Dynamic Control of Beacon Transmission Rate with Position Accuracy in Vehicular Networks

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Abstract

The proper performance of cooperative safety applications in vehicular networks depends of the exchange of beacon messages between neighboring vehicles. A challenge in these networks is to control the beacon transmission rate in real-time to meet the position accuracy requirements of safety applications. In this paper, we propose an adaptive beaconing algorithm based on dynamic control of beacon rate. The beacon rate is adjusted dynamically as a function of the vehicle movement status, to constrain the position error computed by surrounding vehicles. The results obtained from a realistic simulation framework show that, the proposed algorithm successfully controls the beacon rate to maintain a target position accuracy. Further, it adapts to the vehicular traffic dynamics, being able to maintain a better position accuracy compared to other fixed beaconing algorithms.

1 Introduction

Intelligent Transport Systems (ITS) are a technology designed to support road safety and traffic efficiency applications [MP16]. In these systems, the vehicles are equipped with wireless communication devices allowing the information exchange between vehicles, and with infrastructure devices. The Dedicated Short-Range Communication (DSRC) is a short and medium range radio access technology that operates in the 5.9 GHz frequency band, providing communication support in vehicular networks. This technology relies on several standards designed for vehicular communications, including the IEEE 802.11p standard [IEE10], which defines physical (PHY) and medium access control (MAC) layers for Wireless Access in Vehicular Environments (WAVE) [WAV17].

Cooperative vehicular networks have been identified as a promising technology to enable ITS. These networks require the continuous exchange of status information between neighboring vehicles to support cooperative awareness applications. In this process, each vehicle periodically transmits one-hop broadcast messages, called beacons [ETS14], containing its position, speed, acceleration, and heading. The beaconing allows the receiving vehicles to create a local dynamic map (LDM) of the vehicular environment, which is used by cooperative safety applications to avoid traffic accidents. For instance, applications such as intersection collision warning and lane change assistance use the beacon information to detect and mitigate potentially dangerous situations in real-time.

The high mobility of vehicles leads to a rapid expiration of the beacon information. In consequence, the position inaccuracies can impact the proper performance of cooperative safety applications, which rely on real-time accurate information. Beacon transmission rate directly translates into accuracy of cooperative awareness [SLS+10]. Finding the appropriate beacon rate according to the scenario dynamics is essential for the system performance. In traffic jams a beacon rate of 1 beacon/s may be sufficient to provide the position accuracy needed by safety applications. However, this beacon rate is not sufficient to obtain a good level of position accuracy on a multi-lane high speed highway with frequent lane changes.

In cooperative vehicular systems, the precision and freshness of the status information is indispensable for the decision-making process, in real-time, of safety applications. The position error computed by neighboring vehicles directly impacts on the vehicle's systems capability to detect and mitigate potentially dangerous situations on time [SLS+10]. In this paper, we propose and evaluate a novel adaptive beaconing al-

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gorithm that dynamically adjusts the beacon rate to meet the position accuracy requirements of cooperative safety applications. The algorithm adjusts the beacon rate according to the vehicle movement status to limit the position error computed by surrounding vehicles under a target threshold.

2 Dynamic Control of Beacon Rate

The Dynamic Control of Beacon Transmission Rate (DC-BTR) algorithm computes the beacon transmission rate required by a vehicle n_i as a function of its movement status, to limit in real-time the position error computed by surrounding vehicles.

We represent the average position error ($\overline{E}$) as in [SLS+10], which expresses the mean error assuming that the event of looking up the position in the LDM database is uniformly distributed between the minimum and maximum time difference to the transmission event of the beacon,

$$\overline{E} = \frac{\lfloor E \rfloor + \lceil E \rceil}{2}, \quad (1)$$

where $\lfloor E \rfloor$ denotes the lower error boundary resulting from the transmission delay (t_D), and $\lceil E \rceil$ is the upper boundary that occurs when the position of a vehicle is looked up right before receiving the next beacon.

From kinematic equations, $\overline{E}$ is expressed as a function of the velocity (v_i) and acceleration (a_i) of n_i,

$$2\overline{E_i} = v_i t_D + I_{b_i}\left(v_i + \frac{a_i I_{b_i}}{2}\right) + t_D(a_i I_{b_i} + v_i), \quad (2)$$

where I_{b_i} is the beacon interval of n_i (equivalent to the inverse of R_{b_i}). We assume beacon messages of the same size (b_z) and equal data rate (R_D), so t_D is the same for all vehicles.

