Cooperative Positioning in Vehicular Ad-hoc Networks Supported by Stationary Vehicles

Rodrigo H. Ordóñez-Hurtado, Wynita M. Griggs, Emanuele Crisostomi and Robert N. Shorten

Abstract—**In this paper, we consider the use of stationary vehicles as tools to enhance the localisation capabilities of moving vehicles in a VANET. We examine the idea in terms of its potential benefits, technical requirements, algorithmic design and experimental evaluation. Simulation results are given to illustrate the efficacy of the technique.**

Index Terms—**Stationary vehicles, Parked vehicles, queue, cooperative positioning, inter-vehicle communication.**

I. Introduction

Cooperative positioning (CP) for vehicular networks is a very topical problem. Exact road positioning is viewed as a key enabler of services such as road pricing (lane pricing), and lane prioritisation for special vehicles (electric vehicles). In this context, CP is being viewed as a means of overcoming the shortcomings of traditional global navigation satellite systems (GNSS) for vehicular applications.

There already exist a range of CP techniques for realising on-road localisation. Many of these techniques rely heavily on support from dedicated infrastructure. Examples include differential Global Positioning Systems (DGPS), RTK positioning, and Assisted Global-Positioning System (A-GPS). There are many excellent papers on CP, and ideas for realising this technology have appeared in various areas. The interested reader is referred to any one of the excellent papers on this topic; in particular, see the recent survey paper [1].

In the present work, we move away from the idea of using fixed, dedicated infrastructure to realise high performance CP systems. Specifically, we suggest the utilisation of stationary vehicles to enhance the localisation capabilities of moving vehicles in a Vehicular Ad-hoc Network (VANET). This notion is in accordance with recent suggestions that stationary vehicles, given their ability to pinpoint their own locations in a precise manner, may be used as general service delivery platform [2]. We shall show that this idea, as well as being novel, offers excellent performance without requiring any dedicated infrastructure in a CP context, while at the same time offering vehicle owners and can manufacturers a captive opportunity to monetise vehicles in a non-traditional manner.

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Our paper is organised as follows. In Section II of the paper, we examine the state of the art concerning the use of stationary vehicles in providing VANET-related services. In Section III, the benefits of using stationary vehicles in the CP process are discussed. The proposed CP approach is formally stated in Section IV, and the experimental evaluation is presented in Section V. Finally, Section VI concludes the paper.

II. State of the Art

Cooperative positioning is a topic that is of interest in many communities. As we have mentioned, the interested reader is referred to the excellent survey covering CP technologies in ITS applications [1], and to the EU Funded Project TEAM [3] which also covers related technologies and areas. We shall not repeat this discussion here. Rather, we shall focus on the use of stationary vehicles to provision services, as work on this topic is less well-known but is however relevant for the research reported in this paper [2].

Information collected from stationary vehicles (i.e. vehicles with time-invariant position) has been used in the performance analysis of VANETs. For example, information from stationary vehicles has been used to accurately determine the stop-delay or idling times at road junctions. This information is then used to enhance road safety by detecting stop-line violations at signalised/controlled intersection or stopped vehicles inside tunnels, or to determine the availability of free parking spaces [4]. In the past, most of the strategies involving stationary vehicles consider them as passive nodes, and information collected from them has been obtained using passive techniques such as proximity detectors and cameras. However, thanks to the advent of modern ITS technologies allowing V2X communication and cooperative awareness, the use of stationary vehicles as active nodes to enhance services for VANETs is becoming a topic with great relevance. Some of the aforementioned services include: the improvement of multi-channel operations [5], [6], the use as relays in content downloading and distribution [7], [8], and mitigation of signal attenuation in ITS applications [9]. Two main approaches can be distinguished when using stationary vehicles: the use of (1) powered-on vehicles, such as vehicles stopped in a queue; and the use of (2) powered-off vehicles, such as parked vehicles. While the usage of powered-on stationary vehicles does not impose any major technical requirement in the provision of new services, an obvious concerned associated with parked vehicles is battery discharge; we shall have more to say about this shortly. An application highlighting the use of powered-on stationary vehicles is presented in [5], [6]. The main idea therein is to allow parked vehicles to transmit on a different channel to the control channel, in order to improve the spectrum utilisation. In [9], parked cars are postulated as relays in a multi-hop beaconing approach: they do not transmit their own information, but only retransmit information from moving vehicles. Because of the energy consumption issue for powered-off stationary vehicles, in [10] the authors present a study on the impact of the communication system and processing unit on energy consumption. The main conclusion is that the power demanded from the communication system and the processing unit is not highly critical. In particular, given a fully charged battery, services can be provided for more than twenty hours before a critical point of the charge level is reached.

