Leveraging Parked Cars as Urban Self-Organizing Road-Side Units

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***Abstract*—In urban vehicular networks, Road-Side Units (RSUs) take a crucial role in improving the performance of the network, by working as content distribution points, relays for time-critical broadcasts, and points of central coordination. The high costs associated with the installation and maintenance of RSUs, however, keep these units from seeing widespread deployment. One approach to this problem is for cars to be used opportunistically as RSUs, and in urban areas, the presence of large numbers of parked cars make these entities promising candidates for establishing vehicular support networks.**

In this paper we introduce new methods for parked cars to self-organize and act as a support network to the existing urban vehicular network, alleviating the need for costly deployments of fixed road-side units. Our approach considers parked cars that can both complement existing fixed RSUs and take the role of RSUs themselves, improving the network's performance on multiple applications. We show that even a small number of parked cars can bring considerable improvements to the network, and that our proposed methods for self-organization create support networks of parked cars that can cover the urban area with an optimal numbers of vehicles.

***Index Terms*—VANET, Vehicular Ad-Hoc Networks, Self-Organizing Networks, Road-Side Units, Parked Cars.**

I. Introduction

The utility of an urban vehicular network ties directly to that network's ability to relay messages quickly and reliably across the urban area. A vehicular network, however, is often classified as a Delay-Tolerant Network (DTN), due to the unpredictability in the number and location of its nodes (cars). When paired with the challenging and dynamic radio environment of modern urban areas, frequent network disconnections occur, causing high delays in the network: studies show that, in areas with low vehicle density, safety messages being broadcast can take more than 100 seconds to reach all cars in a targeted 1 square km area [1].

These networks require a minimum number of vehicles in order to be well connected and functional, which does not always happen. This may be due to a low number of vehicles on the road, or a lack of radio-equipped vehicles, due to low market penetration. One way to overcome this problem is to supplement vehicle-to-vehicle (V2V) communications with vehicle-to-infrastructure (V2I) support, by deploying infrastructure nodes known as Road-Side Units (RSUs) along the road, in addition to the Dedicated Short Range Communications (DSRC) / IEEE 802.11p [2] units within the vehicles. But deployments of these road-side units have not been occurring at a meaningful rate, in large part due to very high per-unit costs of RSU installations, coupled with the need to provide backbone links to the units so they can perform adequately [3]. RSUs are seen as a costly proposition, despite the crucial improvements they can bring to vehicular networks.

With this work, we propose the use of parked cars as ad-hoc RSUs, to increase and improve the performance and the reach of the urban network. A great deal of vehicular network research disregards parked cars, under the premise that as a car's engine is turned off, so is the power to DSRC electronics. We show that, by selectively keeping this electronic component active at specific cars, one can establish a network of units that support the existing mobile nodes in the vehicular network. With the help of a custom realistic simulation platform that integrates real maps, real building obstruction data, and empirical signal measurements, we show that the performance of these networks for safety applications can be significantly improved, even when only small numbers of parked cars are available.

We then introduce an initial set of mechanisms to allow larger numbers of parked cars to self-organize and decide on which cars should act as road-side units. We propose a method for vehicles to determine their own local map of signal coverage, that reflects the real reach of each vehicle in the network. With this information, we then provide a decision algorithm that optimizes the coverage of this network of parked cars, while requiring only 1-hop exchange of coverage maps and computationally-inexpensive decisions at each local car. Finally, we show, through our realistic simulation platform, how this decision algorithm is capable of reaching near-optimal coverage of the urban area when compared to reference optimal scenarios.

The remainder of this paper is organized as follows. An overview of the current work on cars as network support units is presented in Section II. Section III introduces the ways parked cars can operate as RSUs, in order to provide support to the vehicular network. Details on our simulation platform are given in Section IV, along with lead-in simulation results that establish the benefits that parked cars bring to the timely dissemination of safety messages. Section V describes the methods and algorithms designed for large sets of parked cars to be able to self-organize, and shows how these methods compare to baseline scenarios. Finally, concluding remarks are presented in Section VI, along with directions for future work.