From (2), a second degree polynomial of the form $P(I_{b_i}) = AI_{b_i}^2 + BI_{b_i} + C$ can be obtained as,

$$a_i I_{b_i}^2 + 2(v_i + a_i t_D)I_{b_i} + 4(v_i t_D - \overline{E_i}) = 0. \quad (3)$$

In the general case of $a_i \neq 0$, the polynomial solutions are computed as follow,

$$I_{b_{i\{1,2\}}} = \frac{-B \pm \sqrt{D}}{2A}, \quad (4)$$

where $D = B^2 - 4AC$. On the other hand, if $a_i = 0$, the solution is,

$$I_{b_i} = \frac{2(\overline{E_i} - v_i t_D)}{v_i}. \quad (5)$$

Fig. 1a shows the velocity developed by a vehicle in 12 s, with three different constant accelerations: 1, 3, and 5 m/s^2. The I_b required by the vehicle to constraint ($\overline{E}$) under a target threshold of 1 m, computed by (3), is illustrated in Fig. 1b. The R_b corresponding to the vehicle beacon interval is illustrated in Fig. 1c. To obtain a position accuracy of 1 m, the vehicle uses an adaptive beacon rate, broadcasting more than 30 beacon/s when the velocity reaches 60 m/s and the acceleration is 5 m/s^2. Fig. 1d shows that the average position error obtained remains all the time under the preset threshold of 1 m.

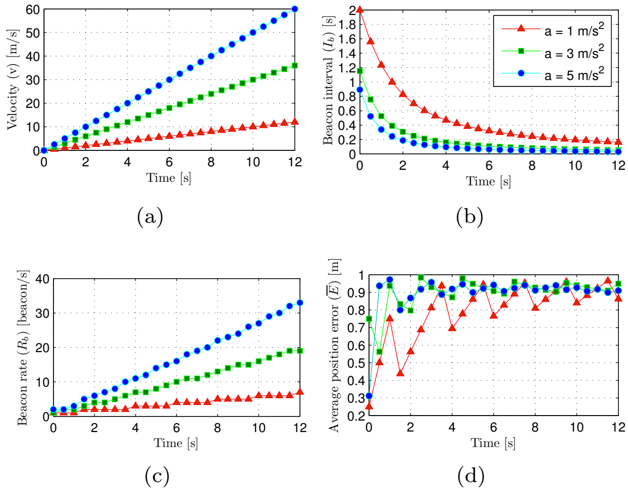


Figure 1: Behavior in time: a) Velocity , b) Beacon interval, c) Beacon rate, and d) Average position error.

Algorithm 1 describes the steps followed by DC-BTR to compute the beacon rate in real-time according to the velocity and acceleration of the vehicle n_i (Line 1) and the target position error (Line 2). The next beacon interval is computed by n_i at each beacon transmission. Lines 9-25 involve the decisions associated according to the movement status of n_i: repose (Line 9-10), the beacon transmission rate is set to 1 beacon/s equivalent to the minimum value required for the proper performance of the less demanding vehicular applications [ETS09]; accelerated movement (Line 11-14), the beacon transmission rate is computed using (4); uniform movement (Line 15-18), the beacon transmission rate is computed according to (5); deceleration (Line 19-25) in order to notify with immediacy to surrounding vehicles a possible braking, it is set a critical beacon interval (I_{b_c}). It should be noted that if two valid solutions are found, the solution that generates the lowest channel load is selected (see Line 12 and Line 21).

3 Performance Evaluation

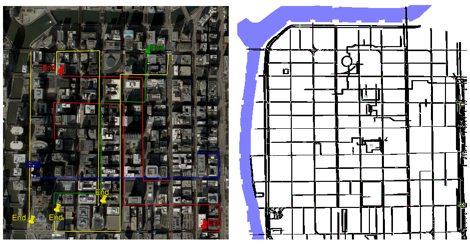
The DC-BTR algorithm has been evaluated in a urban scenario using the well established Veins framework [SGD11].