III. Statistics of stationary vehicles to support CP

A vehicle without any strong time restriction for localisation, and with access to GNSS, can easily fix its location precisely. Thus it can become an anchor (anchor node) and, by broadcasting its location, it can help vehicles whose position is not known precisely (blind nodes) to locate themselves. Such vehicles include vehicles that are stationary for long enough, for whatever reason (e.g. traffic-light queues, bottlenecks, traffic jams and parked vehicles). We now give some basic statistics and simple case studies to illustrate the utility of such vehicles for CP applications.

1) Battery consumption: In the case of parked vehicles, the main technical challenge is keeping the on-board communication systems switched on when the vehicle is powered off. However, recent studies have shown that this is not a critical issue. In particular, by accessing a maximum of 10% of the charge of a 480 Wh car's battery, it has recently been demonstrated that a 1W on-board unit can be constantly powered for up to 2 days [9].

2) Parking duration: It is also worth noting that a car is typically parked on average up to 23 hours a day [11], [12], and most of them are parked in the open-air [7], [9]. For example, in a recent study of 61,000 daily parking events in Montreal City [13], 69.2% of all parked cars were parked on-street, 27.1% were parked in outside parking lots, and 3.7% were parked in interior parking facilities; and the average duration of on-street parking was 6.64 hours [13]. Further, current predictions concerning regulated parking spaces claim that the average portion of on-street parking, as a percentage of overall total parking spaces, will be 30.17% (with up to 56.22% for Italy and 43.30% in Spain) [14].

Thus "parked cars" can be thought of as an unused and dense sensor network with no power or collection constraints, and which are localised very precisely. Consequently, they can be used to solve the CP problem for ITS systems. To further support this premise, we can also refer to the following imaging data that has been obtained in an urban context in Ireland.

3) The reach of powered-on stationary vehicles: Here the idea is to measure the portion of the main streets in Dublin's city centre in which the traffic is stopped or almost stopped (on average). Clearly, such vehicles can be potentially used for CP applications that are most useful during congested periods (rush hours). To this end, we used imagery collected

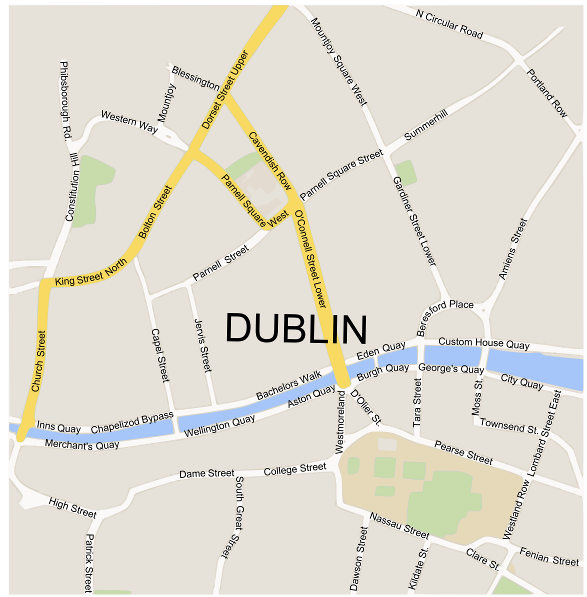


Fig. 1. Roads in Dublin city center monitored between 16th-23rd June, 2014 using AA Roadwatch [15].

from the AA Roadwatch [15] (a service offered by AA Ireland for the on-line monitoring of the current traffic state of some main roads in Ireland) to construct our ad-hoc data base. The data collection was made twice on a daily basis between 16th-23rd June, 2014: one measure at the lunchtime rush hour (at 1 p.m.), and one at the evening rush hour (at 7:30 p.m.). The streets selected for the study are shown in Fig. 1, and the analysis of the collected data is shown in Table I. From Table I it is possible to conclude that, in the context of this small survey, an average of 22.64% and 15.71% of the main streets in Dublin's city centre are covered by powered-on vehicles that are either stopped or have very slow speed (at the weekday lunchtime, and evening rush hours, respectively). Even though the average during weekend rush hours decreases to 14.36% for lunchtime, and to 13.03% for the evening, these numbers still represent a promising scenario to improve the localisation of non-stationary blind vehicles during rush-hours. Note also that the analysis allowed us to also obtain a glimpse of the zones that are covered by powered-on stationary cars; see Fig. 2.

4) The reach of powered-off stationary vehicles: Here the idea is to estimate the maximum covered area by stationary vehicles by examining communication range for different DSRC devices (see Table II), and the availability of on-street parking.

An experimental method to estimate the aforementioned measure is using top-view images of the area of interest (i.e.

TABLE I
PERCENTAGE OF SLOW AND VERY SLOW MOVING TRAFFIC OVERALL TRAFFIC FOR THE MAIN STREETS IN DUBLIN CITY CENTER AND DATES AS SHOWN IN FIGURE 1.

