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Deadline Determination for Real Time Safety Applications in Vehicular Ad hoc Network

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ABSTRACT

Vehicular ad hoc Network (VANET) is a promising technology for enhancing safety and comfort of drivers and passengers by introducing two main classes of applications namely, safety and comfort/commercial applications. Almost all of the Safety applications are time sensitive and need to act at or before their deadlines. However, many studies have been conducted for proposing real time routing protocols for safety applications and assuring their protocols are real time. Meanwhile, the question is what is the time threshold for safety applications? How the routing protocols can be proved to be real time? In this paper, we use the mental processing time of drivers based on human physiological science to define a precise method for deadline determination for high priority VANETs' safety applications, and specify real time constraints. Then, we review and analyze the performance of some well-known routing protocols, and measure their performance regarding time constraints. We also show the effect of real time consideration on collision avoidance and give quantities measures for such application.

Keywords: Vehicular Ad hoc Network, Safety Applications, Mental Processing Time, Real Time Threshold, Routing Protocol.

1. INTRODUCTION

Intelligent Transportation System (ITS) is a combined technology to enhance road safety and terrain efficiency, reduce environmental impact and in general increase the benefits for transportation users [1],[2],[3]. Vehicular Ad hoc Network (VANET) is one of the critical parts of ITS for providing wireless communication between vehicles (V2V) and vehicle to infrastructure (V2I). The intention of VANET is to enable a wide range of applications namely, safety applications and comfort/commercial applications. However, many organizations, researchers, industrial companies and governments contribute to create and standardize different parts of vehicular networking such as bandwidth management (FCC), security issue [4][5], routing protocols [6][7][8], and applications [9][10]; the co-operation and participation of these participants together eventuate reliable base for enabling various types of VANET's safety and non-safety application. However, safety applications are destined to enhance the ability of drivers in difficult situations and prevent road accidents; for instance, chain collision is caused by the lack of drivers' vision and late reaction. Therefore, the related application (Chain Collision Avoidance) tries to notify driver about stopped ahead vehicles and take the best automated reaction before the driver. While safety applications have been proposed to prevent accidents and have direct impact on life of people, they must be very precise and work without error. However, the major part of safety applications correctness depends on routing protocols; the routing protocols have to deliver data (safety notifications) before or at exact timelines. Otherwise, all of the attempts are wasteful and irreparable events might happen. Meanwhile, many researchers have proposed and designed routing protocols for real time communication [11][12][13][14]. However, the questions are: what is the metrics for real time protocol? How can we claim that protocols are real time? What should be the time threshold for high priority safety applications?
According to above questions, in this paper we will define and determine precise time threshold for high priorities safety applications as a reference for real time routing protocols researchers.

The remaining of this paper is structured as follows. In Section 2, we define the high priority collision avoidance applications. Section 3 describes constant part of every vehicle accident and determine exact time threshold for safety applications. In section 4, we review some well-known VANET routing protocols and evaluate their performances under defined time threshold. Section 5 concludes our work.

2. High Priority Vehicular Safety Applications

At the most basic level, the aim of vehicular communications and safety applications is to impede vehicular accidents and improve the safety of driving at roads and streets. To this end, many industry/government partnerships endeavour to find the most important and beneficial safety applications. These organizations include the Crash Avoidance Metrics Partnership (CAMP) in the USA, the Car2Car Communication Consortium in Europe, and the Advanced Safety Vehicle (ASV) Project in Japan [15]. However, the cooperation of the above mentioned organizations yield to identify eight high priority safety applications as follows:

2.1. Traffic Signal Violation Warning

This application alerts the driver to traffic signal situation before he/she approaches an intersection. Road Side Unit (RSU) uses periodic broadcast messages which contain signal phase, timing, its location and affected direction; upon receiving the message from RSU the On Board Unit (OBU) in a vehicle uses its own state or situation (Speed, direction, distance, etc.) and knowledge to inform the driver about upcoming danger or not. Also, an OBU will respond to the RSU about its decision [16]. For example, the RSU broadcast message: *I'm traffic signal located at XY, notice to all vehicles approaching from west, current signal is green, but will change to red in 5.5 seconds.* Thus, based on vehicle information an OBU decides whether the vehicle can pass the intersection safely or not, and notify the driver and RSU.

