

CoP4V: Context-based Protocol for Vehicle's Safety in Highways Using Wireless Sensor Networks

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Abstract

Safety is evergreen vital criteria for road traffic. We propose an infrastructureless solution based on contexts to increase safety of vehicle. Contexts characterize and track the moving environment of a vehicle. Here, environment means the vehicle's own status like geographical position, break-control's functional status, driver's status etc., and the status of neighboring vehicles. Contexts make use of wireless sensors for getting the environmental data. Sensors feed their data continuously to contexts. Contexts keep them as system understandable information. The status of a vehicle is continuously broadcasted to other vehicles. Safety-decisions are derived based on contexts that are available in a vehicle. We have also provided an algorithm for our context-based solution. Finally, safety calculations are given for overtaking decisions through some linear equations.

Keywords. Contexts, Highway, Wireless Sensor Networks, Vehicle Safety.

1 Introduction

Intelligent transport system gains more attention to the safety of road traffic in recent years [3]. This is due to the frequent road accidents that cause numerous human tragedies, as well as huge expenses for society. For instance in the USA, accidents cause approximately 40,000 deaths, 3,000,000 injuries, and 150 billion dollars of financial loss yearly [15]. *Motorways* and *highways* allow high speed increasing the risk for severe accidents. Vehicles are more vulnerable for accidents in highways (i.e. two-ways in single carriageway) than motorways since there is no physical separation between the two directions. Some of the causes for accidents are lack of driver's concentration, bad decisions or risky behavior, e.g., going at too high speed, overtaking without sufficient clear road ahead, using summer tyres on winter roads, etc. Also, the natural problems like snow, heavy rain, fog, hazy, etc. Generally, we categorize the vehicle collisions which happen in highway as *frontal*,

rear-end, and *side*. Frontal collision happens due to the improper overtaking [18], too fast and slid into the opposite lane in a curve, driver fell asleep, lost control of the car, etc. Rear-end collision happens when there is sudden-stop of a vehicle while another vehicle follows it closely [2]. Side collision happens due the erratic behavior of vehicle which comes from (same or opposite direction) the neighboring lane, intersection, bend and corner [15]. In this paper, we propose a Context-based Protocol for Vehicles which goes in Highways (CoP4V, in short) to avoid the crashes between vehicles. *Context* is the information that characterizes the interactions between humans, applications, and the surrounding environment [4]. This engages with the interaction process of an ever-changing environment composed of reconfigurable, migratory, distributed, and multi-scale resources [8]. From a Vehicle perspective, we define the context as a set of common meta-data about the current movement status of itself and other vehicles which are close proximity, and the current status of the driver and the core physical components of the vehicle. Also, context has the capability of communicating as well as negotiating with other vehicles whenever possible. For instance, a vehicle negotiates with another vehicle which goes in-front of it for overtaking safely while there is another vehicle which is approaching in the opposite direction. Overall, CoP4V combines the Context-based processing [4, 8] with Vehicular Ad hoc Networking (VANET) [13] and Wireless Sensor Networking [1]. We refer this as Context-based Wireless Vehicular Sensor Networking (C-WVSN). In this paper, we extend our preliminary investigations that are reported in [9] by providing (i) an architecture that centers the contexts for vehicle safety, (ii) definition of different contexts for tracking the safety of a vehicle, (iii) an algorithm to handle different safety perspectives including some explicit rules, overtaking for instance. In short, CoP4V has four types of contexts, namely: self-position, neighbors-position, driver, and self-condition. Each of these contexts is associated with a separate wireless sensor for getting the respective contextual information. These wireless sensors are fixed in differ-

ent parts of a vehicle, and form a wireless network. *Sensors* feed information to the *contexts*, which feed the information to the *rule-engine* that makes the safety decision. This safety warnings are continuously given to the vehicle's driver for guarding purposes.

This paper is organized as follows. Section 2 identifies the possible vehicle collisions that happen in highways. Section 3 details the *CoP4V* by providing its architecture, contexts, algorithm, and some linear equations to identify the distance between two vehicles for overtaking. Related Works are discussed in Section 4 before concluding this paper in Section 5.

2 Vehicle Collisions in Highways

The possible reasons [15, 3] for vehicle collisions in highways are:

R_1 : *Sudden-stop*. It is due to: (i) mechanical failure of a vehicle that goes in-front, (ii) sudden appearance of some obstacle in the driving route, (iii) maintenance roadwork without prior warning, and (iv) other common reasons like stopping at red lights, because of accidents, etc. This results in rear-end collision between two or more vehicles as a chain. For example, consider that there are two vehicles A and B go in the same direction and closely. Collision happens between A and B when A stops suddenly. This results in a chain collision when vehicle C follows B closely.