	Rush hour	
Day	Lunchtime	Evening
Monday	18.39%	13.07%
Tuesday	17.68%	16.17%
Wednesday	25.03%	14.58%
Thursday	23.49%	20.67%
Friday	28.63%	14.07%
Saturday	14.95%	9.72%
Sunday	13.77%	16.33%

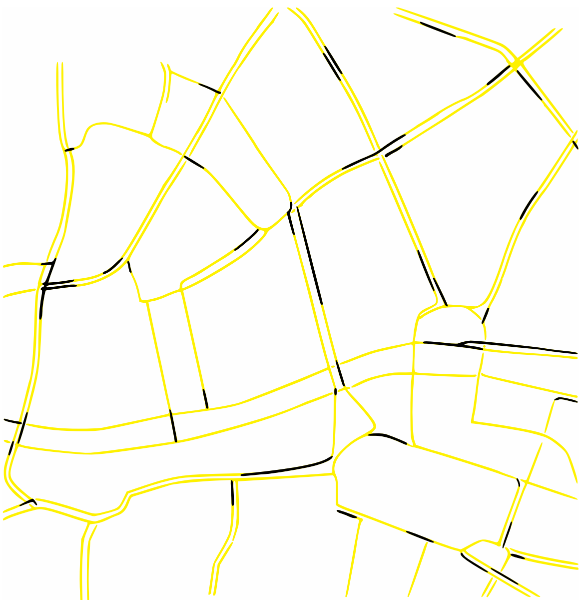


Fig. 2. Measured data on June 17th, 2014, at the evening rush hour. Black sections: occupied by stopped and almost stopped cars; yellow sections: free traffic.

TABLE II
THE UNITED STATES FEDERAL COMMUNICATION COMMISSION (FCC) CLASSIFICATION FOR DSRC DEVICES [16].

Device class	Max. Output Power (dBm)	Communication zone (meters)
A	0	15
B	10	100
C	20	400
D	28.8	1000

satellite imagery) and proceed as follows:

1) Identify area of vehicular transit (see Fig. 3.a), referred as $A_{Transit}$;
2) Identify any stationary vehicles; (see Fig. 3.b) and their total coverage (see Fig. 3.c), referred as $A_{Coverage}$;
3) Calculate the intersection between the $A_{Coverage}$ and $A_{Transit}$, referred to as $A_{C \cap T}$.
4) Calculate the ratio between $A_{C \cap T}$ and $A_{Transit}$ as a function of the levels given in Table III.

For the proposed experimental analysis, we used top-view images from Google Maps. We examine Maynooth Town with an image from October 31st, 2013. The results of this procedure are shown in Fig. 4. The analysis of data in Fig. 4 is presented in Fig. 5 and Table IV.

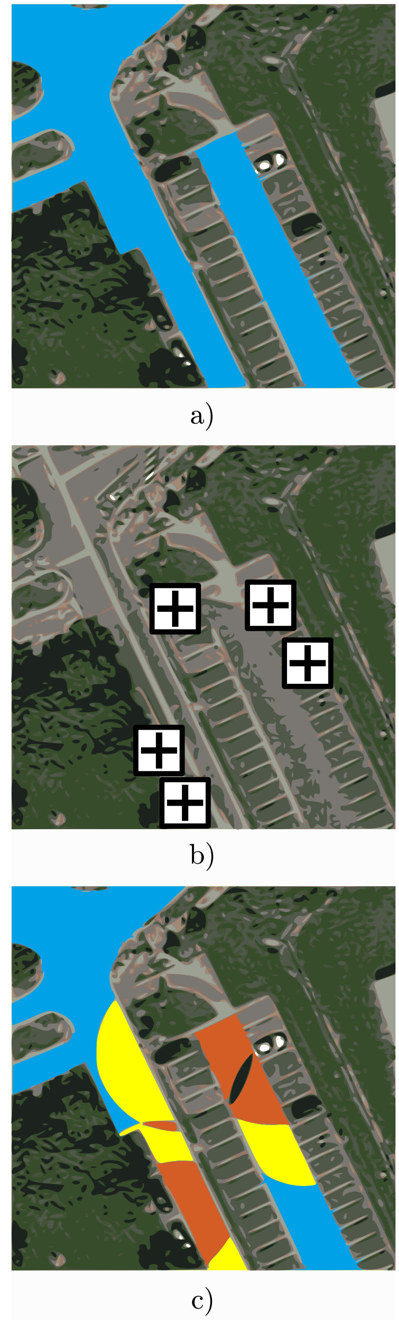


Fig. 3. Illustrative scenario: a) identified allowed areas for vehicular transit (blue); b) identified parked vehicles (black crosses); and c) covered area for a radius equal to 15 m. Color convention for levels of coverage (see Table III): yellow for Level 1, orange for Level 2, and red for Level 3.