2.2. Curve Speed Warning

Inordinate velocity in curves often causes loss of control, road departure, rollover and accident. Taking an appropriate speed in a curve depends on many factors, such as the degree of curvature, whether condition, vehicle and a driver ability, etc. However, Curve Speed Warning application helps vehicle to communicate its condition and negotiate to the RSU for choosing safe speed before a vehicle enters the curve.

2.3. Emergency Electronic Brake Light

This application falls in V2V communications class and tries to notify the driver of hard brake and stopped vehicle in front before the driver vision. In every condition it takes time the driver to find out about stopped leading vehicle, even in limited vision (foggy, rainy, other large vehicle in between, brake lamp defection, etc.) this time goes more and more until it is too late for safe decision. Therefore, when one vehicle suddenly reduces its speed, hard brake or stops the OBU broadcasts this situation with related information like geographical position to upcoming vehicle and the receiver OBU will alert the driver. However, this application can prevent some common accidents like chain collision.

2.4. Pre-Crash Sensing for Cooperative Collision Mitigation

This application aims to collect relevant and beneficial information about possible threats and collision. The information can contain threat side (front, back and rear), impact time, impact speed, struck and striking vehicle size and mass [16]. This application opposite the other collision avoidance applications tries to reduce the impact of collision when it's unavoidable.

2.5. Cooperative Forward Collision Warning (FCW) System

The FWC helps the driver to prevent rear-end collision through warning notifications. The FCW system can aid the driver in early detection of vehicle cut-in into host vehicle path, notify the driver of false sign lane change, detection of stopped vehicles and the host type/size/speed.

2.6. Left Turn Assistant

This application is classified as V2I communications type and alerts drivers to approaching traffic to aid them make a left turn at a signalized intersection without a phasing left turn arrow [15].

2.7. Lane Change Warning

Lane Change Warning uses periodic messages coming from surrounding vehicles (periodic messages contain, velocity, position, type, size, etc.). Thus, if the driver decides to change its lane the application takes the advantages of received messages and considers the required space and it will inform him or her about the safety of lane change.

2.8. Stop Sign Movement Assistant

This application will warn the driver that is about to pass an intersection after having stopped at stop sign [17]. This application uses V2I communications. The approaching vehicles to the intersections send their presence with related information to the RSU and the RSU computes possible threats and will notify all vehicles of intersection situation and other oncoming vehicles.

The 8 high priority safety applications have a lot of technical details which we do not cover in this paper. Table 1 shows the summary of these applications and their requirements briefly.

Table 1: High Priority Safety Applications Details

Application	Comm. type	Freq.	Data transmitted	Range
Traffic Signal Violation	I2V	10Hz	Signal phase, timing, position, road geometry	250 m
Curve Speed Warning	I2V	1Hz	Curve location, curvature slope, speed limit, surface	200m
Emergency Brake Light	V2V	10Hz	Position, heading, velocity, acceleration	200m
Pre-crash Sensing	V2V	50Hz	Vehicle type, position, heading, yaw rate, velocity	50m
Forward collision	V2V	10Hz	Vehicle type, position, Heading, velocity, yaw rate.	150m
Left Turn Assist	I2V/V2V	I2V/V2V	Signal Phase, road geometry, Position, timing.	300m
Lane Change Warning	V2V	10Hz	Position, heading, velocity, turn signal status	150m
Stop Signal Assist	I2V/V2V	10Hz	Position, velocity, heading, warning	300m

According to the brief description of above mentioned applications, all of these applications are time sensitive and the data communication has to take place at proper time to let the driver take best reaction. As mentioned in the introduction, there is no detail about time threshold for these safety applications. To this end, in the next section we present the effective timelines and illustrate how it can be calculated.

3. Dead Line Determination for Safety Application

3.1. Time To Collision (TTC)

It is apparent that road accidents take place due to a wide variety of reasons such as speed, running stop signs, unsafe lane change, leading stopped vehicle, icy and snowy road surface, vision limit, age, etc. However, there is a constant parameter in all of the roads accidents (vehicle to vehicle or vehicle to any obstacles collision), named Time-To-Collision (TTC). The TTC is a period of time that the driver faces with the dangerous situation until it happens [18]. The TTC consists of the following phases:

1) Mental Processing Time (Perception Response Time):

Mental Processing Time refers to the time it takes the driver to see, percept and decide to react and also known as Perception Response Time (PRT). For instance, it is the time when the driver sees stopped vehicle directly ahead and makes a decision to turn the wheel or brake (not react, just conclude to react) However, Mental Processing Time is a combination of four phases as:

- Sensation: the time it takes to sense and feel there is an obstacle in road.
- Perception/recognition: the period of time to identify the definition of sensation.