R_2 : *Ramp*. It is the entry (or exit) point for connecting small roads to highways. Vehicle's speed and traffic varies at this point due to merge of traffic and variation in speed. This results in rear-end or frontal collision between two vehicles. For example, consider that there are three vehicles A, B, and C. A is in entry ramp, B and C are in highway. A is invisible to C and vice-versa. This situation leads to a collision between A and C when A enters in highway.

R_3 : *Bend or Corner*. It may cause frontal collisions due to: (i) cars overtaking in spite of the reduced range of visibility caused by the bend, thus colliding with cars coming through the bend in the opposite direction, (ii) cars going into the curve at excessive speed, thus being unable to keep their lane and sliding into the opposite lane, (iii) an obstacle (e.g., parked car, person, animal, fallen rock or tree, roadwork, ...) may suddenly appear to the driver as going around a bend, causing an abrupt evasive maneuver that brings the car into the opposite lane.

R_4 : *Erratic behavior*. It is due to: (i) failure of break control, gear control, out of one or several wheels, etc. of vehicle, (ii) lack of concentration due to alcohol, continuous driving for a long time, sudden health problems such as heart-attack, etc., and (iii) reckless driv-

ing. This results in a frontal or rear-end or side collision.

We consider only possible collisions among several vehicles and do not consider situations where only one vehicle is involved such as single vehicle accidents like going off the road. Recent statistics¹ of Norway shows that the number of accidents as 5860 from January to September 2008. These accidents included 1215 rear-end collisions including accidents in same direction, 869 frontal collisions including overtaking collisions, and 725 side collisions by crossing the direction of road. So, it is necessary to avoid these collisions as early as possible for minimizing human and financial losses. The reasons R_1 to R_4 cover the possible types of collisions that are reported in the accident statistics of Norway. With these, we provide a general approach as a protocol for providing several useful warnings to a driver. For instance, a warning is given if the system senses that the driver is about to overtake and the remaining straight piece of road up to the bend is too short for a safe overtake.

3 Context-based Protocol for Vehicle

3.1 Architecture

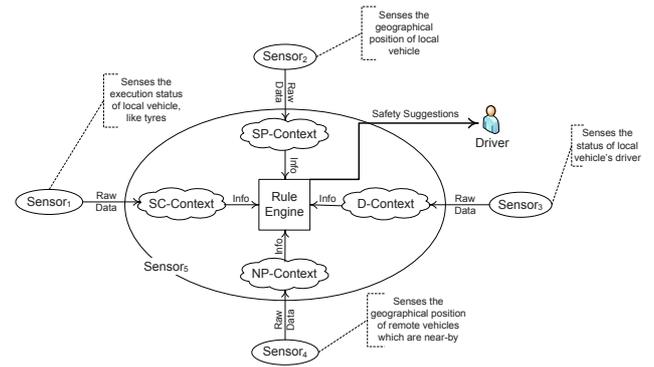


Figure 1. Overall Architecture of *CoP4V*

Figure 1 shows the architecture of *CoP4V*. This architecture has five *sensors*, four *contexts*, and one *rule-engine*. Sensors sense and communicate with the driver and different parts of the vehicle. The output of sensors are some raw-data which need to be processed. Contexts characterize the data that are received from sensors. The rule-engine has some set of rules to make safety decisions. The safety decision is taken based on the contextualized information of different contexts. Five sensors are numbered from 1 to 5 in Figure 1. Sensor₅ leads all other sensors for making safety suggestions. Contexts and rule-engine are available as part of Sensor₅. Sensor 1 to 4 send the respective sensed information to Sensor₅ continuously. Note that Sensor₅ has the built-in memory and data processing ability, whereas