TABLE III
PROPOSED LEVELS OF COVERAGE.

Level of coverage	Description
Level 1	Coverage with only 1 stationary car
Level 2	Coverage with only 2 stationary cars
Level 3	coverage with 3 or more stationary cars

Using this sample point, according to Table IV, $27,78\%$ of the allowed area for vehicular transit can be covered using Class-A DSRC devices, and $97,02\%$ using Class-B DSRC

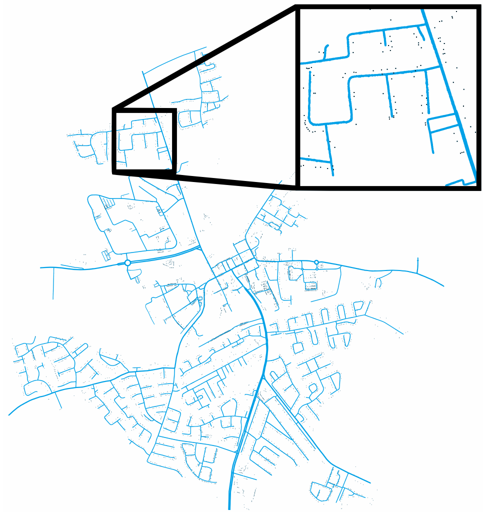


Fig. 4. Allowed area for vehicular transit (blue) and parked vehicles (black) in Maynooth, Co. Kildare, Dublin, using satellite imagery from Google Maps. A total of 4541 vehicles were identified as parked vehicles.

TABLE IV
POTENTIAL COVERED AREAS FOR THE CASE STUDY. THE THE 100% CORRESPONDS TO THE AREAS ALLOWED FOR VEHICULAR TRANSIT.

	Com. zone (meters)	
	15	100
Covered area of Level 3	27.78%	97.02%
Covered area of Level 2	11.98%	0.22%
Covered area of Level 1	14.81%	0.31%
No covered area	45.43%	2.45%

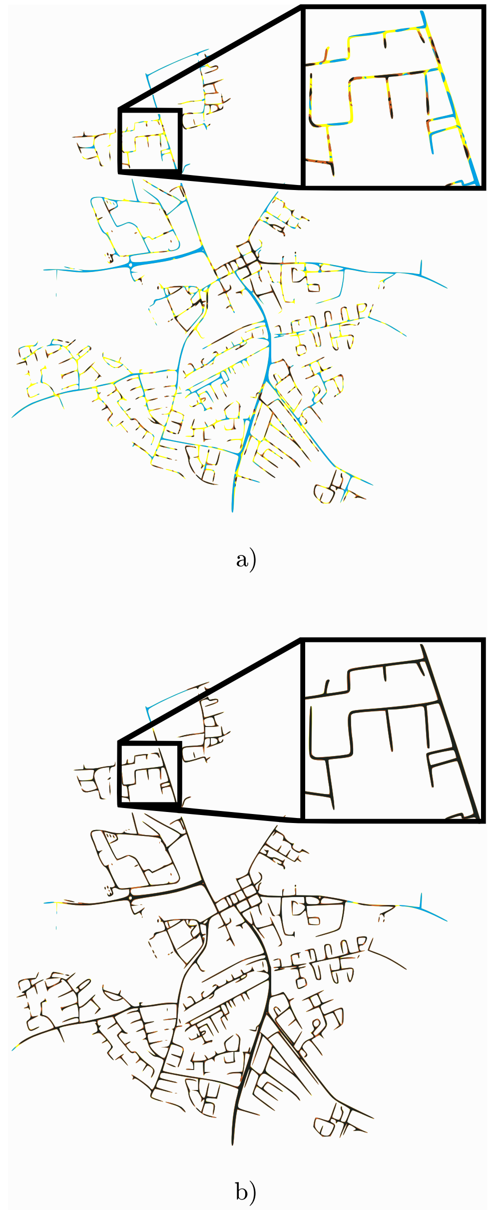


Fig. 5. Covered areas for the case study using different communication zones: a) 15 m (Class-A DSRC devices), and b) 100 m (Class-B DSRC devices). Color convention for levels of coverate (see Table III): yellow for Level 1, orange for Level 2, and red for Level 3.

devices. This illustrates that the use of parked vehicles can be highly beneficial. Note that the devices involved in V2V are normally Class-C devices (i.e. they have a larger communication range) [16] and the devices studied here are low power and inexpensive. Note also that even though the data in Table IV looks promising, multi-path effects and building radio shadow are not taken into account into the estimation because of the technical difficulties in incorporating them into the simulations. However, the conclusions obtained using a communication zone of 15 m can be taken as a lower bound, which anyway represents an improvement of about 54% in the coverage. Finally, it should be noted that most of the parked cars on-street are distributed quite uniformly between intersections. This clearly complements stationary powered-on vehicles, which mainly cover intersections and surrounding downstream sections.

