Experimental Evaluation of Adaptive Beaconing for Vehicular Communications

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Abstract

In this work we developed an experimental setup to evaluate an adaptive beaconing algorithm that helps maintain cooperative knowledge in vehicular communication networks. The algorithm controls the frequency of the beacons with the objective of reducing channel load and mantaining a fixed average position error calculated from the location information received in the beacons from the neighboring vehicles. To evaluate the performance of the adaptive algorithm, we setup a test bed with commercial on board units (OBUs) that are to be used in connected vehicles. The experimental results are compared with simulated results obtained via network simulation tools.

1 Introduction

Modern vehicles are equipped with systems that include ultrasonic sensors used for parking assistance, cameras employed to monitor the lane or detect pedestrians, radar technology that allows the detection and measurement of distance from vehicles or nearby obstacles, among others [1]. However, these sensors have limitations that in most cases can be solved with vehicle to vehicle communication (V2V), which offers an efficient platform for the deployment of safety and data dissemination applications in vehicular environments. Vehicular communication networks convey a reliable system through the exchange of information, mostly related to road safety. The intention is to provide information to each vehicle date, such as the identification and motion parameters of the vehicles that are in the area of influence, especially those that are not in the field of vision of drivers. This is to alert them of possible road hazards with sufficient time so that proper actions can be taken on time [2].

Cooperative knowledge is the basis of multiple applications corresponding to the categories of road safety and traffic management. This cooperative knowledge is built upon the periodic exchange of messages called beacons, which contain important data such as position, speed, acceleration, among others. Using the information provided by cooperative messaging, vehicles and roadside units (RSUs) are able to create a map of their surroundings, which is then used as input for safety applications that detect potentially hazardous situations [3]. However, the effective transmission of beacons is very sensitive to network conditions: a fixed beacon transmission rate can easily increase the channel load and saturate the network, in particular in scenarios where there is a high density of vehicles [4]. Further, a reduction of the beacon transmission rate may decrement in the quality of information that is built with the help of neighboring vehicles.

To address this problem, adaptive beacon algorithms have been proposed in [5] [6] [7] [8], which have shown to improve the effective transmission of beacons by reducing the beaconing load in the channel, increasing the reliability of beacons delivery, as well as adapting the transmission of beacons with the least impact over neighboring nodes. However, these adaptive algorithms have been tested only through computational tools, either numerically or simulated.

The objective of this experimental work is to evaluate the performance of the adaptive beaconing algorithm proposed in [5], using test bed equipment for vehicular communications. This algorithm was selected because to the authors' best knowledge, it is the most recent work that controls the beacon transmission rate to meet the position accuracy requirements of safety applications.

2 Performance evaluation metrics

2.1 Position Error Metric

In [5] the authors proposed the evaluation of an adaptive beaconing algorithm that uses the following criteria as metrics [4]: the *minimum error*, *maximum error*, and *average error* of the last received position information compared with the real physical position of the sending vehicle. The relevant input parameters for the metric are the vehicle velocity v, the beacon rate f_{T_b}, and the transmission delay D_{TbRb}.

Minimum position error (E_{pmin}) : it is the position error that occurs due to the displacement of the vehicle during the beacon transmission. This error is related with the transmission delay, D_{TbRb}, and is typically around 0.001s according to [5].

Maximum position error (E_{pmax}) : it is the position error that occurs when the position of the vehicle is looked up in the neighbor data base before receiving the next beacon from this vehicle. This error is equal to the distance traveled by the vehicle in a time interval equal to the inverse of the transmission frequency of the beacon.

Average position error (E_{prom}) : it is the mean error assuming that the event of looking up the position is uniformly distributed over the minimum and maximum time between the reception of two consecutive beacons. The time parameters that influence the average position error are depicted in Figure 1.

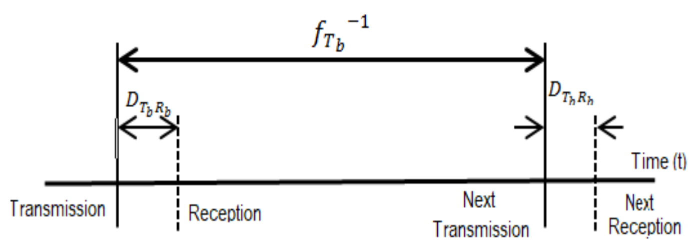

Figure 1: Key parameters to determine position error (Adapted from [4])

The average position error is defined as follows [4]:

$$E_{prom} = \frac{E_{pmin} + E_{pmax}}{2} = \frac{v(D_{TbRb} + f_{Tb}^{-1})}{2}, \quad (1)$$

where f_{Tb} is the frequency of the beacon transmission.