II. Related Work

As research in vehicular networks develops, it remains clear that pure vehicle-to-vehicle networks (V2V) are unable to provide satisfactory levels of reliability and dependability in the challenging scenarios that vehicles navigate in. The most common way to mitigate these issues is a deployment of road-side units in the area of concern, but the high cost of RSUs has kept this often-proposed solution from materializing. Our own RSU deployments in the city of Porto, Portugal show an average installation cost of $2300 per unit, not including the cost of hardware [4].

The concept of cars as road-side units has been proposed for both the highway [5] and urban [6] environments. Leveraging the actual moving vehicles was originally considered, with limited usefulness. The particular idea of enabling parked cars as members of the vehicular network is first proposed in [7], that studies the effects on network connectivity when fixed numbers of parked cars are activated. It reports a 3.3x improvement in node density with 10% active parked cars.

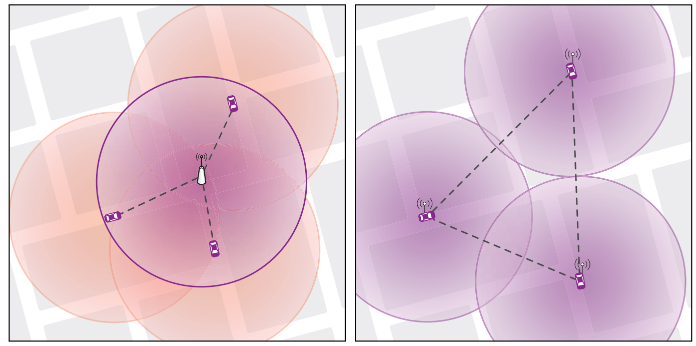
The work in [8] suggests using parked cars as a means to overcome the signal degradation that occurs when there is a building in the line of sight of two cars. By activating parked cars at key intersection points, other cars can use the parked car at the intersection as an unobstructed message relay. With this approach, cars were shown to be able to receive nearby emergency messages up to 17 seconds faster. A follow-up to this work [9] also showed how parked cars could be used to aid existing RSUs in content downloading, by caching content from the RSUs.

The existing body of work on parked cars has revealed the interesting possibilities that can be brought by leveraging parked cars as RSUs, albeit in specific, limited scopes. A better look into the practical considerations of such systems is needed. In this paper, we propose a more extensive use of these parked cars, and introduce methods and approaches for any number of cars to self-organize and create a vehicular network. We also show what the concrete benefits of parked cars are in more common applications, such as the broadcasting of safety messages.

III. Enabling Parked Cars as RSUs

Parked cars share many of the benefits of fixed RSUs, the most important of which is that they are not moving. A parked car in an urban area has a fixed, known position for extended periods of time, relative to the cars in motion – consequently, a much more stable communication channel with nearby cars and RSUs is possible. We propose two methods of operation for a parked car:

- **Extend the coverage of existing fixed RSUs.** Parked cars that are in the range of a fixed RSU can turn on and establish themselves as relays for that RSU (Fig. 1a).
- **Act as standalone RSUs.** For the purposes of broadcasting safety messages and collecting safety data, if a parked car has access to the Internet via on-board cellular radio or any other existing means, it may choose to become a stand-alone RSU (Fig. 1b).



(a) (b)

Figure 1. Illustration of parked cars operating: (a) as relays for an existing RSU; (b) as standalone RSUs.