IV. Proposed CP approach

We now describe our CP approach based on the use of stationary vehicles. By using stationary vehicles at a massively large scale as a proxy for a dense, dedicated infrastructure, it is possible to improve upon any one of a plethora of techniques that are available to realise cooperative positioning (e.g. triangulation, trilateration, as well as cooperative estimation).

A. Requirements regarding localisation capabilities

As powered-off stationary vehicles such as parked vehicles do not have any strong time requirement for localisation, any one of many techniques providing high accuracy such as positioning supported on GNSS information and V2I communication systems (e.g. DGPS, AGPS) can be used to localise them accurately. In addition, if they have access to enough information from anchor nodes via V2V communication, then a simple CP technique such as multilateration can also be used for their localisation. Note that once a stationary vehicle has a precise fix on its location it can itself become an anchor node and be used to support CP of blind vehicles via V2V communication. Assuming that such vehicles exist, we shall now give algorithms to localise other vehicles using these anchor vehicles.

B. *Locating blind stationary vehicles*

A blind stationary vehicle is a stationary vehicle whose location is not yet precise. To locate blind stationary vehicles, the following strategy is adopted.

- If 3 or more anchor neighbours are available:
  - (default option): localise using a CP technique supported on V2V communication to anchor nodes. The "blind" vehicle then itself becomes an anchor node;
  - (backup option): localise over longer time horizon using augmented GNSS information, and then become an anchor.
- If 2 anchor neighbours are available:
  - (default option): localise using a CP technique supported by V2V communication to anchor nodes and additional information from other surrounding vehicles (e.g. previous positions/speeds/ranges) to solve ambiguities. The "blind" vehicle then itself becomes an anchor node;
  - (backup option): localise over longer time horizon using augmented GNSS information, and then become an anchor.
- Otherwise:
  - (default option): localise only using augmented GNSS information, and then become an anchor.

Regarding blind powered-off stationary vehicles, they are included in the VANET as active nodes only after their localisation process is complete (i.e. after they become anchors); otherwise, they cannot help other vehicles in the localisation process.

C. *Locating blind moving vehicles*

In our approach, we will never consider moving vehicles as anchor nodes even when they have access to enough anchors. However, a blind moving vehicle with access to enough information from anchor nodes can be identified as a *pseudo-anchor* node in the CP process, and such nodes can be used in situations where anchor nodes are not available.

D. *Supporting tools*

Our approach has the potential to be energy intensive. Therefore, it is of interest to develop some tools to alleviate battery depletion. Here, we describe some of these tools.

1) Node selection strategy: In many situations, there will be many anchor nodes that can be used for localisation. For this reason, it is important to have strategies for selecting a subset of available nodes (both anchor and non-anchor). Strategies for node selection have been studied in other communities. For example, see [17] where an algorithm is given to select an optimal subset of anchor nodes based on a geometric dilution of precision process. In this paper, we propose a simple deterministic approach that assigns priorities to anchor nodes, pseudo anchor nodes and blind nodes as described in the above subsections. This selection strategy is summarised as follows. At most three surrounding vehicles inside the communication zone of the target vehicle are required in the localisation process. The question is how to choose these (maximum of) three vehicles. Vehicles are ranked and selected according to the following strategy.

- Any surrounding vehicle c_i has a priority level p given by

$$p\left(c_i\right) = \begin{cases} 1, & \text{if } c_i \text{ is an anchor node,} \\ 2, & \text{if } c_i \text{ is a pseudo-anchor node,} \\ 3, & \text{otherwise.} \end{cases} \tag{1}$$

  where 1 is the highest priority;

Vehicles with priority 1 are selected first. Then vehicles with priority 2; and then vehicles with priority 3. In the event that we have a number of vehicles within each priority to choose from, we use the following rule as a tie-breaker.

- Inside each category of priority (i.e. anchor nodes, pseudo-anchor nodes, and blind nodes), nodes are organised according to their distance to the target vehicle.

V. Performance evaluation

In order to evaluate the proposed approach, we used SUMO simulations. Powered-on stationary vehicles are represented by stopped vehicles in the queue of controlled intersections or as part of traffic jams, and powered-off stationary vehicles are represented only by parked vehicles. Moreover, DGPS/AGPS is assumed to be running in parallel, and we also assume any parked vehicle is an anchor node from the beginning of any given simulation.

