Reducing Delay in V2V-AEB System by Optimizing Messages in the System

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ABSTRACT

In V2V-AEB (Vehicle to Vehicle Communication-Autonomous Emergency Braking) system, information detected by the onboard sensor of a vehicle is shared over the V2V network. So that all vehicles can use the shared information to prevent potential collisions. In V2V-AEB system, a major issue to be resolved is the message explosion, which results in message delay in the V2V network. For example, if there are m vehicles in a scenario and each vehicle detects n objects, and they generate one message for each detected object. Then, there will be m× n messages in the scenario. This may lead to communication overload, which results in communication delay due to packet collision and processing delay as each vehicle will be required to process $m \times n$ messages and processing these many messages requires time. In this paper, we try to answer a question: how to reduce the communication delay and the message processing delay in the V2V-AEB network. This paper provides various method to reduce communication delay and message processing delay in V2V-AEB system. The proposed method prevents sending messages related to the pedestrian who is not likely to cause a collision (like the pedestrian who are walking on the sidewalk or who are standing off the road). The other method is grouping the pedestrians with similar features in one message, thus reducing the number of messages in the system, which results in the decrease of the communication and message processing delay. The paper also discusses a method to prevent jamming of the network.

INTRODUCTION

According to World Health Organization, the lives of approximately 1.27 million people are cut short every year as a result of a road traffic crash. Half of 1.27 million people die in road traffic crashes are pedestrians, motorcyclists, and bicyclists [1]. TASI (Transportation Active Safety Institute) at IUPUI (Indiana university-Purdue University Indianapolis) focus on research to reduce the accidents and make road safer. One project is to combine V2V network with AEB system to reduce the accidents.

In V2V (vehicle to vehicle communication) systems, vehicles communicate with each other over a wireless network. A common protocol used for V2V wireless network is Discrete Short Range Communication (DSRC) [2]. Each vehicle in the V2V system acts as a communication node. A node exchanges data about its location, speed, and movement with other nodes and make a decision based on received information accordingly. Traditional V2V message protocol has some limitations. They only broadcast about the information within the system [2]. So the safety is limited to vehicles in the V2V network. The current V2V system does not share the information about: what is happening in the surrounding of a vehicle. Whereas AEB (Autonomous Emergency Braking) system uses its onboard sensors such as radar, LIDAR, camera, infrared, etc. to detect a potential collis ion and alert the driver [3]. Its limitation is that it requires clear line-of-sight to detect what is in the surrounding and it only benefits the safety of AEB installed vehicles. Our idea is to integrate the complementary capabilities of V2V and AEB system to overcome their individual limitations. V2V-AEB is a part of cooperative driving research to reduce accidents in the context of autonomous driving, where the information detected by the AEB system of the car and its own speed, location, and movement is shared over V2V network so that other vehicles can use the shared AEB sensing information to prevent potential collisions.

In vehicle to vehicle communication-Autonomous emergency breaking system (V2V-AEB), vehicles exchange data about the objects detected by its onboard sensor and its own location, speed and movement with other nearby vehicles. The object information detected by a vehicle and the information received through V2V network is processed by every vehicle. If there is an imminent crash and if the driver does not make appropriate braking action, the AEB system alerts the driver and/or applies the brake automatically to avoid/mitigate collison.

To make the V2V-AEB system more effective certain issues need to be resolved[4]. One of the key issues is minimizing the messages shared over V2V-AEB network. If there are n vehicles and m pedestrians in a busy road, and each vehicle is V2V-PCS enabled and is able to detect the vehicles and pedestrians, each vehicle can have at most the information of $m+(n-1)$ objects. If each vehicle broadcasts a messages for each detected object, each vehicle will receive $(m+n-1)\times(n)$ messages. As n and m increases, the number of message will be difficult to process in reasonable time. Since it is possible that many of these objects do not cause collition threat, it is important to send only messages related to the objects presenting a potential collision. In this paper we present some methods to reduce the amount of messages in the system.

The order of this paper is as follows. We first describe the basic architecture of V2V-AEB system. Then we will formulate methods to reduce the messages containing information about pedestrian. The third part is to describe how to prevent jamming of network. Then we describe the method for reducing the number of messages about the information of vehicles detected by V2V-AEB.

