] estimates the active speed of impact (ASI) in order to gauge the possible impact for a certain speed which leads the driver to adjust the speed down to some safe limit. A measure of the vehicles' stopping distance D_{stop} and stopping time T_{stop} after the brakes are applied, is not always constant. In this paper, the speed just before applying the brakes is denoted by Initial speed V_i and the speed after applying brakes is represented as final speed V_f. It is worth considering that after applying brakes the instantaneous speed v follows a certain behavioral trend w.r.t time that varies from vehicle to vehicle. The trend of decreasing speed w.r.t time is because of the fact that a vehicle might follow either concave behavior, convex behavior or linear behavior depending upon the specific gear at which it moves. The information sharing among adjacent vehicles about the type and the initial slope of a specific trend is usually quantified using fuzzy logic to forecast the severity or leniency of the impact among vehicles. The importance of CODS (Co-efficient of Decreasing Speed) is that it almost follows a linear behavior with respect to V_i provided the infinitely large amount of sampled data for PSD (Power Spectral Density) processing and the trend factor no matter what the Behavior of Trend Type (BTT) is, which results in abridgment of the information sent to the adjacent passive vehicle.

A communication model has been presented in [1]. Similarly VICS [2] shows the vehicular information and communication system for how to communicate information from one vehicle to other using radio wave propagation among vehicles. A reliable vehicular collision detector, VCDnet, is discussed in [3] shedding light on how to avoid collision among adjacent vehicles by sending the current speed and position information. Radar technology can be used for the detection of adjacent vehicles [8] but the PHY layer for communication is not discussed in appropriate detail. The protocol design in upper layers of OSI model is however, discussed in [8].

II. Behaviour models of Decaying speed

After applying brakes, the trend of decreasing speed with respect to time can be either linear or it may have moderate response at beginning and have an immediate response later on which is termed as behaving in convex structure. There might be a possibility that the graph slump off rapidly at beginning and then the change in speed slows down later on which is termed as having concave behaviour. Each of the above mentioned trends is termed as a Behaviour Trend Type (BTT). The regression analysis makes the work easier by formulating the data into a specific shape. Let v be the instantaneous speed of the vehicle and S be the constant slope, the linear BTT can then be seen in (1).

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$$v = V_i + S \times t; \quad 0 < t < T_{stop} \quad (1)$$

Where S is the slope of a certain trend provided, V_i is the initial speed just before applying brakes. Variables represented by (1) are t and v which represents the instantaneous time and its corresponding speed respectively.

At a time instant less than $T_{stop}/2$ the convex behaviour of the followed vehicle exhibits the condition of severe collision with the following vehicle as compared to a concave behaviour, depending upon the trend factor and hence the initial slope value S_i. Lower the value of slope, the more severe will be the condition at time instant below $T_{stop}/2$. Mathematically, the convex BTT is expressed in (2).

$$v = at^2 + bt + V_i; \quad 0 < t < T_{stop} \quad (2)$$

Where a and b are the coefficients and a represents a negative value showing that the graph inclines downward from its initial position.

The last BTT to discuss is the concave behavior. This is some-what safer than previous discussed behaviors. It is normally exponentially decaying with a rapid decrease at the start of applied brakes. (3) Represents the concave model behavior.

$$v = V_i \exp(-at); \quad 0 < t < T_{stop} \quad (3)$$

Where a is the decaying factor. Larger the value of a, more rapid is the decay.

Let us take an example to get familiarized with each BTT in more depth by showing the behavioral trend during the time duration T_{stop} under a specific gear-system which is accomplished during the course of deceleration. Figure 1 shows the mentioned behaviors along-with the tangent S_i.