IV. Impact on message broadcasting delay

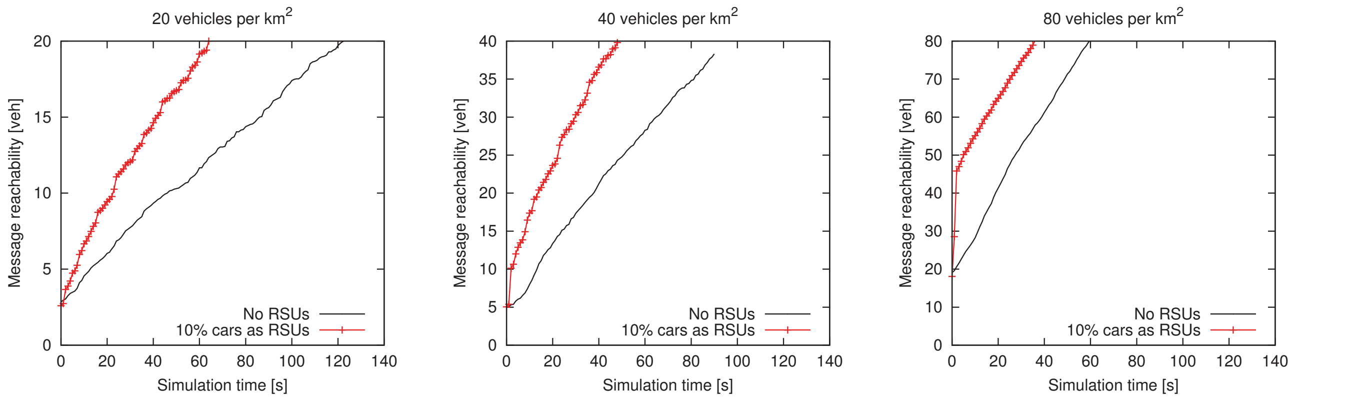
The presence of parked cars at locations that can benefit from extra RSU support is not guaranteed, which in turn means that networks based on parked cars should be seen as best-effort solutions. With this in mind, we study a scenario where the urban area has few DSRC-capable cars, resulting in a sparse network. Our goal is to determine if activating parked cars and directing them to act as RSUs can provide significant benefits to safety applications, when the network is sparse. Our reference scenario is one where an accident occurs, and an emergency notification needs to be sent to nearby vehicles.

Our metric of interest is then the *message reachability*. To serve as a baseline, we selected UV-CAST, a well-known urban broadcast protocol [1]. We adapt UV-CAST to support multiple origins for the message: when parked cars are activated as standalone RSUs, they can rebroadcast safety messages from other parts of the network.

A. Simulation Setup

The urban vehicular environment is extremely challenging and dynamic – hence, a comprehensive simulation platform is key to obtain results that are realistic and reliable. With this in mind, we developed a platform with the following characteristics:

- Realistic vehicle mobility and traffic light patterns, with the use of the popular SUMO mobility simulator [10].
- Real urban street layouts that include road capacity and speed patterns, generated through publicly-available city maps.
- An accurate characterization of urban obstructions, by implementing a vectorial representation of all buildings in the target urban area on a Geographic Information System (GIS), so that the Line-of-Sight status between two vehicles can be determined, as well as the size of the obstructions.



(a) (b) (c)

Figure 2. Multi-origin UV-CAST message reachability over time, with 10% cars on the road parked and active as standalone RSUs.

- Realistic modeling of core wireless network metrics, such as Bandwidth and Link Probability, as a function of node distance and Line-of-Sight status, derived from empirical measurements gathered with actual DSRC/IEEE 802.11p radio-equipped vehicles circulating in the same area [11].

Through the integration of SUMO, GIS, and empirical measurements of network performance, we are confident that our simulation data approaches a real-life scenario.

We set up a simulation in a 1 square kilometer area in the city of Porto, Portugal, featuring a diverse mix of road types with different lane counts, speed limits, and traffic signs, for low traffic densities. As our goal is to evaluate scenarios where the number of parked cars that can take the role of RSUs is limited, we opt for a conservative ratio of 1 active parked car per 10 cars on the road; i.e., a ratio of 1:10. Figure 2 shows how a message travels through the network, with and without the support of parked cars.

The data shows gains of 40-50% in reachability time, a considerable improvement given the small number of parked cars that are being designated to act as RSUs, and the overall randomness in the location of the parked cars and the source of the emergency. These results indicate that even a small number of randomly-distributed parked cars can bring substantial improvements to the connectivity of the network.