V2V-AEB SYSTEM

In V2V communication, vehicles broadcast information about their speed, location, direction of travel and make safety decision based on the received information. The AEB system uses onboard sensors to detect potential crashes, and alerts the driver or applies automatic brake if the driver does not take necessary action. The idea is to integrate the complementary capabilities of V2V and AEB system to allow the information of objects sensed by the onboard sensors to be shared in the V2V network [2].

The overview of V2V-AEB system implemented on each vehicle is described by the block diagram in Figure 1. For better understanding of the system, we divide the system in two parts: the sender side and receiver side.

Sender side: The AEB system gets the input from the camera sensor and the radar sensor, which is processed by AEB system of the car. If there is any object (vehicle, pedestrian, and bicyclist) in the system and the AEB senses the object, it sends its information to the next block where the information is converted in the global coordinates from the local coordinates of the respective vehicle. Then the information of the object is formulated in the

message format along with vehicle state, these message is then broadcast over V2V network.

Receiver side: The messages (V2V-AEB) received by a vehicle are processed. Information in different messages may be merged as different vehicles may send same object information. The vehicle then convert the merged information in its local coordinate system. Then the object information is further merged with the information of objects detected by vehicle's own AEB system. The objects are tracked in real-time and time to collision of the object with respect to the vehicle is calculated in order to make safety related action.
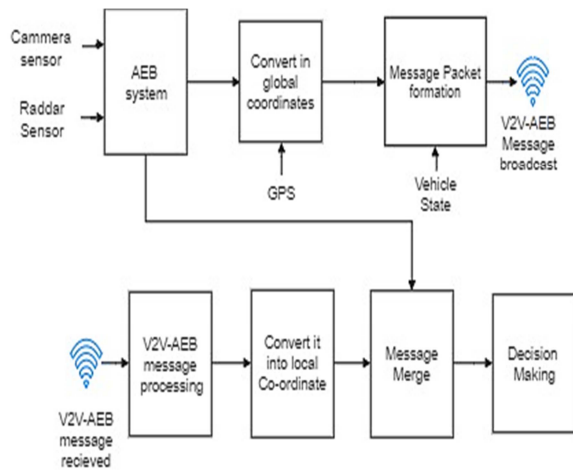

Figure 1. The architecture of the V2V-AEB system.

We have created the V2V-AEB system simulation using PreScan [5] and MATLAB Simulink. The following example simulation scenario has 3 vehicles and 2 pedestrians (See Figure 2). The speed of the vehicle is 14m/s, the maximum deceleration of the vehicle is 12m/s^2, the speed of two pedestrian are 1.2m/s and 1.5m/s, respectively.
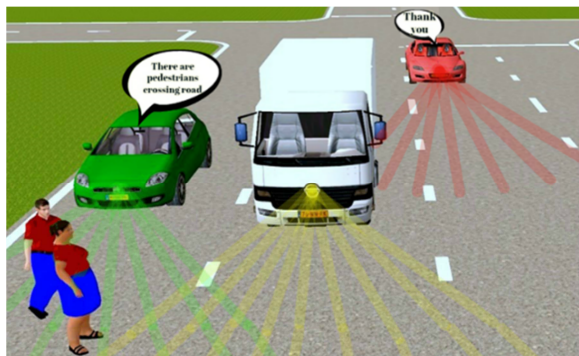

Figure 2. V2V-PAEB test scenario

OPTIMIZING PEDESTRIAN INFORMATION

The vehicle may send the information of all objects it detects. However some pedestrian are just standing and there may not be potential collision. So it's necessary to segregate the information about those pedestrian who can cause potential collision and who does not. The solution to this problem is that vehicle only sends the information about those pedestrians that can be harmed by the vehicle. So for minimizing the V2V messages about pedestrians it is necessary to decide which pedestrian information should be sent.

The pedestrian walking on the sidewalk can be removed from the V2V message, as we assume the vehicle will not go on the sidewalk. This will considerably decrease the amount of V2V messages without sabotaging the safety of pedestrian. However, if a pedestrian is moving towards the road, the vehicle should send the information about this pedestrian as it might cause safety issue.