- Situational Awareness: the amount of time to interpret the meaning of Sensation and Perception/recognition.
- Reaction Selection: the length of time which brain picked out the decision. For example, change the lane instead of braking.

It is important to mention the above steps are considered differently from researchers to researchers. For example, Perchonok et al. [19] described them as, 1) Detection. 2) Identification. 3) Decision. 4) Response. However, it is clear that the concepts of these steps are the same among researchers.

2) Movement Time:

After the driver decides to react, it takes a driver some time to move his/her body, for example, to depress the accelerator and press the brake. The movement time depends on several factors such as, age, physical health, experience, etc.

3) Device Response Time:

When the driver presses the brake, it takes the brake system some time to act and stop the vehicle. The device time or device response time depends on the vehicle type, the braking system, physical laws and several other parameters which are beyond the scope of this paper and we don't cover it any more in this paper. However, the combination of these three steps (Mental Response Time, Movement Time and Device Response Time) together yield TTC. Figure 1, illustrates the TTC.

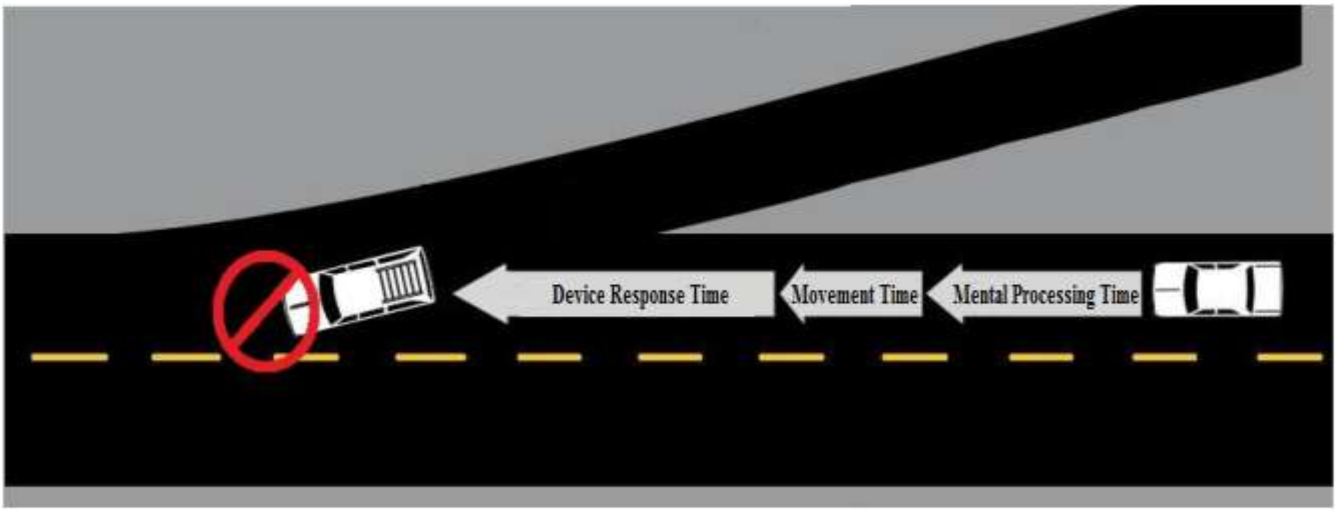

Figure 1: Time To Collision (TTC) components

3.2. Real Time Threshold Definition

According to the TTC it is completely clear and logical the decrease in each of TTC components will enhance the collision prevention. Also, it is obvious the Mental Processing Time is the prerequisite of Movement Time and Device Response Time. It means, before everything could happen, the driver has to see and sense the situation or any event, percept that and decide to react; then other steps (Movement Time and Device Response Time) could begin. However, we choose and focus on Mental Processing Time as real time threshold for safety applications. Before going further and explain why Mental Processing Time can be considered as time threshold, we briefly review some related work for TTC calculation.

