PREVENTING VEHICLE CRASHES THROUGH A WIRELESS VEHICULAR SENSOR NETWORK

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ABSTRACT

In this manuscript we propose a wireless sensor network (WSN) based solution allowing vehicles with merely onboard sensors to avoid frontal collisions in rural highways. Unlike the current solutions that rely on heavy infrastructure, in our vehicular traffic safety solution only tiny low-cost sensors are employed. It can thus replace the infrastructure-based systems in rural and suburban areas, where the deployment of such infrastructure is constrained. It can also serve as an alternative solution for unsophisticated vehicles that are not equipped with aboard computers and cannot take advantage of the current intelligent transportation systems and services.

1. INTRODUCTION

When merging Vehicular Ad hoc NETworking (VANET) and Wireless Sensor Networking (WSN) a new environment emerges as one of the most recent applications of ad hoc and sensor networking, known as Wireless Vehicular Sensor Networking (WVSN). It consists of connecting sensors that are embedded in vehicles as well as the roadside ones using wireless channels. The sensors can also be connected to the roadside infrastructure and take advantage of the existing transportation systems. WVSNs have many applications such as traffic management, environment monitoring, vehicle tracking, and traffic safety. In this work, we deal with the latter kind of applications. All the current solutions proposed for this purpose rely on the roadside infrastructure, and/or the deployment of sensors in the roadside and in the ground (within the route) [1, 2, 3, 4, 5, 6]. Putting the infrastructure and the sensors at some areas, e.g inside a city, at intersections, etc is realistic and feasible. However, deploying such equipments all along routes, especially in suburban and rural regions may be impractical for the time being. This deployment requires a dramatic number of sensors and thus is costly. In addition to the cost issue, there is a risk for the equipment (both the sensors and the heavy infrastructure) to be damaged or stolen in such uncontrollable regions. Still, ensuring traffic safety is mandatory in such regions, particularly in two-way single carriageways routes, where most accidents occur owing to improper overtaking (frontal collisions) [2].

In this letter we propose an infrastructureless protocol to be executed by sensors embed in vehicles aiming at preventing frontal collisions du to improper overtaking. The solution is not eliminating the existing infrastructured systems, but it can be complementary to overcome the absence of the infrastructure in rural areas.

2. NEW SOLUTION

2.1. Assumptions

We assume that each vehicle is equipped with a magnetic sensor and an accelerometer sensor including a GPS receiver. The first one is to provide the distance from and the velocity (speed/acceleration) of the front vehicle. It would be preferable for this sensor to be embedded within the front bumper. The second sensor, which can be fixed anywhere onboard, serves to provide the vehicle position and velocity information. Note that most of the current available transducers include these functionalities (magnetometer, accelerometer,and GPC). Integrating the two sensors in the same one with multiple transducers may represent an optimization, but needs more investigation. We also suppose that the sensors are equipped with directed antennas, that each route segment has a unique ID, and that at the intersections (the segments delimitation points) a simple beacon with directed antenna broadcasts the ID of segments in the appropriate direction and angle. The crossroad is the best position for this beacon (figure 1). However, if the intersection does not include a crossroad then the beacon can be fixed in the roadside, somewhere where it can geometrically cover all the segments. More than one beacon may be used if needed. The cost of these components would be negligible, since their functionality is very simple, i.e. they just periodically broadcast a short message, and they are to be put merely at intersections (not all along the routes). A simple senor is sufficient enough for this beacon operation. This way, a sensor does not need any geographic information system (GIS) to determine in which segment it is moving, and does not need to store and update any road map. In its current version, our solution does not use any multihop communication, so there is no requirement regarding the routing protocol. As for the MAC layer, the most important feature required for our application to perform efficiently is the low delay in accessing the channel. CSMA-based protocols, such as the basic one implemented in the current manufactured motes (e.g of Crossbow), have generally the lowest latency, but more investigation into the hidden terminal effects is required. The MAC protocol is out of the scope of this work, we just assume that it ensures as low latency as possible. In the following, we describe the protocol we propose for collision prevention.