¹http://www.ssb.no/english/subjects/10/12/20/vtu_en/arkiv/tab-2008-10-10-07-en.html

these are optional for other sensors, i.e., 1 to 4. Sensor₅ keeps track of four different contexts internally. The name of the different contexts are: *SP-Context*, *NP-Context*, *D-Context*, and *SC-Context*. *SP-Context* tracks the self-position of a vehicle, i.e., the geographical position of vehicle at a given point in time. For instance, identification of the road where the vehicle is traveling, present position in that road, direction, etc. This makes a vehicle aware of its geographical driving status always. *NP-Context* tracks the geographical position of neighboring vehicles. This makes a vehicle understand about the situation of surrounding vehicles. The neighboring vehicles are determined based on the communication range of the sensor, i.e., Sensor₄ in our case, and their *SP-Contexts* are exchanged through the wireless communication of sensors. *D-Context* tracks the status of vehicle's driver. With this, a vehicle can realize the present situation of its driver. For instance, sight-strength of driver in a given time. *SC-Context* tracks the self-condition of vehicle, i.e., the mechanical condition of different parts for further drive. For instance, availability of fuel, break-control, etc.. This makes a vehicle to understand the executional status of different parts which are required for driving. All the four contexts are associated with a separate (or group of) sensor for getting its contextual information regularly. *SC-Context* is associated with Sensor₁. *SP-Context* is associated with Sensor₂. *D-Context* is associated with Sensor₃. *NP-Context* is associated with Sensor₄. These contexts are formally defined in Section 3.2 including some examples. The data generation rate of sensors are constant and synchronized.

3.2 Definitions of different Contexts

Definition 1 (*SP-Context*). A *SP-Context* is a tuple $\mathcal{C}_{sp} = (vi, ps, cs, p, ns, s, ac, \mathcal{NA})$ where:

- *vi* is the Vehicle Identification which is unique for every vehicle,
- *ps* indicates the name of Previous Segment where a vehicle just came through,
- *cs* shows the name of Current Segment where the vehicle is going on,
- *p* provides the present Position of vehicle in *cs*,
- *ns* shows the name of Next Segment where a vehicle plans to go next,
- *s* points the current Speed of a vehicle, and
- *ac* shows the Acceleration of a vehicle, i.e., rate of change in meters per second,
- \mathcal{NA} is a set which indicates a vehicle's Next immediate Actions if there is any. Some of the identified actions are: *overtaking* including a list of vehicles, and *stop* including the identification of place. This set is

empty when there is no plan for next immediate action, i.e., vehicle will continue the same without any change.

Car navigation system could be used for getting the information of *ps*, *cs*, and *ns*. An example of *SP-Context* $c_{sp} \in \mathcal{C}_{sp}$ is (*NO2022*, *s₁ of NH-24*, *s₂ of NH-24*, 200, *s₇ of NH-28*, 100, 30). This shows that *vi* is *NO2022*, *ps* is *s₁ of NH-24*, *cs* is *s₂ of NH-24*, *p* is 200, *ns* is *s₇ of NH-28*, *s* is 100, *ac* is 30, and \mathcal{NA} is $\{Overtaking, \{NO2023\}\}$.

Definition 2 (*NP-Context*). A *NP-Context* is a finite set of *SP-Context*, i.e., $\mathcal{C}_{np} = \{c_{sp_1}, c_{sp_2}, \dots, c_{sp_n}\}$. Cardinality of \mathcal{C}_{np} is equal to the number of vehicles which are in the communication range of sensor that directly communicates with the near-by vehicles.

For instance, as depicted in Figure 2 car A includes car B and C in its communication range. Car D is completely out of communication range for A. Here, the cardinality of \mathcal{C}_{np} is two, i.e., car B and C.

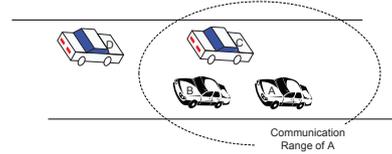


Figure 2. Communication Range of a Vehicle

Definition 3 (*SC-Context*). A *SC-Context* is quintuple $\mathcal{C}_{sc} = \langle \mathcal{B}, \mathcal{E}, f, \mathcal{L}, \mathcal{T} \rangle$ where:

- \mathcal{B} is a finite set of attribute values that shows the present status of Braking system in vehicle. Some of the identified attributes are lubrication oil, coupling plates, and hand control.
- \mathcal{E} is a finite set of attribute values that shows the present status of engine. Some of the identified attributes are piston, cylinder, bearing, carburetor, and exhaust stack.
- *f* indicates the availability of Fuel for further drive.
- \mathcal{L} is a finite set of attribute values that indicates the present status of lights which are in the outer parts of vehicle. Some of the identified attributes are front-left, front-right, rear-left, rear-right, side-left, and side-right.
- \mathcal{T} is a finite set of attribute values that indicates present status of different tyres. Some of the identified attributes are front-left, front-right, rear-left, and rear-right.