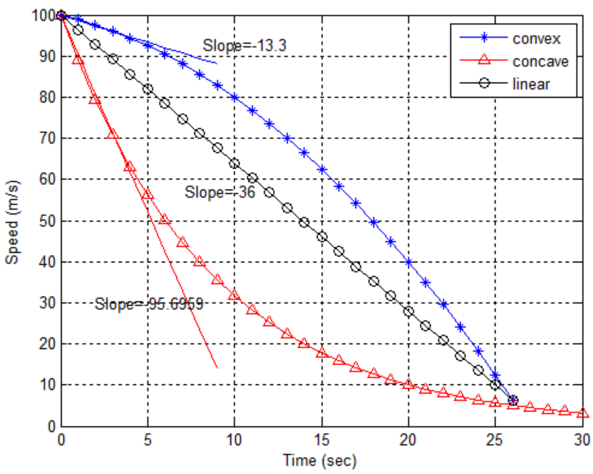

Figure 1. Three possible trend types representing Concave, Convex and Linear Graphs

The behavior obtained for each gear system is updated by the vehicle each time it apply brakes. The initial slope for each behavioral model is engendered by drawing a tangent to each graph initially, characterized by the linear, concave and convex trends. (4) Defines the characteristics of the tangent slope.

$$\tau = -S_i * t + V_i \ ; \quad 0 < t < 10 \, f_{s\_acq} \quad (4)$$

Where f_{s_acq} is the acquired data sampling rate, V_i represents the y-intercept and τ is the straight tangent line. In case of linear behavior, the slope value is constant whereas concave and convex BTT show different slope values at each time instant. For instance we take the value of S_i for convex, concave and linear BTTs. S_f is the final slope taken as tangent to the end of each graph but its exact use is outside the scope of this paper.

III. COEFFICIENT OF DECREASING SPEED

CODS is measured as the decay factor of a vehicle during the time interval $0 < t < T_{stop}$ which gives a direct measure of speed decay of a certain vehicle after the brakes are applied. The most important factor that affects CODS is V_i. Beside V_i CODS is contingent on inertia of the vehicle which in turn depends directly on the mass of the vehicle. Similarly other factors include the specific gear at which the vehicle is moving. It is interested to note that the CODS show a linear relationship w.r.t V_i for which the S_i depends upon the gear at which the vehicle is moving. Certain assumptions are taken into consideration and are discussed below:

- Opening the side windows in a vehicle may affect CODS pertaining to a specific trend type due to the dragging effect of wind. The assumption is not taken into account.
- V_f is kept at 3 m/s.

As a supervised learning technique, regression, is used in order to keep the information updated each time the brakes are applied for the interval $0 < t < T_{stop}$. The technique of measuring CODS is discussed step-by-step in following sub-sections:

A. Regression:

The real-time data is acquired with a sampling rate of f_{s_acq} Hz. A simple regression technique is applied in order to smooth-out the data according to either of three data-set behavioral trends (convex, concave and linear) as discussed in previous section. The simple data-fitting technique is applied in order to shape the acquired data according to a specific BTT. Figure 2 represents a fitted data after regression is applied. The period T is the time-gap between circled-points on graph which is the multiplicative inverse of the acquired data sampling frequency f_{s_acq}. The resulted fitted signal is represented by γ.

B. Multiplication with a Sinusoid:

After regression, the fitted-data is dot multiplied with the sinusoidal signal and the resultant is represented by (5)

$$\delta = \gamma \, . \cos(2\pi f t) \quad 0 < t < T_s \quad (5)$$

Where δ represents the resultant signal after the fitted data γ is multiplied with the sinusoidal signal. f in (5) is the scalar frequency of the sinusoidal signal. Figure 3 shows the graphical representation of δ.