3.1 Evaluation Scenario

The simulations correspond to a real map section of Chicago city, USA, with an area close to 1 km^2. Fig. 2a and Fig. 2b show the scenario seen from Google Earth and Sumo traffic simulator, respectively. The zone has several traffic lights and multi-lane roads with a maximum speed limit of 120 km/h. We use a vehicular traffic model based on flows, where vehicles move between a point of origin and destination. Fig. 2a shows the seven flows that have been configured with 20 vehicles in a simulation time of 500 s. The vehicles use the IEEE 802.11p EDCA model [ES12] of the Veins Framework to represent the MAC/PHY layer. The radio signal propagation is modeled with the Two-Ray Interference path loss model [SJD12], with $\epsilon_r = 1.02$. The communication only occurs on the control channel (CCH) without considering the multi-channel operation. The beacon have 250 bytes and are transmitted with the priority of the voice access category. Each vehicle is 5 m long, 2 m wide and has an acceleration up to 0.8 m/s^2, and deceleration up to 4.5 m/s^2. The antenna height is 1.5 m and data rate is 6 Mbps. Table 1 summarizes the main simulation parameters.

Table 1: Simulation Parameters

Parameter	Value
CCH center frequency	5.890 GHz
Channel bandwidth	10 MHz
Transmit power	20 dBm
Average position error ($\overline{E}$)	1 m
Critical beacon interval (I_{b_c})	0.2 s
Beacon size (b_z)	250 bytes
CW	[3, 7]
AIFSN	2
Receiver sensitivity	- 82 dBm
Thermal noise	- 110 dBm
Data rate (R_D)	6 Mbps
Antenna gain	0 dB
Antenna height	1.5 m
Path loss model	Two-Ray Interference



(a) (b)

Figure 2: Real map section of Chicago, USA, seen from: a) Google Earth, b) SUMO.

3.2 Simulation Results

DC-BTR has been compared with the basic fixed beaconing process, which we named as fixed beaconing algorithm (FB). As in [SLS+10], four typical fixed beacon rates between 1 and 10 beacon/s have been investigated. Both beacon control rate approaches use a fixed transmit power of 20 dBm.

Fig. 3a illustrates the movement status of a generic vehicle in the scenario. The acceleration and velocity are represented in color blue and red, respectively. The mobility pattern shows a continuous change in vehicle status between acceleration, deceleration, and repose, which are typical changes of urban environments. Fig. 3b shows the adjustments that the DC-BTR imposes,

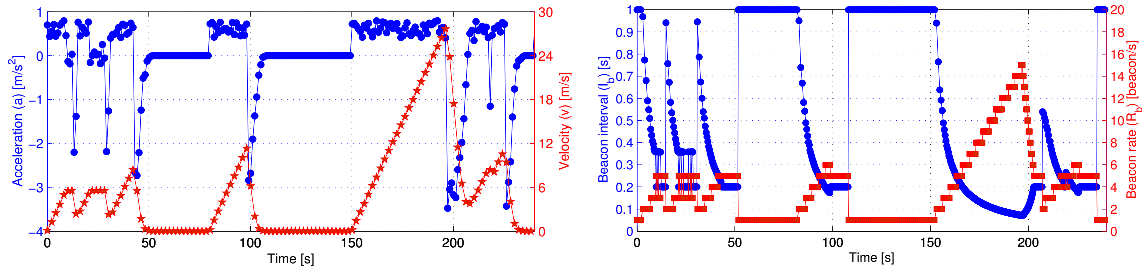
Algorithm 1: DC-BTR

Input : $\{v_i, a_i, t_D, \overline{E_i}\}$
Output: $\{R_{b_i}\}$

Algorithm to execute on each beacon transmission;