4. RELATED WORKS

The first attempts to calculate TTC have been done by J. C. Hayward [20]. Hayward defines TTC as the duration of time while two vehicles will collide if they continue at their current velocity on the same path.

Miller, R. et al. [21] have presented a method to measure TTC; They used velocity, direction and first position of vehicle by considering that the vehicles are two arbitrary points (Figure 2). Afterwards, the equations (1) and (2) have been used to measure the collision point of the two vehicles.

$$x_{+} = \frac{(y_2 - y_1) - (x_2 \,.\, \tan\theta_2 - x_1 \,.\, \tan\theta_1)}{\tan\theta_1 - \tan\theta_2} \quad (1)$$

$$y_+ = \frac{(x_2 - x_1) - (y_2 . \cot\theta_2 - y_1 . \cot\theta_1)}{\cot\theta_1 - \cot\theta_2} \quad (2)$$

After calculating the collision points, a procedure to estimate the time that takes the vehicles to reach the collision point will begin [21]. Therefore, if these times are the same, the TTC will be obtained. However, as it can be seen, Miller, R. et al. use simple procedure for obtaining TTC. Thus, they use safety margin δ for make-up this simplicity. By using safety parameter δ, $|TX1 - TX2| < \delta$ will be used to calculate probability of collision instead of TX1=TX2 where, TX1 and TX2 are the times for vehicle 1 and vehicle 2 to reach the collision point. Figure 2, shows the collision point.

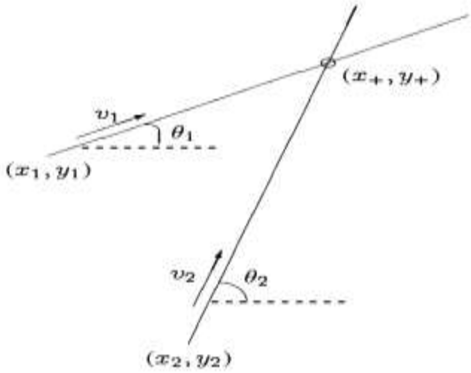

Figure 2: Collision point.[20]

Felipe Jiménez et al. have provided another method for measuring TTC. They use all possible ways which two vehicles can hit each other [22]. Felipe Jiménez et al. show there are 32 possible situations, as each corner of one vehicle can hit any of the 4 sides of the other vehicle and repeat this calculation for both vehicles. However, they use angle α to classify possible collision, as α > 90 and α < 90 (Figure 3). Therefore, two possible classes of collision are obtained and each class contains different possible collisions. Then, they calculate the TTC for α > 90 and α < 90 separately.

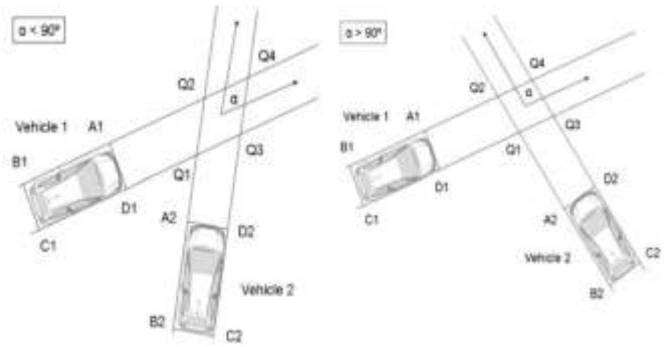

Figure 3. Initial configuration for α > 90 and α < 90.[22]

In the above TTC calculations they measure the time and probability so that two vehicles can collide which each other and neglect the mental process time of driver to understand the situation and decides to take reaction. However, on the other hand, many researchers, institutes and organization focused on Mental Processing Time. For instance, Massachusetts Institute of Technology (1934) [23] have provided comprehensive researches on PRT and they have considered into accounts many aspects, such as visual and sound effect, whether the obstacle was moving or stationary and they have declared the average range for PRT from 0.24 s to 1.65 s. In 1950 Lister [24] has provided wide reviews of results of many previous studies and reported PRT as ranging from 0.44 s to 0.70 s.

Fambero et al. reported PRT as 15% of drivers would respond in less than 0.75 s and 85% would respond within 1.5 to 2.0s [25]. However, as described we use Mental Processing Time/Perception Response Time (PRT) as time threshold for real time safety applications and in the next section we detail how to calculate Mental Processing Time and why it could be time threshold for safety application.