Beaconing schemes that use a fixed frequency and a fixed transmission power have certain tradeoffs. Due to a high f_{T_b} the network produces a low position error, but the probability of collision in the shared channel increases in environments with high vehicular density. Reducing f_{T_b} in such scenarios also reduces the probability of collision, but the error position increases significantly; hence, degrading the level of cooperative knowledge. The algorithm proposed in [5] solves this problem using a joint scheme with adaptive frequency of beacon transmission. The algorithm dynamically adjust f_{T_b} in each vehicle according to its velocity and acceleration, to obtain a limited average position error of 1 m, which provides an acceptable level of error for cooperative knowledge.

2.2 Numerical evaluation

Based on the expression given in (1), we made a numerical evaluation to verify the impact that the vehicle speed (v) has on the average and maximum position error. This evaluation does not evaluate the minimum position error because it only depends on the transmission delay, which is negligible. In our evaluation we use four typical values of velocity to account for different reference scenarios: residential areas (30 km/h ≈ 8.33 m/s), metropolitan areas (50 km/h ≈ 13.88 m/s), rural areas (100 km/h ≈ 27.7 m/s) and highways (150 km/h ≈ 54 m/s) [9]. Vehicles are assumed to move at a constant speed.

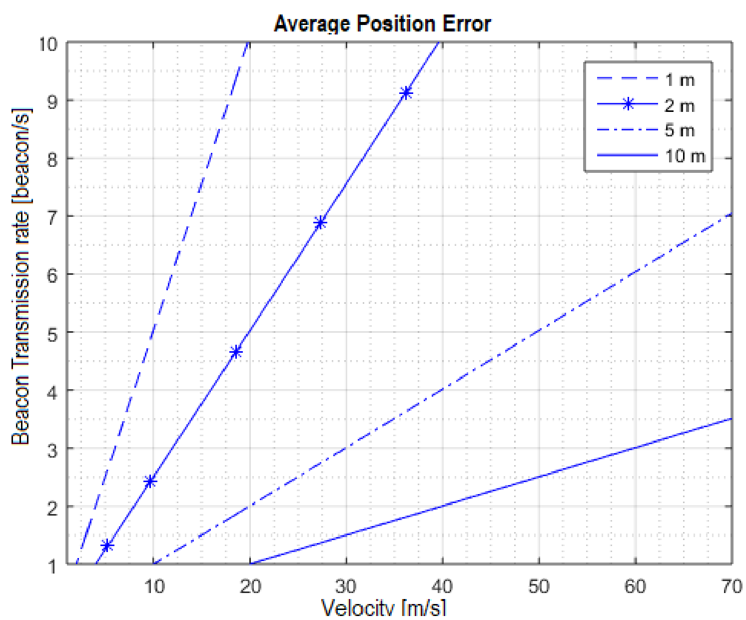

Figure 2: Average position error (m) depending on velocity and beacon transmission rate with D_{TbRb}= 0.001s

Figure 2 shows the relation between several beacon transmission rates and the vehicle velocity according to the average position error provided in expression 1. The average position error achieved is between 0 m and 10 m with a beacon rate varying from 0 Hz to 10 Hz. If the transmission rate is 10 beacons/s, the error can be kept to 1 m only up to 70 Km/h (≈ 20m/s). An average error of 5m is achieved with a beacon transmission rate of 5 beacons/s only up to 180 km/h (≈ 50 m/s). An accuracy of 2 m with a beacon transmission rate of 10 beacons/s is

achieved only with velocities up to 145 km/h ($\approx$ 40m/s).
With the aim of validating the results in [5], which have been obtained through simulations and numerical evaluations through computational tools, in the following section we describe an experimental evaluation setup for the adaptive beaconing algorithm proposed in [5] using a test bed with devices for vehicular communications.

3 Methodology

In order to evaluate the selected adaptive beaconing algorithm, two commercial OBUs from Arada Systems [10] are employed to create the experimental testbed (Figure 3). Each OBU is installed on a bicycle to test the communication with other OBUs. The OBU equipment supports Dedicated Short-Range Communications (DSRC), IEEE 802.11p, IEEE 1609.2, IEEE 1609.3 and 1609.4 protocols, the frequency transmission range is between 5.7 GHz and 5.9 GHz [11]. To obtain preliminary results, we first built a pilot test between a fixed OBU and a moving portable OBU installed on a bicycle to assess the average error in a controlled environment.