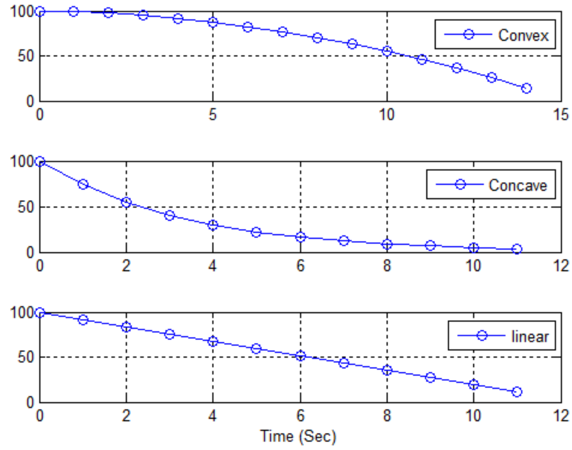

Figure 2. Behavior Representation after Data-Fitting is Applied

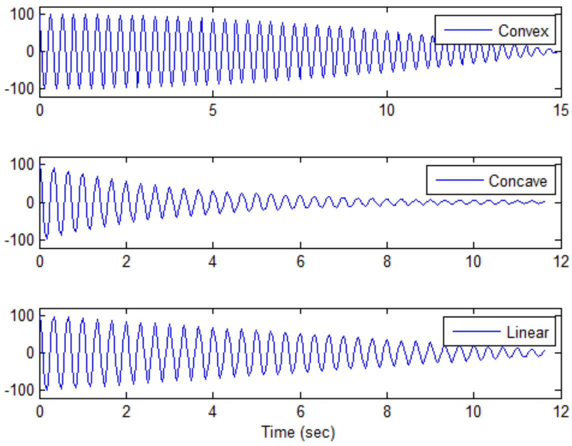

Figure 3. Resultant Data After Sinosoidal signal is multiplied

C. *PSD Estimation Using Welch Method:*

Welch Method is a popular technique for calculating the Power Spectral Density (PSD) of a signal by efficiently exploiting the discrete sampled data δ in such-a-way as to reduce the noise up-to a great extent.

For instance, if f_{max} is the center frequency of maximum PSD then $f_1$is termed to be the first half power frequency and f_2 is the second half frequency. Figure 4 elaborates the graphical representation of PSD. It can be seen that $f \approx f_{max}$where f is the frequency of the sinusoidal signal. CODS can be calculated after knowing the values f_1, f_2 and f_{max}, as shown in (6).

$$\text{CODS} = \frac{f_2^2 - f_1^2}{2f_{max}^2} \qquad (6)$$

From Figure 4 It can be seen that more the width of PSD, higher the value of CODS. For instance, while calculating the values of CODS obtained from example shown in Figure 4, it is observed that CODS for convex behaviour shows a value of 0.0690. Similarly the CODS for concave show's 0.0567 whereas linear CODS expresses the value of 0.0728. These values show the fact that CODS is inversely proportional to $T_{stop}$and D_{stop}.

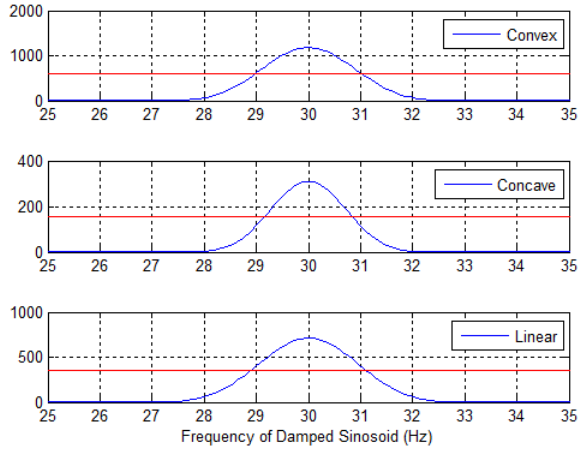

Figure 4. PSD Representation of Damped Sinosoidal Signal

IV. DATA FRAME

One of the significance of CODS is that it behaves almost linearly w.r.t V_i if a large amount of sampled data is taken for estimating PSD and due to this inherent property there is no such complex computation by the passive vehicle in recovering the stopping time T_s of the active vehicle using the dependent variable of a linear equation. (7) Shows a linear curve-fit equation for the data-set shown in Figure 5.