The CP technique used for comparison with the approach based on stationary vehicles in our simulations is the one introduced in [18]. This CP technique uses an Extended Kalman filter implemented with distributed architecture to fuse inter-vehicle distance measurements and vehicle kinematics (speed information), i.e. we are obtaining a sequential Bayesian estimation of the cars' position. The motion model used, which incorporates velocity measurements, is given by

$$\boldsymbol{A}_k = \boldsymbol{A}_{k-1} + T_s \mathbf{u}_{k-1} + T_s \mathbf{w}_{k-1} \tag{2}$$

with

$$\boldsymbol{A}_k = \left[x_{1,k}, x_{2,k}, ..., x_{n,k}, y_{1,k}, y_{2,k}, ..., y_{n,k}\right]^T,$$
$$\mathbf{u}_{k-1} = \left[v_{x1,k-1}, ..., v_{xn,k-1}, v_{y1,k-1}, ..., v_{yn,k-1}\right]^T,$$

where n is the number of vehicles in the cluster (i.e. at most 3 for the current case study) at time step k; T_s is the update rate of the filter; $v_{xi,k-1}, v_{yi,k-1}$ is the velocity of the car i in the x and y directions at time $k-1$, respectively; $\mathbf{w}_k$ is a zero-mean Gaussian random variable with covariance matrix $\mathbf{Q}_{k-1}$, describing the mobility variations. More extensive definitions are given in [18].

The observations of the inter-vehicle measurements are expressed as

$$\mathbf{z}_k = \mathbf{h}_k\left(\boldsymbol{A}\right) + \mathbf{v}_k,$$

where $\mathbf{h}_k\left(\boldsymbol{A}\right)$ is an equation describing the measurements at time step k, and is nonlinear because the inter-vehicle distance between car i and car j is nonlinear on (x_i, y_i) and (x_j, y_j); and $\mathbf{v}_k$ is a zero-mean Gaussian random vector with covariance $\mathbf{R}_k$, describing the measurement noise.

Then, the extended Kalman filter algorithm is based on (2) as follows:

$$\mathbf{A}_{k|k-1} = \mathbf{A}_{k-1|k-1} + T_s \mathbf{u}_{k-1},$$
$$\mathbf{P}_{k|k-1} = \mathbf{Q}_{k-1} + T_s^2 \mathbf{\Gamma}_{k-1} + \mathbf{P}_{k-1|k-1},$$
$$\mathbf{A}_{k|k} = \mathbf{A}_{k|k-1} + \mathbf{K}_k \left(\mathbf{z}_k - \mathbf{h}_k\left(\mathbf{A}_{k|k-1}\right)\right),$$
$$\mathbf{P}_{k|k} = \mathbf{P}_{k|k-1} + \mathbf{K}_k \hat{\mathbf{H}}_k \mathbf{P}_{k|k-1},$$
$$\mathbf{K}_k = \mathbf{P}_{k|k-1} \hat{\mathbf{H}}_k^T \left(\hat{\mathbf{H}}_k \mathbf{P}_{k|k-1} \hat{\mathbf{H}}_k^T + \mathbf{R}_k\right)^{-1},$$

where $\hat{\mathbf{H}}_k$ is the Jacobian matrix[1] given by

$$\hat{\mathbf{H}}_k = \left.\frac{d\mathbf{h}_k(\boldsymbol{A})}{d\mathbf{A}}\right|_{\boldsymbol{A}=\mathbf{A}_{k|k-1}},$$

where $\mathbf{\Gamma}_{k-1}$ is the covariance matrix for the uncertainty in the velocity measurements. Note that when no surrounding vehicles are available, the above algorithm updates the position of the vehicles using past estimations and new velocity measurements, which causes undesirable effects of error propagation. Hence, to avoid long term effects of this cumulative error, we propose that any vehicle c_i uses its measured GPS position as the better position estimation when a random number $r_{i,k} \sim U[0,1]$ satisfies $r_i, k < 0.1$ (i.e. to emulate an intermittent availability of GPS signals).

The parameters used in all the simulations are as follows:

- $\mathbf{Q}_{k-1} = \sigma_{\mathbf{Q}}^2 \mathbf{I}$, $\mathbf{R}_k = \sigma_{\mathbf{R}}^2 \mathbf{I}$, and $\mathbf{\Gamma}_{k-1} = \sigma_{\mathbf{\Gamma}}^2 \mathbf{I}$, with $\sigma_{\mathbf{Q}} = 2$, $\sigma_{\mathbf{R}} = 0.05$, $\sigma_{\mathbf{\Gamma}} = 0.5$, and $\mathbf{I}$ the identity matrix with proper dimensions;
- GPS noise covariance $\sigma_{GPS} = 100$; and
- $T_s = 1$.