Figure 3: Arada LocoME Mobile Device and installation in the bicycle

4 Preliminaries Results

The algorithm in [5] has been implemented with a Software Development Kit available for the Arada Systems equipment. The initial experiment is performed with a fixed OBU acting as the receiver and a mobile portable OBU acting as the transmitter of beacons. Data rate was set to 6 Mbps and the average packet size was fixed to 81 bytes. The testing scenario is in O'Higgins Park, located in Santiago de Chile (Figure 4). The distance traveled by the mobile OBU is 200 meters with the fixed OBU located in the middle of the route to take advantage of the range of coverage. The experimental setup and the evaluation parameters are depicted in Figure 5 and Table 1, respectively.

The first result analyzed is the packet loss rate according to the distance between transmitter and receiver OBUs. It can be observed in Figure 6 that for distances below 50m, the algorithm achieves a beacon reception rate near 100%. The loss rate is around 10% for distances between 50 m and 80 m. However, the packet loss rate increases up to 50% for distances longer than

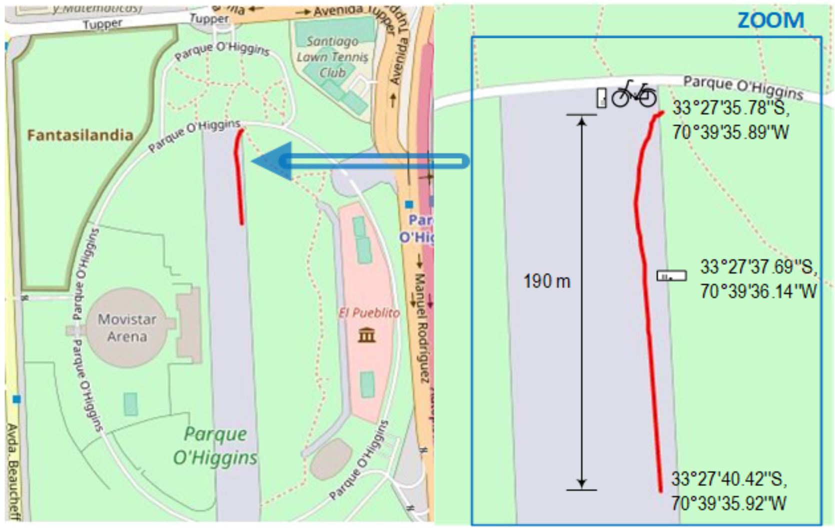

Figure 4: Experimental scenario: Start of the route (Top point), End of the route (Bottom point)

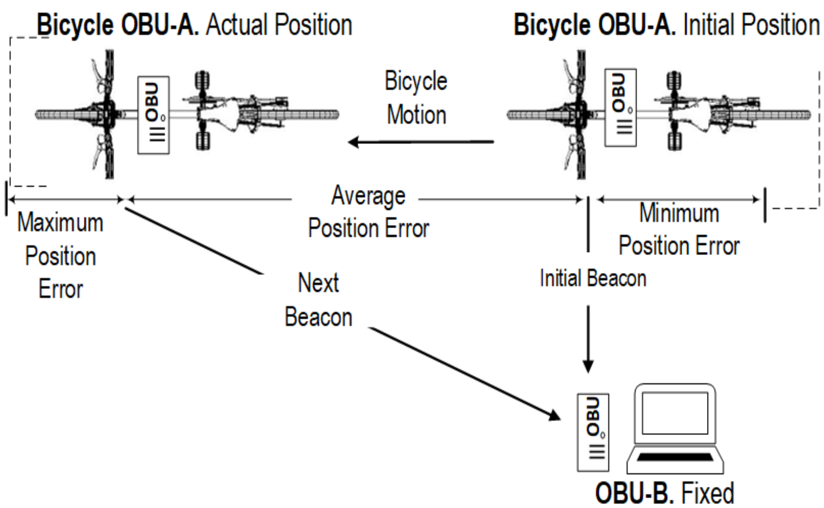

Figure 5: Schematic illustration for experimental evaluation of adaptive beaconing algorithms

80 m. This results in the degradation of the neighbor's position information created at the receiving OBU.

The next evaluation corresponds to the maximum and average position error achieved when employing a fixed frequency for beacon transmission compared to the adaptive algorithm proposed in [5]. The fixed transmission frequency f_{Tb} is set to 1Hz, which could be considered an appropriate frequency to avoid the channel congestion at the cost of degrading the accuracy for neighbors' position information.