Bifurcating the pedestrian using GPS coordinates: Assume that vehicles can get accurate GPS information and road boundary information through on board sensors, the location and boundary of a road can be found out via combining them with google maps. If the position of the pedestrian or other objects is not on the road, then the car can neglect that object. As in the near future, GPS will be more accurate to centimeter range[6]. It can be seen from Figure 3 that Google maps can be used to determine the boundaries of roads. So this information about the road can be used to see if the pedestrian is on the road or not.

Figure 3. GPS Location of road boundary from Google map

Eliminating objects not likely to cause collision

If a pedestrian is behind a forward moving vehicle on a road, sending the information of the pedestrian to that vehicle does not help improving the safety (See Figure 4).
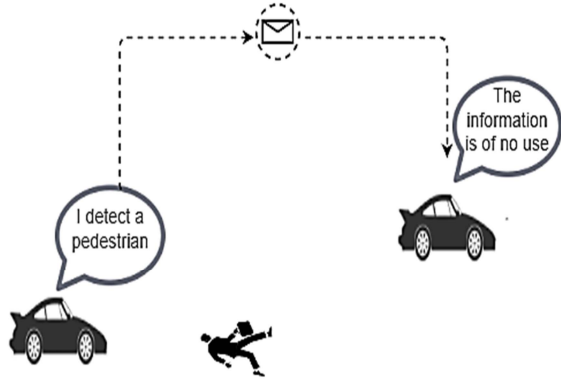

Figure 4. Sending information of pedestrian in front

Therefore, a subject vehicle can neglect sending messages of the detected objects if the objects are behind the vehicle in front and there is no vehicle behind the subject vehicle. However, the question is the definition of "no vehicle behind the subject vehicle".

Calculating which pedestrian information to be sent: In V2V environment, vehicles share their speeds, accelerations, positions, directions over V2V network. This information is available with vehicle to decide. If a subject vehicle that can detect a pedestrian and any vehicle in surrounding area can reach a point where pedestrians are crossing the road, should broadcast the message with the pedestrian information.

Let the pedestrian speed be V_p, the width of the road that the pedestrian has to cross be L, maximum speed of vehicle in the scenario be V_v and maximum acceleration be a_v. Assuming that the acceleration of the pedestrian is 0, the time for pedestrian to cross the road (T_p) is

$$T_p = \frac{L}{V_p} \qquad \text{(Equation 1)}$$

The maximum distance, S_v, between the vehicle behind the subject vehicle and the road-crossing pedestrian detected by the subject vehicle is used to determine if the pedestrian message should be broadcast or not. S_v can be determined by distance

formula considering (T_p)(Equation 1) as time required by pedestrian to cross a road and maximum vehicle speed and acceleration.

$$S_v = V_v \times \frac{L}{V_p} + \frac{a_v \times L^2}{2 \times V_p{}^2} \qquad \text{(Equation 2)}$$

Where,
   V_v= the speed of vehicle in behind
   a_v= the acceleration speed of vehicle in behind

If a pedestrian is crossing the road, and there is a vehicle behind the subject vehicle that detected the pedestrian, and the vehicle behind is at less than a distance of S_v to the detected pedestrian (Equation 2), then the subject vehicle should send the pedestrian information to the V2V network.

However, if there are many pedestrians and vehicles in the system, the CPU time to process all the information will be large. To tackle this problem, we can select one extreme case such as the pedestrian with minimum speed, the maximum value of V_v and a_v.
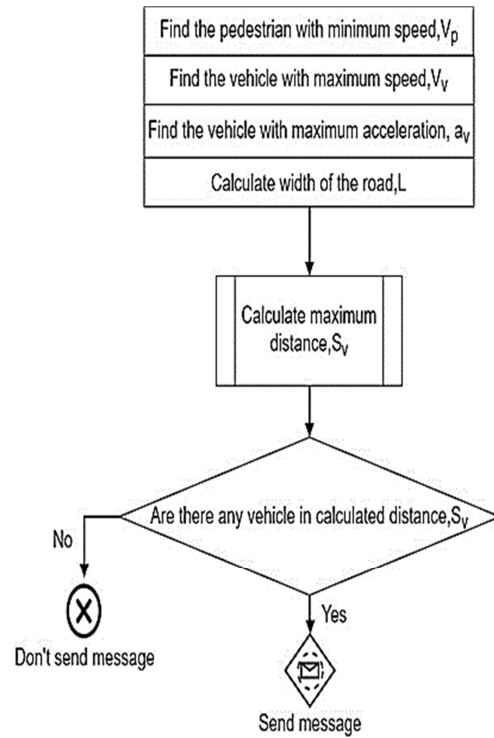