A. Small scale scenario

The first scenario to be tested is a street circuit inside the NUIM North Campus (Fig. 6). Here, the main idea is to evaluate the performance of the proposed approach in terms of the range of communication zones for V2V communication corresponding to Class-A/B DSRC devices (see Table II), i.e. 15 m and 100 m. The results obtained for an ensemble of 100 experiments per CP approach are given in Table V.

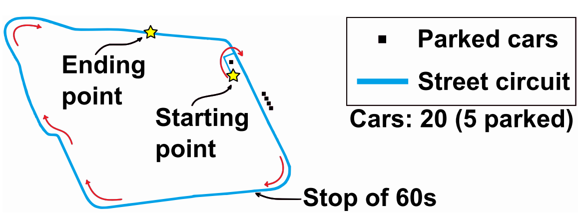


Fig. 6. Circuit for the small scale test (blue) and selected parked cars (black).

In Table V we observe that an average improvement of up to 55.13% in the localisation RMSE can be obtained when using stationary vehicles as prioritised nodes in the CP process. The preliminary results also allow us to conclude that a communication zone of even 15 m offers a significant

[1]The Kalman filter requires an observation equation with linear form.

TABLE V
RESULTS FOR THE SMALL SCALE SCENARIO IN FUNCTION OF THE COMMUNICATION ZONE: LOCALISATION RMSE AND IMPROVEMENTS FOR THE TARGET CAR.

		RMSE (meters)				
		Traditional CP		Proposed CP		
		Mean	σ	Mean	σ	Average improvement
Com. zone (meters)	15	11.60	6.96	10.53	6.68	9.22%
	100	9.04	5.09	4.06	2.97	55.09%

Mean: average of 100 different measurements.
σ: standard deviation.

improvement for the proposed CP approach over the traditional approach, while a communication zone of 100 m offers very significant improvements.

Even though this example includes some real-world elements, a more realistic scenario must be evaluated including: realistic distribution of powered-off stationary vehicles, realistic generation of zones with powered-on stationary vehicles, realistic street circuits, and a large number of blind vehicles. The next example is a more realistic approximation to such a scenario.

B. Large scale scenario

The second scenario to be evaluated is a large scale network of vehicles deployed around Maynooth town, based on the information provided in Section III. Here, we take into account a large number of cars (both moving and stationary), and also a number of controlled intersections.

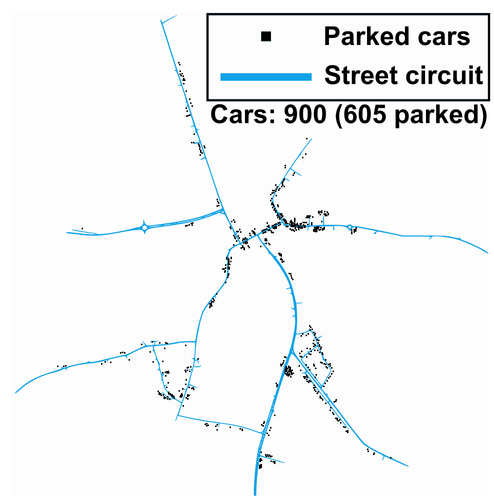
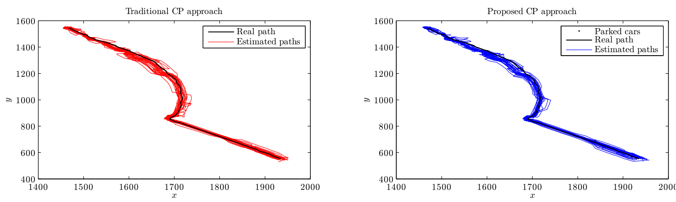
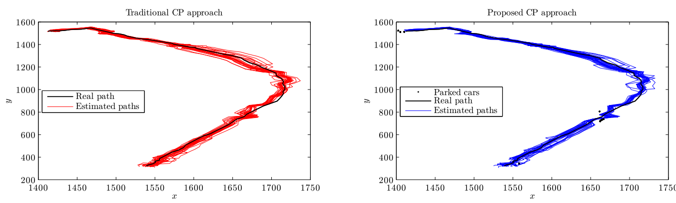


Fig. 7. Chosen street circuit for the large scale test (blue) and selected parked cars (black).