5. SAFETY APPLICATIONS TIME THRESHOLD (MENTAL PROCESSING TIME)

The main idea of VANET safety applications is to inform the driver to possible threats before the driver can sense or feel them. On the other hand, as mentioned Mental Processing Time is the time when the driver sees or senses unexpected situation until he or she interprets the situation, understands its meaning, and decides to make a reaction.

Therefore, if the safety application can inform the driver before a driver Mental Processing Time, they are useful and can be assumed as real time. Otherwise, they are wasteful. Thus, a driver Mental Processing Time is a time threshold for safety application and we show how it can be calculated.
Once the driver see obstacles (stopped and non-stopped vehicles, pedestrian, animal, etc.) on the road ahead, the driver will analyse and evaluate two set of factors, *sensory* and *cognitive* respectively. The sensory phase consists of eye's capability to see the object and its features like size, motion, colour, etc. Then, the driver should interpret the sensory information to understand the meaning of situation. This step is called cognitive phase.

5.1. Real Time Threshold Definition

Once the driver sees an object in front of its eyes on the roadway at time T (Figure 4), it builds an image in its brain. Then, when the driver approaches the object, the size of image goes larger at time T+1. Thus, the faster approaching to the object will eventuate the faster expansion rate.

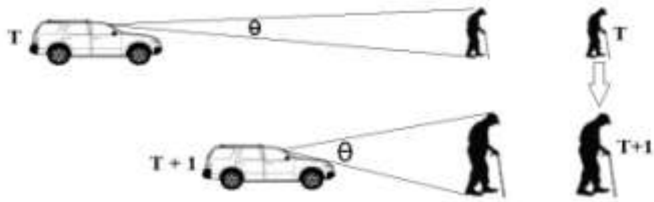

Figure 4. Image size and expansion rate of obstacle.

We can use expansion rate and image size to obtain TTC as (3):

$$\tau = \frac{d\theta}{(\frac{d\theta}{dt})} \qquad (3)$$

where τ is TTC (seconds); θ is retinal image viewing angle and $d\theta/dt$ is expansion rate of image (radian/second). More explanation the TTC could be obtained as shown in Figure 5:

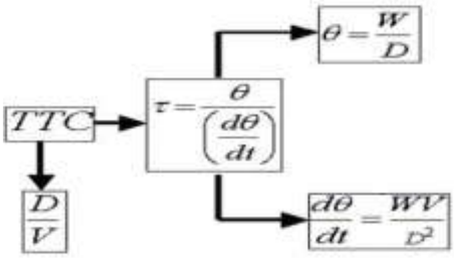

Figure 5. TTC calculation

W is the object width (meter?); D represents distance (meter) and V shows closing velocity in (meter/sec). However, based on the above formula, Table 2 represents the TTC for a vehicle moving at 60 mph (88.02 ft/sec) and by considering width 8 feet (normal truck).

Table 2: TTC obtained for a vehicle with 60mph faced to an obstacle with width 8 feet.

Thresh (rad/sec)	Distance (feet)	TTC (sec)
0.003	484.4	5.50
0.004	419.57	4.47
0.005	375.28	4.26
0.006	342.58	3.89
0.007	317.17	3.60
0.008	296.68	3.37
0.009	279.71	3.18

Table 2 shows when the driver sees truck, he has 5.50 second before accident and this time will decrease by approaching to the truck. (Note: this range is for best condition, good visibility, no drunk, etc.). However, it's important to note this range is thorough TTC which includes Mental Processing Time, Movement Time and Device Response Time. However, as mentioned we are interested in Mental Processing Time and according to deep and comprehensive research about physiological science in [18], the Mental Processing Time/PRT is based largely on expectation and experience as follow:

- Expected: once the driver is completely alerted to the situation and the meaning of that and has good experience, in this situation Mental Processing Time/PRT is 0.7 s.
- Unexpected: the driver discerns typical signs from leading vehicle or obstacle and has normal experience, in this situation Mental Processing Time/PRT is 1.2 s.
- Surprise: the driver faces very irregular situation and has no experience about that, in this situation Mental Processing Time/PRT is 1.5 s to many seconds.