V. Mechanisms and Algorithms for Self-Organization

In the previous section we showed how the urban vehicular network can see considerable benefits, even with a small percentage of parked cars joining the network. For most cities of average population density, however, one is faced with the opposite problem: an excess of parked cars to choose from. This becomes a problem in itself, as it is wasteful to keep all parked cars with their DSRC radios active, possibly causing or worsening issues of congestion and interference.

A survey of parking events in a dense borough of the City of Montreal, Canada, provides an extreme case study of this problem, where densities of 3,000 to 4,000 parked cars per square kilometer can be expected at any time of day [12]. We expect that less than 2% of these cars will be required to fully cover the same area. These numbers provide strong motivation for studying methods to decide which cars should become RSUs, to avoid a scenario where large numbers of parked cars keep their radios activate unnecessarily.

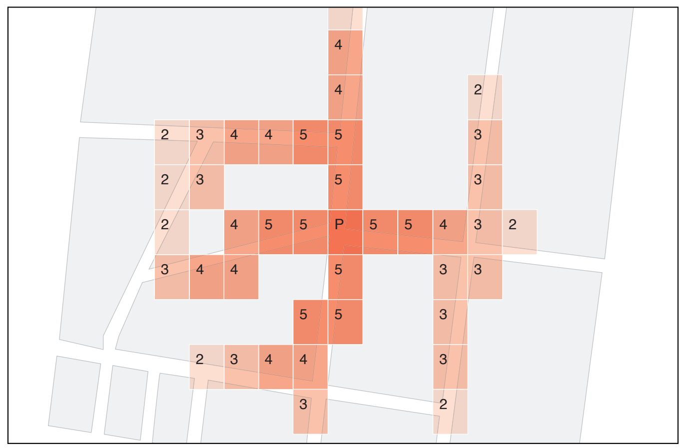


Figure 3. Example of a local self-observed coverage map.

In order to optimize global signal coverage, one needs to know which areas can be reached by each node. To accomplish this, we first divide the urban area into a logical 2D cell map that is common to all cars. By aligning cells to GPS coordinates (e.g.: 1 GPS second, a geographical unit), we ensure that all cars have the same addressing system, without the need to pre-distribute maps. Second, we introduce a system where parked cars listen to beacons from other cars and use those beacons to track their own coverage area on this 2D cell map. These beacons have been standardized and are designated as Cooperative Awareness Messages (CAM), which include position, speed, and bearing [13], and are broadcast at a rate no slower than 1 Hz.

As a car parks, it listens to beacons that are broadcast by neighboring cars, which it can then use to build a map of cells that the parked car knows, with certainty, that it can reach. If the received signal strength of the beacon message is available from lower layers, the car can also register that important piece of information. Figure 3 exemplifies one such map built by a car parked near an intersection, where the parked car is marked as ‘P’, and signal strength is classified in a scale of 0 to 5.

We can now use these self-observed Local Coverage Maps to design algorithms that optimize global network coverage.

A. Decision Algorithm

The decision algorithm is based on a score, which we name $\mathrm{d_{score}}$, that each vehicle computes by itself. The outcome of this algorithm ultimately decides whether the parked car should become an RSU, or switch to a power-saving (sleep) mode. We opt to keep the decision down to each individual car, while relying only on information from the car's 1-hop neighbor nodes, in order to keep network traffic to a minimum. Consequently, each car should inform its 1-hop neighborhood of its observed Local Coverage Map, so that neighbors can make informed decisions.

With the Local Coverage Maps of neighbor RSUs, the algorithm begins by building a Neighborhood Coverage Map, thus giving it a picture of how the area that surrounds it is currently being served. $\mathrm{d_{score}}$ then represents that car's benefit to that picture, should it become active. When $\mathrm{d_{score}}$ is positive, the car becomes an RSU; when negative, the car goes into a power saving mode.