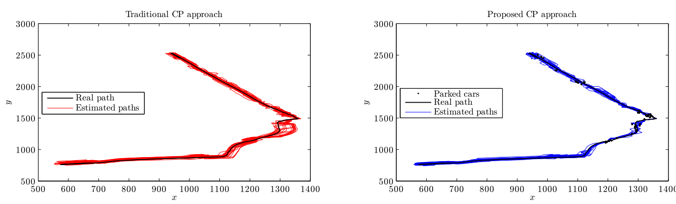
The street circuit for this test is mostly composed by secondary and tertiary roads, and the parked cars to be used are those in a proximity of 15 m to the selected roads (a total of 605 parked cars), as shown in Fig. 7. The main reason to include only parked cars within this proximity is because we want to simulate a communication zone of 15 m, and the parked vehicles beyond this proximity are useless in the localisation process. Besides, the ideas behind simulating only a 15 m communication zone are, firstly, to assume that the line-of-sight condition between parked cars and blind cars is satisfied (and so a Gaussian model for the measurement noise can be used), and secondly, to evaluate a lower bound of the potential benefits in function of the communication range.



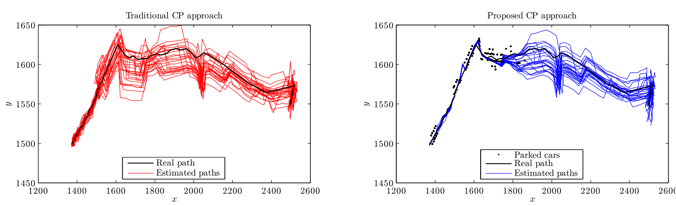
(a) Car 1.



(b) Car 2.



(c) Car 3.



(d) Car 4.

Fig. 8. Simulations results for the four cars with the longest routes (25 different estimations).

Our experiments are constructed as follows. 295 blind moving cars are divided into two groups: 200 cars are selected with a random route and with initial position randomly distributed along the entire street circuit, and 95 other cars enter the street circuit at a rate of one every 4 seconds with a route defined by a random starting/ending pair of edges. Since in this scenario the large amount of information to be processed causes an enormous increase in computational load, and simulation time, when compared with those from the small scale scenario, here we analyse this scenario based only on an ensemble of 25 simulations per CP approach. The obtained results for the four cars with the longest routes are presented in Fig. 8, Table VI and Fig. 9.

From Table VI is can be observed that the proposed CP approach gives an improvement of up to 62.85% in the localisation RMSE for the best case, with respect to the traditional approach. The average is 33.01%, which is a remarkable feature of the proposed CP approach. From Fig. 9 note also that, while Car 5 came across with an average of 33.14 parked cars per kilometer, the corresponding value for Car 1 was only 0.44 cars per kilometer: this supports the idea that the higher number of surrounding powered-off stationary cars, the higher chance to improve the localisation RMSE.

TABLE VI
RESULTS FOR THE LARGE SCALE SCENARIO USING 15 M OF COMMUNICATION ZONE: LOCALISATION RMSE AND IMPROVEMENTS FOR THE FOUR CARS WITH THE LONGEST ROUTES.

	RMSE (meters)				
	Traditional CP		Proposed CP		
	Mean	σ	Mean	σ	Average improvement
Car 1	10.78	5.81	9.50	5.55	11.94%
Car 2	9.53	6.43	7.73	5.69	18.92%
Car 3	11.93	9.66	7.50	7.46	37.12%
Car 4	8.46	6.97	3.14	6.27	62.85%

Mean: average of 25 different measurements.
σ: standard deviation.

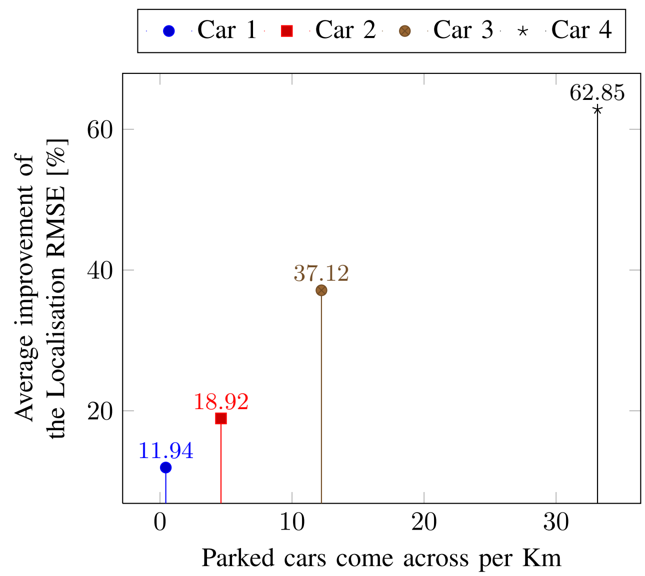


Fig. 9. Localisation RMSE in function of the number of parked cars come across per Km for the four cars with the longest routes.

VI. Conclusions and Future Work

A new approach for CP was proposed in this paper. This approach states to include powered-off vehicles as anchor nodes, and take advantage of unexploited features of VANETs by prioritising vehicles with access to anchor nodes to help blind vehicles in their CP localisation process. This approach is shown to yield remarkable improvements in the localisation process under real world conditions.

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