Figure 5. Flow chart to determine which pedestrian information should be sent

Example 1.
A pedestrian is crossing a 4 lane road at a speed 1.2 m/sec. The width of each lane is 3.7 m. The maximum velocity among all the vehicles behind the subject vehicle is 80km/hr (22.22 m/s) and the

maximum acceleration among all the vehicles be $2m/s^2$

Thus, from Equation 3

$$S_v = V_v \times \frac{L}{V_p} + \frac{a_v \times L^2}{2 \times V_p^2}$$

$$= 3.7 \times 4 \times \frac{22.22}{1.2} + \frac{1 \times (3.7 \times 4)^2}{2 \times 1.2^2}$$

$$= 426.15\ meter$$

So, if a vehicle finds any other vehicle in the range of 426.15 meter in V2V network it can broadcast the information about the pedestrian.

Grouping of pedestrian

In V2V-AEB, each vehicle sends the information about the pedestrians they have detected along with their own vehicle information. Consider a scenario of *m* V2V-AEB enabled vehicles and *n* pedestrians at a road intersection. If each vehicle can detect all pedestrians and broadcast them to the V2V network, then each vehicle will receive $m \times n$ messages. The receiver vehicle has to process all this messages to make a safety decision. To reduce the number of messages we propose a method to cluster the pedestrian information in groups before sending them. Thus reducing the processing time of the vehicle on receiver side and the communication delay due to packet collision in VANET.

For clustering these pedestrians we should guarantee that safety is not compromised. Pedestrians having similar information can be grouped as one pedestrian such that all pedestrians stay in one group until the time they cross the road safely so that they can be considered as one entity.

Working of the system: To group the pedestrian, we use a clustering method. If the distances between two pedestrians is less than a predefined threshold *a* and their speed difference is less than *b*, they are grouped in one cluster and the pedestrian information is sent as a single pedestrian with the speed of minimum one which ensure us all the pedestrian will cross the road safely and as one entity. The value of *a* and *b* are selected such that pedestrian will remain in the same group until they cross the street safely.

When a pedestrian is detected, we calculate its distance from the detecting vehicle and thus evaluate its position in x-y plane before converting it into GPS coordinate as shown below.
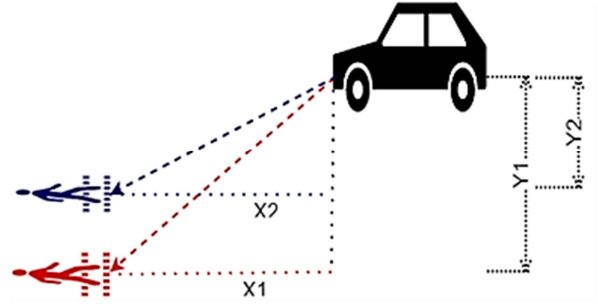

Figure 6. Pedestrian detection by the vehicle

After calculating the x, y coordinate, velocity and direction of pedestrian the information is put in matrix form.

Table1: Matrix for pedestrian information

Ped	Location (x)	Location (y)	Velocity	Direc-tion
1	x_1	y_1	v_1	D_1
2	x_2	y_2	v_2	D_2
3	x_3	y_3	v_3	D_2
4	x_4	y_4	v_4	D_1
5	x5	y5	V5	D2

To send the information of pedestrians as a group, the pedestrians are arranged in ascending order as per their positions in the y-axis. The first pedestrian is selected from the list and made as a hub. Then the pedestrians are selected and formed as a group whose distance from the hub is less than or equal to threshold *a*, difference between their speeds is less than the threshold *b* and they are moving to the same direction. Similarly, all the groups are created. The grouped pedestrian is broadcast as the single entity with the average location of the pedestrians in the hub and the lowest velocity among all the pedestrians in the hub. Before broadcasting the information, the location is converted in the form of GPS coordinates.