An example of *SC-Context* $c_{sc} \in \mathcal{C}_{sc}$ is $\{\{normal, free, normal\}, \{normal, normal, hot, hot\}, 5.2liters, \{on, on, on, on, off, off\}, \{normal, normal,$

low, normal}). This shows that the *lubrication-oil* of \mathcal{B} is normal, *coupling-plates* of \mathcal{B} is free, *hand=control* of \mathcal{B} is normal, *piston* of \mathcal{E} is normal, *cylinder* of \mathcal{E} is normal, *bearing* of \mathcal{E} is hot, *carburetor* of \mathcal{E} is hot, *f* is 5.2liters, *front-left* of \mathcal{L} is on, *front-right* of \mathcal{L} is on, *rear-left* of \mathcal{L} is on, *rear-right* of \mathcal{L} is on, *side-left* of \mathcal{L} is off, *rear-right* of \mathcal{L} is off, *front-left* of \mathcal{T} is normal, *front-right* of \mathcal{T} is normal, *rear-left* of \mathcal{T} is low, and *rear-right* of \mathcal{T} is normal.

Definition 4 (\mathcal{D} -Context). A \mathcal{D} -Context is a tuple $\mathcal{C}_d = (\text{eyeContact}, \text{heartBeat}, \text{audibility}, \text{control})$ where:

- *eyeContact* shows the present eye contact path of driver. It includes the values of dull, sharp, and dozy.
- *heartBeat* indicates the number of heart beats of driver.
- *audibility* points whether the given alert is audible for the driver or not, its data type is boolean.
- *control* shows the control of driving. It is *self* when driver drives the vehicle, otherwise *auto*.

An example of \mathcal{D} -Context $c_d \in \mathcal{C}_d$ is (*sharp, 30, true*). This shows that the *eyeContact* is sharp, *heartBeat* is 30 per minute, and *audibility* is true.

