The Deployment of Roadside Units in Vehicular Networks Based on the V2I Connection Duration

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***Abstract*—The use of roadside units (RSUs) in vehicular networks can increase the efficiency of the network by providing hot spots for data dissemination between vehicles and an infrastructure-based networking integrating specialized systems. To maximize the effectiveness of the network, the locations where roadside units are deployed require special attention. In this work, we introduce a novel strategy for the deployment of roadside units in vehicular networks to maximize the number of vehicle-to-infrastructure contact opportunities. By using this strategy, we intend to provide a larger time window, increasing the vehicular communication and the QoS provided by the underlying network. As baselines, we consider the FPF and KP strategies. FPF projects the flow of vehicles in a Markovian approach, while KP is a heuristic for the 0-1 Knapsack Problem and does not consider any mobility information. Simulation results based on a realistic scenario demonstrate that the proposed method can find locations of roadside units more efficiently in comparison to FPF and KP methods in terms of the average number of satisfied vehicles (5.31% more than FPF and 35.64% more than KP).**

***Index Terms*—Vehicular Networks, Roadside Units, Deployment, Connection Duration, Quality of Service, V2I.**

I. Introduction

Vehicular Networks [1] are envisioned to be part of our daily lives soon, and they represent an interesting kind of mobile networks where nodes move fast with short duration of the connection between nodes (i.e., vehicles), and the arrangement of nodes along the road network change very fast. Such intrinsic mobility of vehicles imposes considerable challenges for data communication. Network designers can improve the connectivity by deploying a set of communication devices along the road network (roadside units), providing a backbone for data communication. Roadside units play a key role in overcoming the inherent challenges of vehicle-to-vehicle communication by providing a high-availability communication channel for information transfer. Over the years, several studies have demonstrated the gains obtained by using the infrastructure-based communication [2]. However, installing and maintaining such network infrastructure is not cheap [3].

However, the fast movement of vehicles leads to short-term connections between vehicles and roadside units, which may cause insufficient time for data exchange in V2I communication mode. This issue motivates us to introduce a new problem for measuring the Quality of Service in vehicular networks. We consider, for a fixed number of possible roadside units (η), the minimum V2I connection duration (t_{min}) that the vehicles must reach when traveling along the road network in an urban environment. Our objective is to maximize the number of vehicles reaching this minimum V2I connection duration. Undoubtedly, the connection duration parameter is assumed to change accordingly to the service provided over the vehicular network.

To tackle this problem, we use a novel greedy approach to define the locations where η roadside units must be installed to provide at least t_{min} seconds of V2I connection for the maximum number of vehicles. We referred this approach as Connection Time Based (CTB) algorithm. In other words, regarding V2I connection, CTB-Deployment strategy determines the best locations for installing roadside units not only to guarantee a certain level of QoS (defined by t_{min}) for the maximum number of users but also save on roadside unit deployment cost by considering a limited number of units (η).

Regarding the real traffic data-set of Cologne, Germany [4], in a partitioned network, we compare our algorithm to FPF (Full Projection of the Flow). This algorithm utilizes mobility information of vehicles to deploy roadside units. FPF tries to maximize the number of vehicles experiencing at least one connection to infrastructure [5] regardless of connection duration. Besides, we have worked on another deployment method where infrastructures are located in busy urban areas, respectively. This model is a heuristic 0-1 Knapsack Problem [6], and we refer to it as KP. This strategy selects the densest location of the city for coverage. Our approach presents better results compared with both baseline algorithms when we intend to assure minimum V2I connection duration for the maximum number of vehicles.

The remainder of this work is organized as follows: Section II discusses the related work. Section III presents how we represent road networks in the proposed solution. Section IV formalizes the definition of the problem. Section V presents the proposed algorithm (CTB). Section VI discusses the strategies used as baseline in this work. Section VII describes the simulation scenarios and discusses the associated results. Section VIII concludes the work.

II. Related Work

Connected vehicles are obtaining increasing attention in both industrial and academic communities. Weeratunga and Somers [7] present a comprehensive discussion on the future of connected vehicles. Where they notice although the advancement of connected vehicles and automated vehicles is occurring mostly independently, the convergence will take place through vehicular communication.

The impact of different placement strategies for roadside units on network efficiency is relevant and several approaches have been proposed. A comprehensive survey on infrastructure-based vehicular networks is presented in [8].