As the pedestrian are arranged in ascending order of their y location, when we discover the distance of a pedestrian to other pedestrian in the same hub is greater than *a*, a new hub is created to other

pedestrians. This process iterates until all pedestrians are grouped.

Algorithm

Step1 Differentiate pedestrian as per their directions of crossing the road (here we consider 2 directions whether pedestrians are moving from left to right or from right to left with respect to the vehicle. Other pedestrians who are not in these two categories are not grouped.

Step 2 Arrange pedestrian in increasing order of their location in y axis.

Step 3 Select pedestrian 1 from the array and make it as a hub of a group. The current group number m is 1.

Step 4
For pedestrians i= 2 to total number of pedestrians in the same moving direction of crossing the road
{ Already exist=0; // *assigning variable to check the condition*;
Calculate the distance of pedestrian i to the hub of group m
   Calculate speed difference of pedestrian i and that of the hub if group m.

  If (distance > a or difference of speed > b)
  {   j=m,
     while(j ≥1)
    {   Calculate distance of pedestrian i
      to hub of group j
      Calculate the speed difference of
      Pedestrian i with hub of group j
         If ((distance ≤ a) and (speed ≤ b))
            Already exist=1
              j=j-1
         else
             j=j-1
         end
    }
    If (Already exist == 0)
    { m=m+1;
      make pedestrian i as a hub of group m.
    }
  }
} //end of for loop

Repeat step 4 for the other direction

Step5: Broadcast the hub information of all groups over the V2V network

//the pedestrians are grouped as soon as they are detected by vehicles AEB system

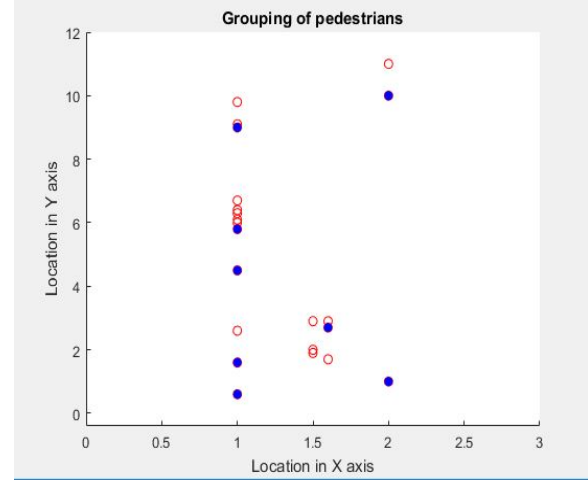Figure 7 shows the output for grouping of 24 pedestrians.

Figure. 7 Grouping of pedestrian using MATLAB (blue dots indicate the hub)

The sender side needs to process the 24 pedestrian in order to form groups and convert the location of the hub of groups to GPS coordinates. The 24 pedestrians were grouped into 8 groups by the algorithm. Suppose these 24 pedestrian and 20 cars are on the road, by using the grouping algorithm, we can reduce the number of messages from 480 to 160. Thus on the receiver side instead of processing 480 messages it just has to process this 160 messages. Each blue dot indicates one hub whose information is broadcast through the V2V network.

Example 2.
The example in Figure 8 shows how the 10 pedestrians are grouped using the proposed algorithm. Figure 8 represents the data array (dashed box) of the pedestrians. Xs represent the pedestrian by parameter (x, y, and v), where x is his location in x-axis, y in y-axis, and v is its speed. The pedestrians are arranged in ascending order, according to their locations in y-axis in an array.