In sum, we take best situation 0.7s (Expected) as real time threshold for real time safety applications; it means if the VANET routing protocols be able to deliver safety messages before the driver Mental Processing Time at best condition (Expected) they could be assume as real time protocol. To this end, in the next section we are going to analysis some of the well-known VANET routing protocols which have been designed for safety applications.
Note: our research should not be interpreted to that the Mental Processing Time is exactly 0.7 seconds; because of there is a lot of parameters which can affect this time. However, we claim the Mental Processing Time (without attention to its time) could be real time threshold for safety applications.

6. VANET ROUTING PROTOCOLS

Wide varieties of VANET routing protocols have been proposed and designed for both safety and non-safety applications. However, the main idea behinds the routing protocols in VANET is to deliver data from source vehicle to the destination at proper time, this time completely depends on the application requirement. For example, for non-safety applications like email this time could be elastic; on the other hand for collision avoidance application the deadline is very hard. Thus, it’s vital to safety applications to be run at or before their deadlines. To this end, several routing protocols have been proposed by researchers to enable safety applications. In this section we analyze the functionality of some of routing protocols and measure their performance regarding time constraints.

6.1. Urban Multi-hop Broadcast (UMB)

This protocol has been proposed by Gokhan Korkmaz et al. [26]. The UMB has been conducted to mitigate broadcast storm and deliver data in multi-hop manner in urban areas. In order to satisfy real time safety applications, the UMB tries to assign re-broadcast duty to only one vehicle to save bandwidth and prevent collisions. However, UMB assigns rebroadcast duty to the farthest vehicles in the sender’s Coverage Area (CA) to observe time lines.

6.2. Weighted p-Persistence; Slotted 1-Persistence and Slotted p-Persistence Broadcasting

Weighted p-Persistence, slotted 1-Persistence and slotted p-Persistence broadcasting have been proposed by Wisitpongphan et al. [27]. These three protocols have been designed to be used at Network layer. Also these protocols are the subset of probabilistic protocols, which use probability features to select relay node. The aims of weighted p-Persistence, slotted 1 -Persistence and slotted p-Persistence are to alleviate contention at MAC layer and also decrease packet loss ratio and keep end-to-end delay at an acceptable level for real time applications.

6.3. Adapting Geographical DTN Routing (AGDR)

This protocol (AGDR) aims to enable communication between vehicles (V2V) [28]. The AGDR takes the advantages of periodic hello messages to obtain the neighbours velocity, geographical position and motion direction. To this end this protocols use Global Positioning System (GPS). However, the main idea behind the AGDR is, this protocol uses the Direct Indicator Light (DIL), that is the indicator of vehicle motion path and has three states as follow:

- 0: signify the vehicle will continuous to its current direction.
- 1: exhibits the vehicle will change its motion path at next exit way.
- -1: refers to the vehicle come from opposite direction.

According to the DIL information and the destination of the packet, the source vehicle selects the appropriate vehicles as next-hop to relay message.

- **Ad-hoc On demand Multipath Distance Vector (AOMDV)**

Vipin Bondre et al. have proposed and evaluated AOMDV routing protocol to establish multiple path from source vehicle to destination instead of relying on one path [29]. AOMDV selects a link and transmit data over that until link breakages and then switches to another pre-selected link. In the AOMDV the source node send requests to all nodes in its CA and selects those nodes which are located in reliable range and checks whether selected nodes are free to communication or not. Then, the source node selects supporter paths to the destination; supporter will be used in the case of link breakages. When the node is selected as next-hop, this node selects another node till to the destination.

7. SIMULATION

In order to evaluate the performance of mentioned routing protocols in the case of defined real time threshold we analyzed and simulated those using Network Simulator 2.35 (NS2.35) [30] under following setup (Table 3):

Table 3: Simulation Setup

Parameter	Value
Wireless standard	IEEE 802.11p
Channel model	Nakagami-m(m=1.5)
TxRange (Antenna range)	300meter
Communication Type	V2V
Data Packet (Size)	100 KB
Network Density	100-200/km
Velocity Range	80 to 120 km/h
Simulation Time	200 Seconds
Simulation Area	1000 meter × 100 meter
Velocity Range	80-120 km/h

7.1. Simulation Result

Several metrics have been proposed to represent the performance of routing protocols, such as channel overhead, packets delivery ratio, link breakage percentage, end to end delay, etc. However, paying attention to the subject of this paper we just consider End-to-End Delay and evaluate the performance of mentioned protocols for this metric. Figure 6, illustrates the End-to-End delay.