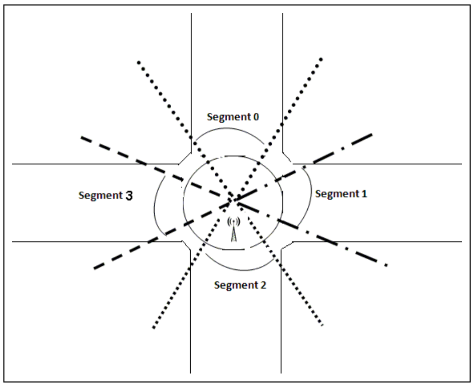

Fig. 1. Directed Beacon in a Crossroads

2.2. Protocol Description

As soon as a vehicle tries to make an overtaking, the onboard sensor broadcasts an overtaking request (OREQ) packet, including its current position and route segment. The onboard sensor can be connected to the vehicle overtaking indicator, so that it automatically captures the overtaking attempt event. Each vehicle (its onboard sensor) that receives this packet replies to the sender and provides it with its position and speed, then the latter can decide whether the overtaking is safe or not as we will see later. In figure 2, where vehicle A wishes to overtake B, all the other vehicles can reply if they are in the A's vicinity (power rang). Indeed, only vehicle c can cause a frontal collision when overtaking, but not the others. Vehicle d and e are back and do not affect A's overtaking, vehicle f is completely in another segment, and finally vehicle B is in A's magnetic sensing vicinity so that its position and speed are captured by the bumper sensor (no reply from this vehicle is needed). Therefore, it is a waste of bandwidth and delay to let all these sensors respond to the OREQ, and it is more optimal and realistic to eliminate all these redundant replies. First, the use of a directed antenna eliminates the vehicles behind the sender, such as d and e in our example. Vehicle A merely needs to fix its antenna forward as it is moving. To eliminate outside vehicles (located in another segment), the receiver of OREQ does not reply immediately but

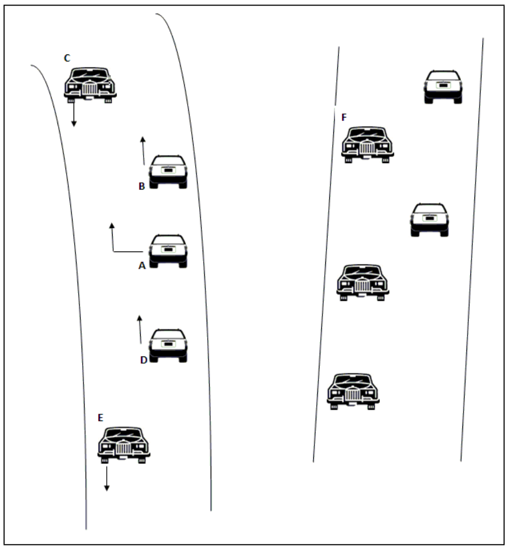

Fig. 2. Example of vehicles in two differrent routes

first checks if its segment is the same as of the one in OREQ (of the sender). Finally, to eliminate responses from vehicles in the same lane and moving in the same direction (B), the receiver has just to make sure before replying that it has not recently passed through the sender's position. We will see in the next section how this verification can be performed. Algorithm 1 illustrates our protocol, which is executed by each onboard sensor. The primitive *passed(pos)* returns FALSE if the vehicle has not passed through the position pos, while *safe_overtaking* returns FALSE if the overtaking is estimated to be unsafe. These issues will be clarified in the following.

2.3. Safety and Replying Conditions

We have seen that a vehicle (node) first verifies if it recently passed through the sender's position before replying to a OREQ. This can be ensured using the following procedure: The vehicle keeps information regarding its last n positions obtained from its GPS receiver. The interval between two receptions is small and could be about 1s. The movement is considered to be in a straight line during this short interval, and then the receiver compares the position it receives with the ones it passed through. Mathematically speaking, if we denote the n positions of the receiver (vehicle B) by $(x_0, y_0), (x_1, y_1), ...(x_{n-1}, y_{n-1})$, and since the movement between any couple of positions (x_i, y_i) and (x_{i+1}, y_{i+1}) can be expressed by the simple linear equation: $y = ax + b$, then the parameters a and b for this linear sequence of movement, say a_i, b_i, are given by:
$a_i = (y_{i+1} - y_i)/(x_{i+1} - x_i)$, $b_i = y_i - ax_i$

B passed through a given position (Xr, Yr) reported in OREQ iff:

$$\exists i, 0 \leq i \leq n-2, Yr = a_i Xr + b_i \quad (1)$$

One may think about possible problems in bends, where the movement is not linear. Generally speaking, overtaking is forbidden in any area containing a bend (before and after the bend for some tens of meters). If drivers do not accurately respect the highway code, at leas the overtaking must not *start* exactly at the band, so that the position reported in OREQ cannot be one of the bend region. The parameter n should be high enough to cover the power range distance, the maximum distance from which an OREQ can be received. It depends on the vehicle (receiver) speed and the interval between two GPS received positions. For instance, if the interval is fixed to $1s$ and the speed is $80km/hr$ then fixing n to 12 would be enough to cover a distance of $250m$, and 23 to cover $500m$. Saving such number of coefficient couples (a,b) is really of negligee memory space.