After arranging the pedestrians, group is greedily selected in multiple iterations. The pedestrians whose location difference are less than or equal to 1 meter and the magnitude of difference between speed is less than equal to 0.1m/s is included in a group of the

respective hub as described below. A group is defined starting from a pedestrian we call it a hub.
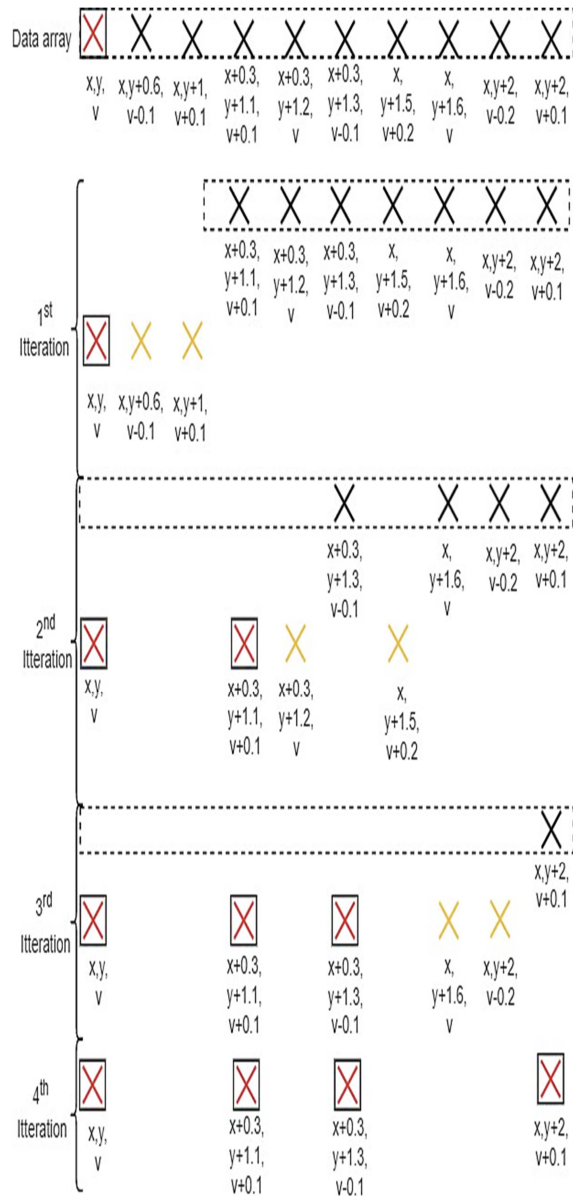

Figure.8 groping of pedestrian example

Iteration 1: The first element of the array is created as a hub (showing in red color and in a box with solid line.) of group 1. The box with solid line represents the hub of the group 1. The pedestrians in group 1 are selected, whose distance to the hub is less than or equal to 1 meter and difference of speed is less than or equal to 0.1m/s with respect to the hub. Yellow X denotes that 2nd and 3rd pedestrians are selected pedestrians. As we see that the distance from the 4th pedestrian from the hub is

1.14 meter which is greater than 1 meter, thus it is not included in group 1.

Iteration 2: The 4th pedestrian is selected as the hub of group 2. Pedestrians 5 and 7 are selected to form a group as explained in iteration 1. Pedestrian 6 does not belong to group 2 since its velocity difference from the hub is |0.2|m/s which is greater than 0.1m/s limit.

Iteration 3: Pedestrian 6 is selected as the hub og group 3. Pedestrians 8 and 9 belongs to group 3 as they satisfy the group conditions as described in iteration 1.

Iteration 4: The 10th pedestrian is the hub of group 4. Since there is no other pedestrians, it forms its own group.

The iteration stops when all pedestrian are grouped. The information of all hubs are sent over V2V-AEB network.