$$\text{CODS} = -0.0001813V_i + K1 \qquad (7)$$

Where *K1* is a constant for the data-set in Figure 5 and its value is 0.08407 which is the maximum possible value of CODS for V_i=0. In this section, an efficient data frame and the associated protocol is modeled through which the adjacent vehicle (following/followed) could decide the extent of decreasing speed in order to avoid the possibility of adjacent vehicle collision. For f = 30 Hz and f_s = 300 Hz, the passive vehicle can compute the stopping time T_{stop} using (8).

$$T_{stop} = -1.453 \times 10^4\text{CODS} + K2 \qquad (8)$$

Where *K2* is a constant showing the maximum possible value of T_{stop}. Computing T_s from CODS is possible only if the extremely large amount of sampled data, normally greater than 10^{12+x} samples for x ≥ 1 is provided for the previously taken example.

A. *AVCA ver1 Protocol:*

Data packet which the active vehicle sends to the passive vehicle needs to be efficient such that the passive vehicle receives only that information on relatively high data-rate which requires immediate update. Several methods for identifying the vehicle identity have been proposed in previous work, like adaptive traffic beacon [4] using inter-vehicular communication [4,5,9]. Similarly inter-vehicular communication among adjacent vehicles was discussed in [7].

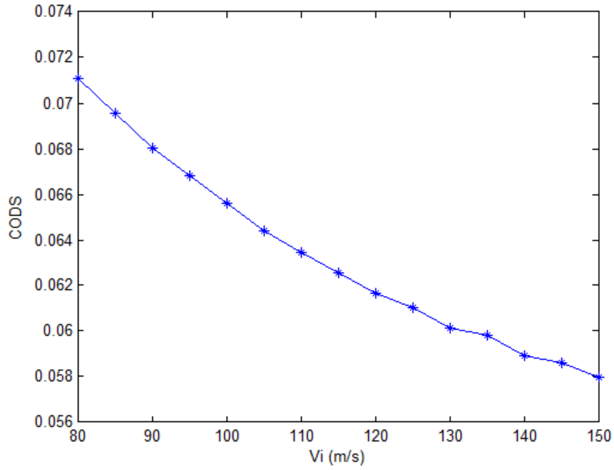

Figure 5. Relation between CODS vs. Vi

Due to space limitations we have confined ourselves to the packet design whereas the PHY layer modeling is left for future work. The vehicle identity I along with update of the active vehicle is needed by the passive vehicle only if the active vehicle is replaced by some other vehicle or if the time-stamp deadline expires. Similarly the BTT update is needed by passive vehicle only if the active vehicle changes the gear or if the time-stamp duration is completed. The time stamp for the update of variables I and BTT is larger than V_i(Initial Speed), S_i (Initial Slope) and S_f (Final Slope). An efficient protocol which is termed as Adjacent Vehicle Collision Avoidance (AVCA) protocol (Table 1) is hence designed which consists of minor frames and a major frame. The data rate of the frame is kept constant so that the overheads due to initial negotiation are minimized to its best. Such initial negotiations are discussed in [4]. The minor frame is one represented by the Bit Sync identity with a fixed size of four cells. One major frame is comprised of 64 minor frames. The resolution of each cell is 16 bits. Let the bit rate among the adjacent vehicles be 100bps which must be same in both the adjacent vehicles sharing information, then the sampling frequency of I and BTT is 0.0488 Hz which means the information is updated after every 20.48 seconds. Similarly for the given configuration, the information about V_i, S_i, S_f and CODS is updated after every 1.28 seconds. The last column is left for any future extension that might prove useful in further refinement of the proposed idea.

It is interesting to note that the AVCA ver 1 protocol is triggered back to BitSync (1) during its run-time after the gear is changed or the adjacent vehicle is replaced by another one. This is because the time-stamp for I and BTT update is a-bit long which need triggering information to update itself before the time-stamp comes to an end.