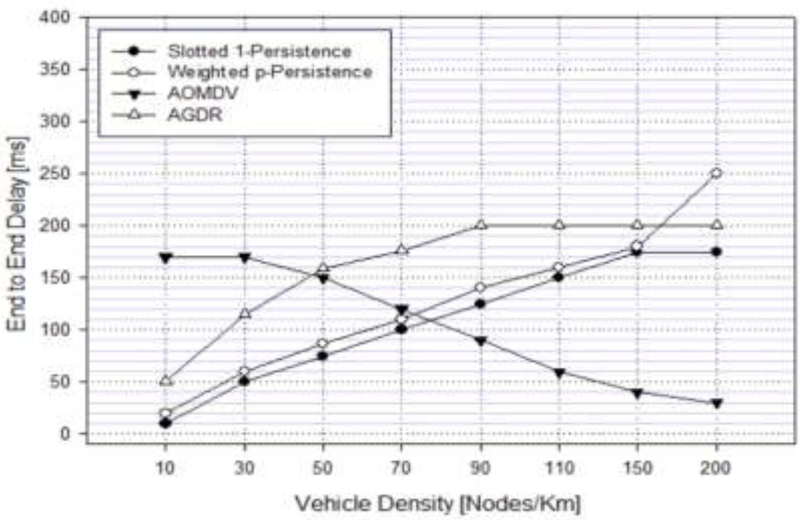

Figure 6: End-to-End delay.

The simulation result shows End-to-End delay for Weighted p-Persistence, Slotted 1-Persistence, AGDR and AOMDV. However, paying attention to the simulation result and predefined real time threshold the mentioned routing protocols are able to observe and satisfy real time threshold up to 200 vehicle/km. According to Figure 6, the End-to-End delay for the AOMDV is opposite than other; because of, as mentioned AOMDV selects multiple path to destination and when the vehicles density grows, the AOMDV can select more path than low densities and switch between them (links) without wasting time. On the other hand, Weighted p-Persistence, Slotted 1-Persistence and AGDR have better performance in spars area than high densities.

7.2 Effect of Mental Processing Time over collision prevention

In order to show the effect of choosing Mental Processing Time as real time threshold and its effects on collision prevention we compare that in best condition (0.7s) with the performance of Weighted p-Persistence protocol in terms of End-to-End delay (0.25s) obtained from simulation result. To this end, we assumed Mental Processing Time is 0.7s (Discussed in previous section), Movement time and Device Response Time are 0.4s and 1.5s respectively [18] and vehicle moving at 80 km/h. Figure 7 and Figure 8 show the effect of selecting and reducing Mental Processing Time in collision prevention.

Figure 7. TTC in best condition (Mental Processing Time=0.7s)

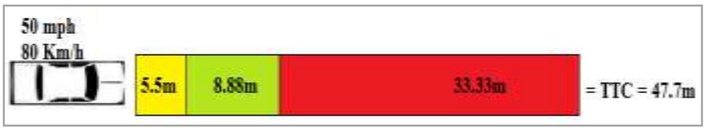

Figure 8: The effect of reducing Mental Processing Time on TTC by Weighted p-Persistense

According to Figure 7 and Figure 8, the weighted p-Persistance reduced the Mental Processing Time from 0.7 s to 0.25 s (15.5m to 5.5m), it means, by using this protocol the deriver could be alerted before its Mental Processing Time and this pre-alarm will gives the driver 10 meters additional to prevent collision.

8. CONCLUSION

Several routing protocols have been proposed for enabling real time safety applications and claim their protocols are real time. However, there is no information about real time deadline and its threshold. Therefore, in this paper we propose new parameter which named Mental Processing Time or Perception Response Time (PRT) obtained from human psychophysics to be considered as real time threshold for safety applications and set that to 0.7s in best circumstance. Then, we evaluated the performance of some proposed routing protocols in terms of End-to-End delay; the simulation result shows those protocols which their latency are less than 0.7s can be considered as real time protocols. Thereafter, we compare the Mental Processing Time in best condition with the performance of Weighted p-Persistence and we show how real time protocols can reduce Mental Processing Time and prevent collision.

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