This decision score is calculated, per cell, as follows: if we are the first to provide coverage to a cell, add points equal to the signal strength that will be provided ($\mathrm{d_{new}}$); if a cell is already being served by another RSU and we improve on the signal strength at that location, add points equal to that signal improvement ($\mathrm{d_{boost}}$); for each cell that we add coverage to, subtract points (penalize) equal to the number of RSUs already covering that cell ($\mathrm{d_{sat}}$); and finally, penalize based on battery usage. The decision score is thus given by

$$\mathrm{d_{score}} = \kappa \cdot \mathrm{d_{new}} + \lambda \cdot \mathrm{d_{boost}} - \mu \cdot \mathrm{d_{sat}} - \mathrm{d_{bat}}, \qquad (1)$$

where the coefficients κ, λ and μ can be optimized through search heuristics to be able to react to a variety of network scenarios. Finally, to prevent race conditions, parked cars that have the role of RSUs (i.e., that remain active) reevaluate their d_{score} whenever new coverage maps are received, or new RSUs establish themselves in the neighborhood. We will now show, for a specific scenario, how the city's coverage behaves as a function of the parameters in Eq. (1).

B. Expansive Coverage of Urban Areas by Parked Cars

With a cell map division, our core metrics are: **Signal Coverage**, an average of each cell's best signal strength of the RSUs that serve it; and **RSU Saturation**, an average of how many RSUs are covering each cell in the area.

We compare these metrics with the optimal solution to the problem, that can be determined by evaluating each possible combination of active and inactive parked cars. This process is not practical, as it would require $2^{\#\ \text{parked cars}}$ tests, which would quickly exceed millions of computations with just 20 parked cars. Our simulation evaluates a 1 km^2 region in the city of Porto, where 24 cars are instructed to park at random times in a 0.18 km^2 section of the map. This constraint forces the cars to park in nearby streets, so that their coverage overlaps and a decision should be made on which cars to keep active.

For comparison purposes, we first determine the optimal solution by bruteforcing the 2^{24} possible combinations (approx. 16,7 million runs), and we also show the results of simply activating all available parked cars. The results can be seen in Table I. We can see that activating all RSUs, predictably, results in the best coverage, but at a cost of an average of 8 RSUs covering each and every available cell, which is problematic. The optimal solution gives roughly the same level of signal coverage, with only 1.6 RSUs covering each cell – just 5 out of the 24 cars are left active. This shows that, given perfect decisions, 19 of these 24 parked cars are not needed and can conserve their battery power. Extrapolating these results to the 1 km^2 area, we can infer that 28-30 parked cars per km^2 may be sufficient, an order of magnitude smaller than the typical density of parked cars in a city.

The data in Table I results of an after-the-fact analysis of the scenario in question. We now analyze our self-organizing approach, with sharing of coverage maps and decisions taken at each node, and see whether it can approach an optimal solution. To do so, we vary the weights of each component in the decision criteria $\mathrm{d_{score}}$, rerun the simulation scenario, and plot the resulting coverage and saturation metrics.

The data in Figure 4 shows that, in our reference scenario, this decision process can reach a global signal strength of 3.93, which is only 3% worse than the Optimal selection. For this particular scenario, that occurs by setting $\mu = 0.1$ (the $\mathrm{d_{sat}}$ coefficient). However, the end result is also that 7.2 parked cars remain active, which is 2.2 cars more than the optimal solution. If keeping the number of active cars to a minimum is more desirable, with $\lambda = 8$ the resulting signal strength is of 3.76 (7% worse than Optimal), and only 5.6 parked cars remain active, on average.

These results show that our decision process can obtain near-optimal results without the need to have a global picture of the network, and it can also be directed towards specific goals, such as better signal strength or fewer active parked cars. The next steps involve the design of an on-line optimization method that can choose the best set of coefficients to reach predefined goals, for any underlying combination of road structures, obstructions, or node densities.

Table I
REFERENCE OPTIMAL METRICS.