BTT is computed by the passive vehicle taking V_i and T_{stop} as inputs. θ_{ref} can be computed using (9).

$$\theta_{ref} = \tan^{-1}\left(\frac{V_i}{T_{stop}}\right) \qquad (9)$$

TABLE 1. V2V AVCA VER1 PROTOCOL

BitSync(1)	*Vehicle Identity*	BTT	FFFF
BitSync(2)	V_i	S_i	FFFF
BitSync(3)	CODS	S_f	FFFF
. . .	. . .	. . .	. . .
BitSync(31)	V_i	S_i	FFFF
BitSync(32)	CODS	S_f	FFFF
BitSync(33)	*Vehicle Identity*	BTT	FFFF
BitSync(34)	V_i	S_i	FFFF
BitSync(35)	CODS	S_f	FFFF
. . .	. . .		. . .
BitSync(63)	V_i	S_i	
BitSync(64)	CODS	S_f	FFFF

θ_{ref} acts as reference angle for comparison with θ. θ can be computed using (10).

$$\theta = \tan^{-1}(|S_i|) \qquad (10)$$

If $\theta > \theta_{ref}$, then BTT is referred to be concave in nature. Similarly if $\theta < \theta_{ref}$, then BTT is convex. For a linear behavior, the condition for its determination is that of $\theta = \theta_{ref}$.

Like BTT, the trend-factor is computed by the passive vehicle as the ratio of θ to θ_{ref}. For convex behavior, the value of trend-factor is less than 1 and greater than 0. Concave behavior shows the value of trend-factor to be greater than 1 whereas for linear behavior the value is 1.

B. *Measuring ASI and Alarming Threshold:*

AVCA frame (A part of ACVC Protocol) is one which is sent by active vehicle to update the passive vehicle about the important information to avoid any possible collision. The passive vehicle interprets the information and reconstructs the ASI by considering its own distance and the distance of active vehicle which is attended if the brakes are applied simultaneously. It means a mutual distance of interest is measured just before impact. The update information shown in AVCA ver 1 frame is the minimum possible data from which the ASI estimate can be reconstructed back by the passive vehicle which requires further investigation in terms of minimizing error and processing time. To elaborate the concept of ASI, let us take an example of two vehicles that apply brakes simultaneously. Let both the adjacent vehicles detect a time gap of X_t seconds and a distance gap of X_d meters. Taking the gap of both X_t and X_d into consideration, if the brakes are applied simultaneously by both the vehicles and the collision is expected to happen at time *t* seconds such that the speed of following vehicle just before collision is *V1* and that of followed is *V2*. In such a situation we can say that ASI = $|V2 - V1|$ which is the speed of interest for the indication of a pre-emptive signal.

V. CONCLUSIONS AND FUTURE WORK

A novel collision avoidance technique among adjacent vehicles has been discussed with the introduction of AVCA ver 1 protocol used by the active vehicle in order to exchange critical information regarding any possible collision in advance after the brake is applied by the followed vehicle. Similarly the concept of CODS is introduced in order to obtain a precise measure of the stopping time. AVCA protocol uses CODS along with other variables providing mandatory updates to avoid collisions while minimizing the required bandwidth for information exchange. The variables like BTT and Vehicle Identity are updated at lower sampling rate as these variables are changed at slower rate. The key parameters for future work are:

- The fractional effect due to road was assumed constant. Further research needs to take this factor into account and minimize errors between actual and simulated estimation.
- The slipping distance (Due to faulty brakes or low road friction due to rain etc.) was considered negligible. The mentioned distance decreases T_{stop} which needs consideration.
- The air dragging effect due to opening the side windows was neglected. This effect should be considered in future research.
- The efficient technique to measure ASI with minimum error and processing time by exploiting the use of S_f, and defining the alarming threshold is also a potential research area.
- Using the trend-factor to forecast the severity of collision.

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