Analytic studies are also found in the literature. The deployment strategy in [9] aims to make a compromise between network coverage and cost. The problem is modeled as an integer linear problem and then solved with CPLEX software. Also, by considering a given expected delivery delay requirement, the authors in [10] have modeled the deployment problem as roadside units service coverage problem. While in [11] a binary differential evolution scheme is proposed to solve the problem. Additionally, Patil and Gokhale [12] have used the definition of Voronoi diagram and proposed a deployment strategy where roadside units are located at the convex polygons generator points, and the convex polygons contours surround the units according to the network design criteria.

Graph theory is a useful tool in modeling urban areas in vehicular networks. In [13], the road network is considered as a graph whose intersections are vertices, and roads are edges. Intersections are considered as options for roadside units installation. The procedure begins by placing roadside units at the intersections. The coverage of each roadside unit expands on every side. The extension continues until the average reporting time is reached to the optimal value. Furthermore, in [14] by deploying the minimum number of RSUs, the transmission time between units and the vehicles does not exceed a certain range. The authors have utilized the greedy algorithm to place some infrastructures and then with the Minimal Steiner Tree method, another series of unis are added to the scenario in order to ensure the wireless connectivity of roadside units.

Data dissemination is the key factor of services provided by vehicular networks. Sanguesa et al. [15] present the summary of 23 different kinds of dissemination schemes discussing the strengths and drawbacks associated with each one. Kai and Lee [16] propose an adaptable mathematical model for data dissemination in dynamic traffic environments. Where, in heavy traffic data is periodically broadcasted to moving vehicles and in light traffic scenarios, vehicles query on-demand for traffic information.

Bruno and Nurchis [17] assume vehicles equipped with cameras and the problem is how to deliver the images to remote data collectors. However, some vehicles may report an event simultaneous and to address duplicated data, the authors propose an algorithm to collect information capable of removing the redundancy of data transmitted by moving vehicles.

Deployment for file downloading is addressed in [18]. Whereas, the encounter between vehicles and roadside units is modeled as a Markov chain and the road network as an un-directed weighted graph. With these assumptions, the authors introduce an approach for locating roadside units based on the depth-first traversal algorithm. Additionally, Silva et al. [19] work on the application of Content Delivery Networks (CDN) in the vehicular networks. Thus the distribution of different contents within distinct levels of QoS is modeled on the assumption that each content type is related to a target region where it must be made available.

In [20], the authors use taxis' GPS devices to obtain vehicles' data and then by considering the deployment cost and latency performance a multi-objective optimization is proposed to solve the roadside unit placement problem, while authors in [21] apply the 0-1 Knapsack algorithm to manage a limited deployment budget by maximizing the total centrality of roadside units placement.

In terms of communication architectures, Silva et al. [22] propose the use of a hybrid architecture composed of mobile (based on drones) and stationary roadside units, while Reis et al. [23] propose the use of parked vehicles.

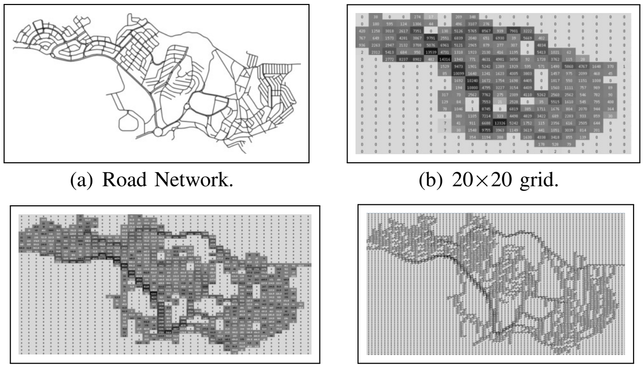
In terms of evaluating the QoS and/or performance of vehicular networks, Luan et al. [24] focus on the MAC layer for V2I communications where multiple fast-moving vehicles with different on-top applications and QoS requirements compete for the transmissions to the roadside infrastructure, while Harigovindan et al. [25] develop a mechanism for fair channel allocation.

The genetic algorithm is another useful method to help researches for finding the best roadside units locations. Different metrics can be assumed and the genetic algorithm is capable of meeting the criteria of the problems [26].

Unlike previous works, we consider V2I connection duration in the proposed infrastructure deployment strategy. In addition, real mobility information of vehicles and uneven vehicle densities in a real road network is a missed consideration in some previous works.

III. Representing Road Networks

In this work, we evaluate the deployment strategies considering a real road network. Before applying different deployment approaches, we employ partitioning to transform real road network into a set of equal-size rectangular cells. Once the area has been divided, the real road network is abandoned, and we rely on the path of vehicles in terms of urban cells, and also the time interval that vehicles spend within each cell. The use of rectangular cells does not incur any damage to our intents. The goal is to merely divide the city into urban cells and reduce the number of locations to be examined by the strategies. The exact location of each roadside unit inside a given urban cell is out of our scope but can be discovered by recursive applications of our strategy until reaching the desired level of granularity.