Algorithm 1 Protocol Illustration

When overtaking

Construct OREQ packet
OREQ.position= node.position
OREQ.segment = node.SegID
OREQ.speed= node.speed
OREQ.acceleration=node.acceleration
OREQ.sender = node.ID
broadcast OREQ in the frontal 180^0

When receiving a beacon packet BQ

node.SegID=BQ.SegID

When receiving OREQ

if node.SegID==WREQ.segID **then**
  if passed(WREQ.position) == FALSE **then**
    construct OREP
    OREP.position=node.position
    OREP.speed=node.speed
    OREP.acceleration=node.acceleration
    send OREP to OREQ.sender
  end if
end if

When receiving OREP

if safe_overtaking(OREP, node, front_node)==FALSE **then**
  Alert the driver
end if

When receiving GPS information

update(node.position)

When receiving information from the magnetic sensor

update(front_node.distance, front_node.speed, front_node.acceleration)

Now we discuss how the sender of the OREQ can detect that an overtaking is unsafe and alert the driver. Note that no alarm is launched as long as there is no evidence of a danger. As illustrated in figure 2 we consider that the vehicle A is the one that tries to overtake B by sending the OREQ, and the closer approaching vehicle is C, whose OREP is the most significant (allows to detect an unsafe overtaking). C could be either in its normal lane (as depicted in figure 2), or in the opposite lane (of A and B) to overtake another vehicle. We denote the distance between A and C by d_c , the one between A and B by d_b, the safety distance to be maintaned by any two subsequent vehicles in the same lane by d_{saf}, and let d_{th} be a threshold of distance that should be maintained by two frontal vehicles (one in each lane) during the overtaking, to enforce safety. Also, we denote the accelerations and speeds of A, B and C respectively by a_A s_A, a_B, s_B, a_C, s_C, the distance traversed by them in time by $X_A(t)$ $X_B(t)$ and $X_C(t)$, and we consider $t = 0$ the time of sending OREQ. Note that the information related to C is obtained from the OREP packet, while the one related to B is captured by the bumper magnetic sensor. The overtaking is considered safe iff:

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

When applying movement equation: $X(t) = a * t^2 + s * t$, the first condition of formula 2 is transformed into: $(a_A + a_C)t^2 + (s_A + s_C)t - (d_C - d_{th}) < 0$

The solution of this inequality is $t \in]0, t_1[$, where:

$$t_1 = \frac{\sqrt{(s_A+s_C)^2+4(a_A+a_C)(d_c-d_{th})}-(s_A+s_C)}{2(a_A+a_C)}$$

On the other hand, the second condition of 2 becomes: $(a_A - a_B)t^2 + (s_A - s_B)t - d_B - d_{saf} > 0$

The resolution of this inequality is $t \in]t_2, +\infty[$, such that:

$t_2 = \frac{\sqrt{(s_A - s_B)^2 + 4(a_A - a_B)(d_B + d_{saf})} - (s_A - s_B)}{2(a_A - a_B)}$

Therefore, the resolution of 2 is $t \in]t_2, t_1[$. The solution exists ($\neq \varnothing$) iff $t_2 < t_1$, otherwise there is no solution for a safe overtaking.

To summarize, the condition for warning the driver (unsafe overtaking estimation) is $t_2 \geq t_1$, which is given by:

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

3. SUMMARY AND PERSPECTIVES

In this letter we propose an ad hoc solution to avoid unsafe overtaking in two-way single carriageway routes. The unique feature of our solution is the infrastructureless, which makes it appropriate to get over the poor coverage of infrastructure-based traffic systems in rural areas, and to less sophisticated vehicles. Our protocol is based on wireless sensor networks, and requires a vehicle to be equipped with just two sensor motes, whose cost is low and will be negligible in the near future. It helps the driver by possibly alerting him about unsafe overtaking, especially in difficult visibility conditions (foggy wheatear, at night, in areas with bends etc.). Nonetheless, it is far from replacing the driver maneuvers and vigilance. The driver should switch on the overtaking indicator light upon the overtaking attempt, and should start the overtaking in a smooth acceleration. Since the response of its request should be in the scale of few milliseconds, he can rapidly cancel the overtaking and go back to his lane when warned by its sensor, or go ahead and increase his acceleration as long as there is no warning. More investigations into the solution and its parameters, as well as the evaluation by simulation and the real implementation of a prototype in sensors are in our perspectives. Dealing with other kind of collisions, such as rear-end collisions that are common in motorways because of sharp traffic stop (in the case of an accident for example), is also in the perspectives.

4. REFERENCES

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