	Signal Coverage	**RSU Saturation**	**RSU Count**
All RSUs active	4.13	8.28	24
Optimal selection	4.06	1.63	5

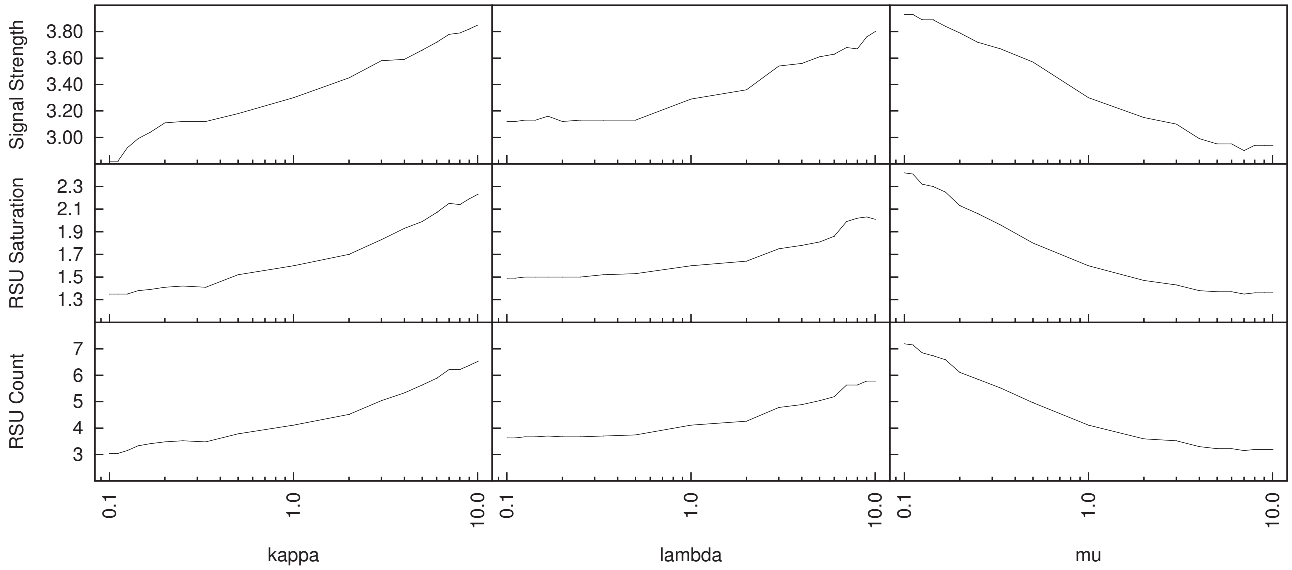


Figure 4. Effect of varying the coefficients κ, λ and μ on signal strength, RSU saturation, and total number of cells covered.

VI. Conclusion

In this paper, we proposed mechanisms and algorithms to allow parked cars in an urban environment to self-organize and act as road-side units, effectively supporting the existing vehicular network comprised of mobile vehicles. We began by showing that even small numbers of parked cars acting as RSUs can bring tangible, meaningful improvements to the performance of functions of a vehicular network as essential as the broadcasting of time-critical safety messages. Our simulation platform integrates real city maps, realistic mobility, real building obstructions, and real signal measurements with 802.11p equipment, lending confidence to our simulation data. Then, we introduced a method for parked cars to determine their local map of signal coverage, and presented an algorithm that, with minimal exchange of network data, allows cars to determine whether they should become RSUs. With the help of our simulation platform, we then showed that the network that results from this decision algorithm approaches optimal levels of coverage of the urban area, when compared to reference baselines of complete coverage and optimal decision processes.

As future work, we plan to address the dynamic optimization of the weights of the decision algorithm and node selection, and to handle the dynamics of arrivals and departures of vehicles in the dynamic decision process.

Acknowledgment

This work was partially funded by the Portuguese Foundation for Science and Technology through the CMU-Portugal Ph.D. Scholarship SFRH/BD/67145/2009, through national funds by FEDER in the framework of the PT2020 agreement in the framework of the project UID/EEA/50008/2013, and by IT Internal Project SenseBusNet (UID/EEA/50008/2013).

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