3.3 Algorithm

Algorithm 1: $CoP4V$

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1 while  $SP.p$  is in road do
2   acquire  $SP, NP, SC, D$  continuously in a defined frequency;
3   broadcast  $SP$  continuously;
4   if vehicle's driver likes to overtake then
5     set overtaking in  $SP.NA$ ;
6     receive the details of vehicles which are in the opposite
7     direction (i.e., part of  $NP$ );
8     assess the safety of overtaking according to their  $SP$  and local
9      $SP$ , and report the result to driver;
10  for every vehicle  $v$  in  $NP$  that has overtaking do
11    if  $SP.p$  has not passed through  $v$ 's  $SP.p$  then
12      indicate driver about this overtaking interest;
13      filter  $NP$  based on forward direction and send it to the
14      respective vehicle including  $SP$ ;
15    else
16      no action;
17  if  $SC.B$  or  $SC.E$  or  $SC.B$  or  $SC.T$  is failed then
18    alert driver and broadcast failure status to the vehicles in
19     $NP$ ;
20  if  $NP$ 's  $SC.B$  or  $SC.E$  or  $SC.B$  or  $SC.T$  is failed then
21    assess failed neighbor's  $SC$ 's and  $SC.ac$ , and alert driver;
22    broadcast this information to the vehicles  $NP$  if there can be
23    any impact;
24  if  $D.heartBeat$  is low or  $D.eyeContact$  is dull then
25    vibrate driver and wait for few milliseconds;
26    if still  $D.heartBeat$  is low or  $D.eyeContact$  is dull then
27      take auto-control and broadcast this info to vehicles in
28       $NP$  with updated  $D$ ;
29      park the vehicle in near-by safe place;
30    else
31      no action;
32  if  $NP$ 's  $D.heartBeat$  is low or  $D.eyeContact$  is dull then
33    alert driver for adjusting  $SP$ 's and  $SP.ac$ ;

```

The general algorithm of $CoP4V$ is given in Algorithm 1. We have given only the limited cases of vehicle's behavior in Algorithm 1 due to the space limitations. Those are: overtaking, mechanical failure of vehicle, and natural illness or significant tiredness of driver. This algorithm starts when a vehicle is on road. The details are:

- Receive $\{SP, NP, SC, D\}$ and broadcast SP context continuously from respective sensors. (Lines 2 and 3)
- Set NA of own SP -context as overtaking when driver likes to overtake any vehicle(s). After receiving the details of neighbors which are in opposite direction, assess the safety of overtaking with their position and own position, and report the results to driver. A linear equation based approach is given in Section 3.4 for this assessment. Driver continues overtaking the respective vehicle if the results are positive. (Lines 4 to 7)
- For every vehicle that has overtaking interest, check whether it passed through the self position or not. If it has not passed through the self-position then inform driver about this and send the details of self-position and neighbors position that are in forward direction. Based on this, neighbor which is interested in overtaking takes the decision. A linear equation based approach is given in Section 3.4 for this decision-making. (Lines 8 to 13)
- Indicate the driver if there are any failure in brake-control, tyres, etc., and broadcast this information to others. (Lines 14 to 15)
- If any of the neighbors brake-control, tyres, etc., fails then assess its speed and acceleration, and alert the driver and broadcast this information to others. (Lines 16 to 18)
- For any of the major problems of driver like heart-attack, vibrate the driver first. If there is no response further then take the auto-control and broadcast this information to others. After that, park the vehicle in a safe position. (Lines 19 to 25)
- When any neighbor's driver has any major problem as indicated before, adjust self speed and acceleration based on the position of neighbors. (Lines 26 to 27)

3.4 Calculations for Overtaking

A vehicle (say, B) that receives an overtaking request verifies whether it has recently passed through the requesting vehicle's (say, A) position or not. The reply will be sent if the present position of A was not recently passed by B. Here, we provide a way for ensuring this verification. Every vehicle is expected to keep its history of self-position that are received in SP -Context. Theoretically, we say that a vehicle keeps n past self-positions, and the interval time between two receptions is very small like one second. This makes

the movement of a vehicle as linear (i.e., straight-line) between two self-positions. If we denote the n self-positions of B as $(x_0, y_0), (x_1, y_1), \dots, (x_{n-1}, y_{n-1})$, then the movement between two consecutive positions i.e., (x_i, y_i) and (x_{i+1}, y_{i+1}) is a linear equation $y = ax + b$. Here, a and b represent the linear sequence of vehicle's movement i.e., in general terms: $a_i = (y_{i+1} - y_i)/(x_{i+1} - x_i)$, $b_i = y_i - ax_i$. B passed through the supplied position (say, (x_r, y_r)) of A if and only if:

$$\exists i, 0 \leq i \leq n-2, y_r = a_i * x_r + b_i \quad (1)$$

Here, n is based on the maximum communication range, the speed, and the interval time between two self-positions of B. For instance, if the interval time is one second and the speed is 80km/hr , and the communication range as 250m then the value of n would be 12.

B makes the safety decision for overtaking A after receiving response from C. which comes in the opposite direction of A and B. C is near to A in the forward direction. We make the following assumptions. The distance between A and C as d_c , A and B as d_b , and threshold distance that should be maintained between two vehicles (one in each lane) while overtaking as d_{th} . The accelerations and speeds of A as a_A and s_A , B as a_B and s_B , and C as a_C and s_C . The distance traveled by them in time as $X_A(t)$, $X_B(t)$ and $X_C(t)$. We consider the time of sending overtaking request as the reference i.e., $t = 0$. The overtaking is safe if and only if:

$$\exists t > 0 : \begin{cases} X_A(t) + X_C(t) + d_{th} < d_c & \text{and} \\ X_A(t) > X_B(t) + d_b + d_{saf} \end{cases} \quad (2)$$