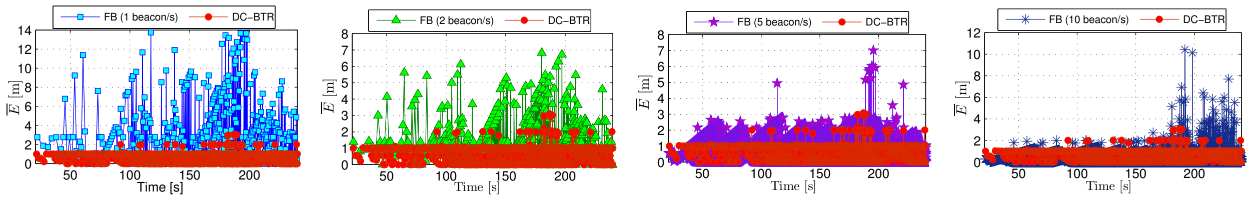
Get v_i, a_i;
Set $\overline{E_i}$;
$t_D \leftarrow b_z/R_D$;
$A \leftarrow a_i$;
$B \leftarrow 2(v_i + a_i t_D)$;
$C \leftarrow 4(v_i t_D - \overline{E_i})$;
$D \leftarrow B^2 - 4AC$;
$I_{b_{i\{1,2\}}} \leftarrow (-B \pm \sqrt{D})/2A$ according to (4);
if *(v_i == 0 && a_i == 0)* **then**
  $I_{b_i} \leftarrow 1$;
else if *(v_i >= 0 && a_i > 0)* **then**
  $I_{b_i} \leftarrow maximum\{I_{b_{i\{1\}}}, I_{b_{i\{2\}}}\}$;
  if *(I_{b_i} > 1)* **then**
    $I_{b_i} \leftarrow 1$;
else if *(v_i > 0 && a_i == 0)* **then**
  $I_{b_i} \leftarrow 2(\overline{E_i} - v_i t_D)/v_i$ according to (5);
  if *(I_{b_i} > 1)* **then**
    $I_{b_i} \leftarrow 1$;
else if *(v_i > 0 && a_i < 0)* **then**
  if *(D > 0)* **then**
    $I_{b_i} \leftarrow maximum\{I_{b_{i\{1\}}}, I_{b_{i\{2\}}}\}$;
    if *($I_{b_i} > I_{b_c}$)* **then**
      $I_{b_i} \leftarrow I_{b_c}$;
  else if *(D <= 0)* **then**
    $I_{b_i} \leftarrow I_{b_c}$;
$R_{b_i} \leftarrow 1/I_{b_i}$;
$R_{b_i} \leftarrow \text{ceil}(R_{b_i})$;
return R_{b_i};

in real-time, on beacon interval (color blue) to meet a target average position error of 1 m. Fig. 3b also shows in color red the beacon rate corresponding to the beacon interval required by DC-BTR. Note that, the increase in velocity demands an increase in the beacon rate, ensuring that, for high velocity values, the beacon interval is shortened to maintain the target position accuracy, as illustrated in the interval from 150 s to 200 s. In this time interval the velocity achieves 28 m/s, demanding 15 beacon/s. The adjustment not only responds to changes in speed, but also to variations of acceleration, as illustrated in the time intervals where the vehicle moves with constant velocity. In this time intervals, the transmission rate oscillates between 5 and 3 beacon/s. Note also that, when the vehicle is stopped, DC-BTR sets a rate of 1 beacon/s, which is considered the minimum beacon rate. In special cases where the vehicle slows down (see interval from 100 s to 105 s), DC-BTR uses a critical beacon interval equal to 0.2 s, so that neighboring vehicles immediately record any changes in their movement sta-



(a) (b)

Figure 3: Vehicle parameters in time: a) Velocity and acceleration, b) Beacon interval and beacon rate.



(a) (b) (c) (d)

Figure 4: Average position error in time for fixed and adaptive beacon control rate approach.

tus. Fig. 4 evidences the effectiveness of DC-BTR for the dynamic control of the beacon rate, restricting the average position error computed by surrounding vehicles to a value that remains most of the time below 1 m. As can be seen, the estimated error complied with the imposed constraint, except on some occasions, due to packet collisions which lead to harmful position errors. Note that DC-BTR achieves a higher position accuracy than FB algorithms for the different beacon transmission rates, especially for higher velocities.

4 Conclusion and Future Works

In this paper we have proposed the use of an adaptive beaconing algorithm in cooperative vehicular networks, which dynamically adjusts the beacon transmission rate to meet the position accuracy requirements of safety applications. The simulation results have shown that the proposed algorithm successfully limits the average position error under a target threshold. Further, it outperforms the fixed beaconing algorithms addressed in this paper, in terms of position accuracy. However, packet collisions lead to harmful position errors. For this reason, in future works we plan to propose a joint power and rate control algorithm, to limit the position error while reducing packet collisions.

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