(a) Road Network. (b) 20×20 grid. (c) 40×40 grid. (d) 80×80 grid.

Figure 1. Partitioning the road network in a grid-like structure.

Fig. 1(a) shows the road network of a given city. Fig. 1(b) overlaps a 20×20 grid, resulting in 400 urban cells. Fig. 1(c) overlaps a 40×40 grid, resulting in 1,600 urban cells, while Fig. 1(d) overlaps an 80×80 grid, resulting in 6,400 urban cells. Partitioning allows us to represent the road network and its associated flow by a grid structure of arbitrary granularity. When we need more accuracy, we simply increase the number of grid cells covering the region.

IV. Problem Definition

Given a set of vehicles $K = \{1, 2, ..., k\}$, a set of urban cells $U = \{1, 2, .., u\}$, the trajectories of vehicles in terms of urban cells G, the number of available roadside units (η), and the minimum time interval that vehicles must be within the range of roadside units to be considered covered (t_{min}), the goal is to select the best set of urban cells to be covered by roadside units in order to maximize the number of distinct vehicles covered for, at least, t_{min} units of time.

Moreover, as it is intuitive, along the trip, any vehicle may contact zero or more roadside units, depending on the path followed by the vehicle. Whenever the vehicle crosses an urban cell having a roadside unit, it receives coverage during that period of time. Analogously, any roadside unit contacts all vehicles crossing the urban cell where it is deployed.

For this problem, an Integer Linear Programming (ILP) formulation M can be proposed:

Let's assume the following sets:

K: set of vehicles where $K = \{1, 2, ..., k\}$;
U: set of urban cells $U = \{0, 1, ..., u\}$;

Let's assume the following variables:

$$a_u = \begin{cases} 1, & \text{if urban cell } u \text{ receives a roadside unit} \\ 0, & \text{otherwise.} \end{cases}$$

$$v_k = \begin{cases} 1, & \text{if vehicle } k \text{ belongs to the solution} \\ 0, & \text{otherwise.} \end{cases}$$

and the following set of parameters:

$$m_{uk} = \begin{cases} 1, & \text{if vehicle } k \text{ crosses urban cell } u \\ 0, & \text{otherwise.} \end{cases}$$

η: number of available roadside units.

t_{min}: The minimum time that a vehicle must be connected to units to belong to the solution.

t_{uk}: The time the vehicle k spends at urban cell u.

The deployment of roadside units is modeled as follows:

$$\max \sum_{k \in K} v_k \tag{1}$$

Subject to:

$$\sum_{u \in U, k \in K |\ m_{uk}=1} a_u \leq \eta \tag{2}$$

$$\sum_{u \in U |\ m_{uk}=1} t_{uk} a_u \geq t_{min} v_k \quad \forall k \in K \tag{3}$$

$$a_u \in \{0, 1\} \tag{4}$$

$$v_k \in \{0, 1\} \tag{5}$$

Objective function (1) maximizes the number of distinct vehicles reaching roadside units. Constraint (2) ensures that the number of selected urban cells is $\leq \eta$. Constraint (3) ensures that whenever the vehicle k is covered, at least one of the urban cells crossed by k has a roadside unit. Constraints (4) and (5) are the integrality constraints.

V. Proposed Algorithm

Here, we present our strategy to solve the allocation of roadside units in order to maximize the number of vehicles reaching t_{min} time units connected to η roadside units deployed along the road network partitioned in $\psi \times \psi$ urban cells. The CTB algorithm receives as input the number of available roadside units (η), the set of urban cells U, the set of vehicles (K), the trajectories of vehicles G, the density of vehicles in each cell (matrix *D*), passing time of vehicles through each cell (t_{uk}), the minimum connection duration (t_{min}), and it outputs the set of selected cells for installing roadside units (X). The CTB strategy is presented in Algorithm 1.

At the beginning of the CTB algorithm, the cell with the most significant number of vehicles is selected to receive the first roadside unit (line 3). When the CTB selects a cell for installing a roadside unit, the number of uncovered vehicles in other cells is calculated. Uncovered vehicles are vehicles that are not able to communicate with installed roadside units, or their connection duration is less than t_{min}. Then, we operate another iteration of the algorithm in which the cell with the largest number of uncovered vehicles is selected to deploy the next roadside unit. This process continues until all of the available η roadside units are assigned to η chosen cells.