The first condition of Equation 2 becomes as: $(a_A + a_C)t^2 + (s_A + s_C)t - (d_c - d_{th}) < 0$ when we apply the movement equation $X(t) = a * t^2 + s * t$. The resolution of this inequality is $t \in]0, t_1[$, where $t_1 = \frac{\sqrt{(s_A + s_C)^2 + 4(a_A + a_C)(d_c - d_{th})} - (s_A + s_C)}{2(a_A + a_C)}$. The second condition of Equation 2 becomes as: $(a_A - a_B)t^2 + (s_A - s_B)t - d_b - d_{saf} > 0$. The resolution of this inequality is $t \in]t_2, +\infty[$, where $t_2 = \frac{\sqrt{(s_A - s_B)^2 + 4(a_A - a_B)(d_b + d_{saf})} - (s_A - s_B)}{2(a_A - a_B)}$. Therefore, the resolution of Equation 2 is $t \in]t_2, t_1[$. The overtaking is safe ($\neq \emptyset$) if and only if $t_2 < t_1$. In other way, overtaking is unsafe if $t_2 \geq t_1$, i.e.,

$$\frac{\sqrt{(s_A - s_B)^2 + 4(a_A - a_B)(d_b + d_{saf})} - (s_A - s_B)}{\sqrt{(s_A + s_C)^2 + 4(a_A + a_C)(d_c - d_{th})}} \geq s_A(a_B + a_C) + s_C(a_B + a_A) - s_B(a_A + a_C) \quad (3)$$

4 Related Work

Vehicular ad hoc networking (VANET) is one of the active research area in mobile ad hoc networking [13]. Chisalita et al illustrate the usefulness of VANET for ensuring vehicular traffic safety in [7] including its advantages over centralized technologies. Peterson [14] have shown the feasibility of wireless communication between sensors

through a real wireless vehicular sensor networking scenario using Mica2motes (www.xbow.com) which are embedded at different parts of a moving car. In [12], Lidstrom et al treat vehicular safety from the perspective of wireless sensor networks and proposed an approach to estimate the reliability and availability of wireless medium at hazardous locations. Several mobility models that consider the constraints a vehicle can encounter have been proposed and implemented in network simulators [10]. Many efforts have been devoted to use several wired sensors embedded in vehicle for road safety, such as [16, 5, 6]. Unfortunately, all these proposals suffers from the same limitation of not considering the communication between vehicles or roadside things to provide awareness about the environment. Such awareness increases the level of safety for a vehicle [3]. *CoP4V* has awareness about its environment through wireless sensors, and establishing communication across a vehicle while making safety decisions.

Karpinski et al [11] suggest to put magnetic sensors along the two sides of roads in every few meters. This allows the sensors to exchange information about the passing cars for maintaining the realtime information of road-state. This information consists of relative position and speed of all vehicles traveling along the road. Here, sensors are fixed outside and the safety information is continuously updated to the onboard computer of vehicle. However, it is extremely difficult to get such infrastructure in real for all highways. This is due to the requirement of too many sensors on roads for providing safety. The difficulties could be expressed in terms of establishment and maintenance cost, security, etc. Safety warning system of Xing et al [17] also suffers from the unscalable assumption of deploying sensors all along the roads. Whereas, our approach does not have these limitations since it uses in-built vehicle sensors for vehicle's safely.

Sawant et al [15] proposed a solution to form a multi-hop ad hoc network, it relies on in-vehicle sensors. Onboard millimeter-wave radars and visual sensors (cameras) are used for detecting the presence of obstacles that are in front. An inter-vehicle communication protocol (*ivc*, in short) is proposed to exchange the data sensed by in-vehicle sensors, using both periodic and alert messages. The difference between our protocol (*CoP4V*) and *ivc* are: (i) *CoP4V* defines the messages clearly in terms of different contexts for exposing different kinds of situations, whereas it is not clear in *ivc*, and (ii) *CoP4V* provides safety in different perspectives (i.e., self-position, remote-position, self-condition, and driver), whereas *ivc* focuses only in terms of position. Yoo [18] have given a solution for safe overtaking in two-way single carriageway based on in-vehicle sensors. ID of a vehicle is broadcasted continuously to inform its presence to other vehicles. A vehicle has to make a request before overtaking other. After receiving the over-

taking request, LED is operated manually by the driver for indicating the clearance of overtaking. This clearly shows that this approach is semi-automatic, i.e., driver is expected to be cautious always. Whereas, our approach is completely automatic.

Biswas et al [3] provided a protocol for direction-aware broadcast data forwarding to minimize the chain collision. Direction-awareness is realized as a context, which prioritizes the forwarding data and reduces the number vehicles that are involved in broadcasting chain. Here, the context is just used for forwarding data. Whereas, the context usage is not limited in *CoP4V*. Moreover, *CoP4V* is adaptive for accepting new contexts in its architecture. This allows *CoP4V* to handle wide range of safety problems.

5 Conclusion and Future Work

We have proposed a context-based infrastructureless solution for increasing the safety of vehicle. Contexts are formally given for characterizing and tracking the environment of a vehicle. Sensors feed data that are required for contexts continuously. Wireless communication is used between sensors for data transmission. Driver is alerted with one or more safety warnings according to contexts. Finally, safety calculations are given for overtaking as an example of safety decision-making. In future, we plan to investigate on identifying false-alarms and reducing its rate, minimizing the safety workload of driver by increasing the level of automatic safety decision-making and control, and providing safety suggestions to vehicle even when there is no built-in safety decision-making system.

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