Parameter	Value
Position of the Fixed OBU	33° 27' 37.69"S, 70° 39' 36.14"W
Position of the Mobile OBU	Initial: 33° 27' 35.78"S, 70° 39' 35.89"W Final: 33° 27' 40.42"S, 70° 39' 35.92"W
Speed of the Mobile OBU	(0 m/s - 6 m/s)
Average Distance Route	190m
Frequency	5.9 GHz
Channel Bandwidth	10 MHz
Desired Error Position	1m
Data Rate	6 Mbps
Transmition Power	20 dB

Table 1: Evaluation Parameters

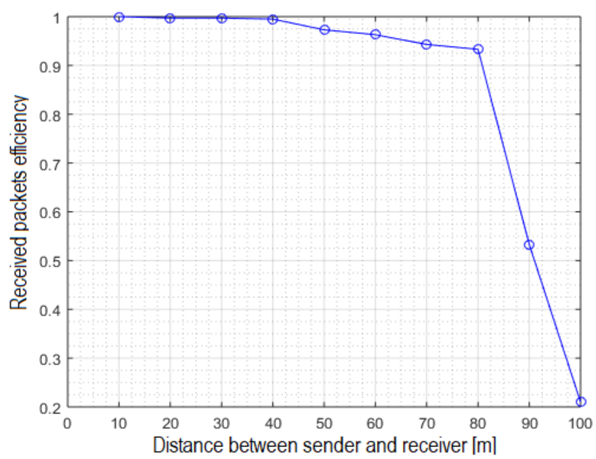

Figure 6: Packet reception rate according to the distance between OBUs

The average and maximum error position obtained from the experimental setting is depicted in Figure 7. At the beginning of the test, both the velocity of the OBU and the beacon transmission rate of the fixed beaconing algorithm are low (i.e., 1 beacon/s). The error position obtained in the experiments is similar to the one reported by [5]. However, in cases when the velocity increases in intervals of 3m/s and 6m/s, the observed error position also increases to values around 4 m and 6 m for average and maximum position errors, respectively. When the tests is performed with the adaptive beaconing, we set the frequency f_{Tb} to 1Hz only for the initial state. When the velocity increases during the experiment, the algorithm implemented in the OBUs computes the velocity between two consecutive beacons and calculates f_{Tb} for the next transmission. The objective is to keep the error position bound to 1 m [5], but in this work the average error position with adaptative beacon transmision is 1.3 m. Results show the improvement of the adaptive beaconing versus the fixed beaconing scheme. Both the average and maximum error position are reduced when the frequency is adapted according to the velocity of the vehicle. Our preliminary results are consistent with the theoretical results of the evaluated algorithm.

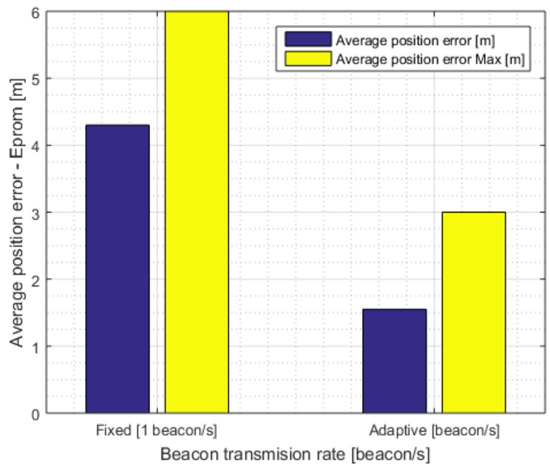

Figure 7: Average and maximum position error percibed by the fixed node

5 Conclusions and Future Work

In this work we have presented a methodology to perform experimental tests of adaptive beaconing algorithm for the maintenance of cooperative knowledge in vehicular networks. The algorithm aims to maintain a proper accuracy of the information measured through the difference between the known and the real position of the vehicles. In previous works, adaptive beaconing algorithms have proved to be effective in reducing the position error, increasing beaconing delivery and reducing channel load. However, the validation has been performed exclusively through numerical and simulation tools. In this work the average error position with adaptative beacon transmision is 1.3 m. For distances below 50m, the algorithm achieved a beacon reception rate near 100%, whereas the loss rate is around 10% for distances between 50 m and 80 m. Future work involves the installation of OBUs in cars to assess the average position error with vehicular velocities. We will refine our implementation to proceed to artificially increase network density using a USRP to simulate high-density traffic conditions. The experimental results will be compared with simulation data obtained using software tools. We expect to establish which physical layer aspect of the network may be used to improve the performance of the algorithm via cross layer design.

Acknowledgements

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