Algorithm 1 : The Proposed CTB Algorithm

Input: $\eta, K, G, U, D, t_{uk}, t_{min}$;
Output: X (best cells for deploying roadside units);
1: $X \leftarrow \emptyset$;
2: $C \leftarrow$ get cell with maximum number of vehicles (D);
3: $X \leftarrow X \cup C$; ▷ add C to solution set
4: **for** i=2 to η **do**
5: $T \leftarrow$update connection duration of vehicles (K, G, U, t_{uk});
6: $D \leftarrow$ update D by removing covered vehicles (i.e., vehicles that have reached the connection target)(D, T, t_{min});
7: $C \leftarrow$ cell with maximum number of uncovered vehicles (D);
8: $X \leftarrow X \cup C$; ▷ add C to solution set
9: **end for**
10: **return** X;

T saves the connection duration of vehicles. Whenever the connection duration of any vehicle is greater than or equal to t_{min}, we consider this vehicle as covered (our target coverage for this particular vehicle has been reached). Then, this vehicle is deleted from the D-Matrix, and it is never again processed (line 6). The algorithm in each iteration selects the cell having the largest number of uncovered vehicles and adds it to set X (lines 7-8). Thus, the CTB algorithm democratizes the network by covering as many uncovered vehicles as possible, and also provides sufficient connection duration for the target share of vehicles.

VI. Baselines

We consider two strategies as baselines: (i) FPF [5] and (ii) KP [6]. FPF [5] is a mobility-driven strategy for roadside units deployment. The strategy is based on the global behavior of drivers, and uses the density of vehicles within each cell and the migration ratios of vehicles between urban cells to select the most promising cells for receiving coverage. Although the FPF strategy aims to maximize the number of vehicles contacting the infrastructure at least once, it does not take into account the connection duration, a key factor for defining the kind of applications that can on top of the network.

On the other hand, Trullos *et al.* model the allocation of roadside units in vehicular networks as a Maximum Coverage Problem. In this formulation, vehicles represent elements, while locations of the road network represent sets, and the goal is to find a collection of sets that maximizes the number of vehicles driving through roadside units. In the work [6], the authors propose the KP (0–1 Knapsack Problem) strategy for solving this problem. Basically, the strategy sorts the urban cells in decreasing order according to the density of vehicles observed during a given time interval, and then it returns the first η urban cells. Although locating roadside units at the densest urban cells may seem reasonable, we must recall very popular urban cells tend to be near to each other, and vehicles traveling popular routes end up receiving high coverage, while the great majority of vehicles starve.

VII. Simulation Results

Now, we evaluate the proposed strategy (CTB) in comparison to the baselines. CTB focuses on maximizing the number of vehicles presenting connection duration to roadside units of (at least) t_{min} seconds. The performance of CTB is evaluated by considering the real-world urban environment of Cologne, Germany [4], and realistic vehicular traces having 7,200 seconds of duration, and consist of 75,515 vehicles. Experiments are performed using a set of tools designed by our team. Cologne is partitioned into a grid of 100×100 urban cells, each cell having an approximate area of 270m×260m, an acceptable range for roadside units [26].

A. Evaluation of the share of covered vehicles versus the connection duration

In this section, we focus on the performance of CTB, FPF, and KP by increasing the connection duration (t_{min}) from 20s up to 70s, assuming the selection of η=40 urban cells for receiving coverage. The goal is to verify the impact of different connection duration thresholds for each of the algorithms. The study is presented in Fig. 2, where the y-axis indicates the share of vehicles experiencing connection duration along the whole trip of (at least) t_{min} seconds, while the x-axis groups the results in terms of increasing connection duration values.

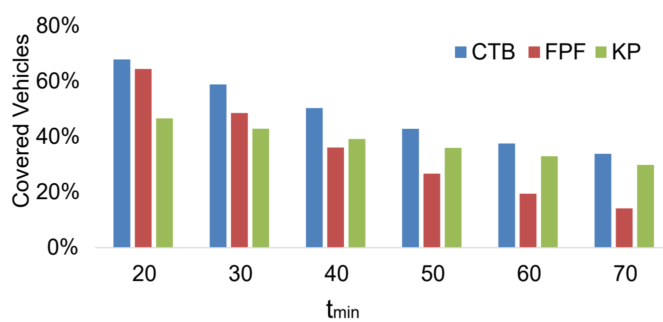


Figure 2. Percentage of covered vehicles versus minimum V2I connection duration required to assure QoS for users (t_{min}). The y-axis presents the share of vehicles experiencing at least t_{min} seconds connection duration, while the x-axis demonstrates different connection duration values.