JAMMING OF NETWORK

Preventing from sending messages while jamming of network
There might be cases when there are many pedestrians on the road. For example, around 14,000 pedestrian walk in one hour near west 34th street as per 2015 studies [7]. Also, according to reports [7], there were as many as 55 pedestrian fatalities. If all the information is shared over the V2V network, it will cause network overload, leading to large number of packet collision, communication delay, and message processing delay. Thus, if there are too many pedestrians in the environment, the best option will be preventing vehicle to send pedestrian messages (except in critical emergency conditions such as medical emergency condition) over V2V network, in order to prevent congestion of network.
Therefore, the question arises what is the maximum number of pedestrians detected that vehicle should stop sending pedestrian messages. However, it will not be appropriate to select based on the number of pedestrians, because it might be possible that just one vehicle is able to detect all pedestrians, whereas the pedestrians are not in the line of sight of other vehicles. In this case, information from the vehicle who can detect all the pedestrians is very important. So instead of determining by the number of pedestrian we use the time delay in the network to decide whether a vehicle should broadcast message of observed objects or not. When the network is congested and

the time delay in the system is such that no safety decision can be made in time to benefit safety by using received information through V2V network, the vehicle can stop sending messages of observed objects.

That is $t_d \geq Maximum\ delay, Md$

Such that, $ttc < ttb$
Where,

$t_d = message\ processing\ time\ delay$

Maximum delay (M_d): the threshold time delay above which the AEB system cannot avoid collision.

ttc = time to collision i.e. time when the car will collide with the object.
ttb = threshold time for braking, i.e. minimum time required by the vehicle to stop the car.

Therefore, the vehicle can stop sending messages when the time delay in the system is above maximum delay and will continue sending message only when delay of the system becomes lower than the maximum delay. The proposed method can be implemented as shown below (see Figure 9).
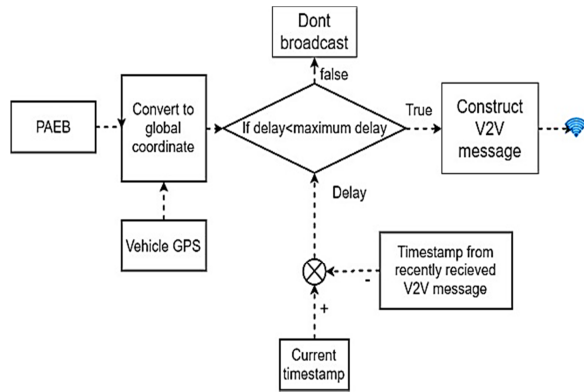

Figure 9. Sending information of pedestrian in front.

The received message from V2V-AEB message has the information about when the message is generated. The time stamp from the received message is compared with the current time to calculate the delay in receiving message. If the calculated delay is found above maximum delay, the vehicle does not construct the V2V message to broadcast the object detected by its onboard sensor over V2V network. Where, maximum delay is the threshold time delay above which the AEB system cannot avoid collision i.e., when time to collision

to an object is greater than threshold time for braking (i.e., minimum time required by vehicle to stop) as it can be seen from Figure 9.

OPTIMIZING VEHICLE INFORMATION

In V2V-AEB system, the car sends the information about the pedestrian and vehicle that it detects through its onboard sensor. It is important to decide if sensed information about the vehicle should be sent. If the sensed vehicle is in the V2V network, the location and the speed of the sensed vehicle is already shared in the network. Then it is not beneficial for another vehicle to send the same but less accurate sensed vehicle information to the network again.

How to decide which vehicles are in V2V network? There can be various ways to identify if a vehicle is in the V2V network. One way is to make the car capable with V2V communication can bear some logo so that other vehicles can neglect processing those vehicles information and not sending it in the V2V network. The other way can be that vehicle can compare the information from AEB system and those received from V2V network. If the two vehicles have almost the same information, it can restrain itself from broadcasting those information in V2V network. As GPS has some error we cannot get the exact location of the vehicle. But we can find the similar data having similar location, speed and direction. However, in this case as the vehicles have to process the information it will take computation time.

CONCLUSIONS

The proposed system helps to reduce communication delay and processing delay in the system by reducing number of message in the V2V-AEB network. Thus, it increases the chance that V2V-AEB system makes decision on time. Using the method of elimination, information about some pedestrians are not sent if they are not on the road or there is no vehicle in the range to cause potential collision. Further, the proposed method of grouping is tested in a simulation with 24 pedestrians which were grouped in 8 groups.The grouping of pedestrian help us to reduce the number of messages in V2V-AEB system thus reducing communication deal, packet collision and processing delay or senders side. We also discussed method to prevent V2V network jamming, by monitoring delay in the network.

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