We notice that CTB (blue bar) provides for more vehicles reaching the connection duration than the other approaches. Moreover, according to our intuition, as we increase the connection duration constraint, fewer vehicles can achieve such target. Then, fewer vehicles are marked as covered by all three strategies (the tighter condition reduces the number of vehicles complying). We also notice that KP (green bar) outperforms FPF (red bar) when the connection duration threshold is high. In fact, since KP covers the most popular routes, it tends to provide more coverage to the same vehicles, leading to such results when the connection duration is increased.

In the previous scenario, any vehicle may contact more than one roadside unit to reach t_{min}. However, if we consider each vehicle has the chance to contact roadside units only once on its entire journey, how many vehicles can achieve more than t_{min} with only one contact? 40 roadside units have been installed by different strategies, and Fig. 3 presents the covered vehicles (in percentage terms) which can reach different values of t_{min} by connecting to roadside units only once. Although the CTB performs better than FPF and KP, the coverage achieved by different deployment schemes decreases significantly by increasing t_{min}.

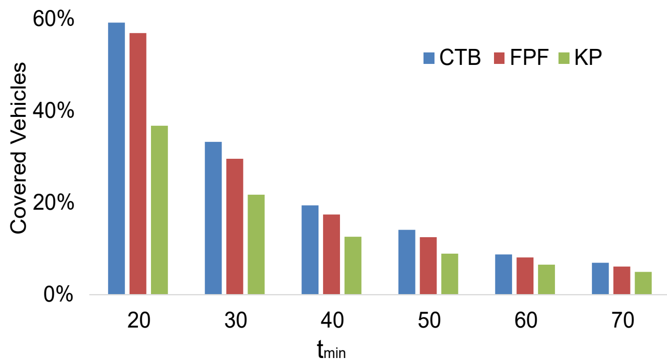


Figure 3. shows the percentage of vehicles experiencing at least t_{min} connection duration with only one V2I connection. The scenario considers the coverage of 40 urban cells ($\eta = 40$), and t_{min} varying from 20s up to 70s.

B. Evaluation of covered vehicles by increasing deployed roadside units

Here, we study the impact of increasing roadside units on the coverage of different algorithms. We assumed t_{min}=20 s and η varying from 50 up to 250. Roadside units are deployed using CTB, FPF, and KP algorithms. The study is summarized in Fig. 4. The x-axis indicates the number of urban cells covered (recall that each urban cell is covered by deploying one single roadside unit). The y-axis indicates the number of vehicles reaching the threshold t_{min}=20 s. There, we can notice in all algorithms, the increment of η results in more covered vehicles which is understandable since more areas of the city are covered.

By covering 2.0% of Cologne (selection of 200 urban cells out of 10 000), we reach the following percentage of vehicles: CTB = 95.2%; FPF = 90.2%; KP = 76.2%. Where all these vehicles communicate with roadside units for t_{min}=20 s or more. In other words, the proposed algorithm is able to cover 5% more vehicles than FPF and 19% more than KP. Based on the results, it seems that having 200 roadside units is an appropriate choice for this city. Since, with 25% increase in the number of roadside units (having 250 roadside units), the number of covered vehicles increases only 1.4%, and it is obvious that 25% increase in installation and maintenance

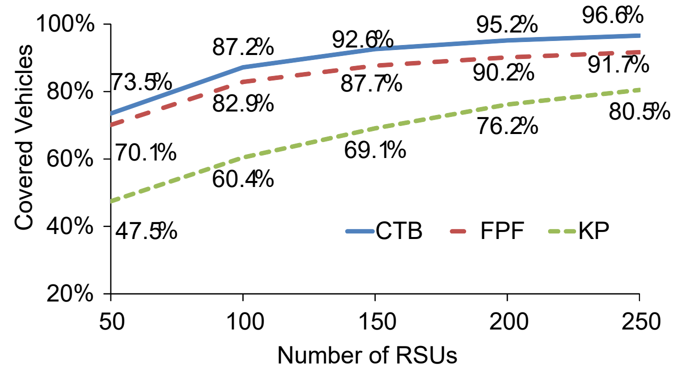


Figure 4. presents the study considering the realistic mobility trace of Cologne, Germany [4]. The x-axis indicates the number of deployed roadside units in a real scale where the number of units varies from 50 to 250. The y-axis highlights the number of vehicles achieve more than 20 s of V2I connection (in percentage terms) provided by CTB (blue) when compared to FPF (red) and KP (green).

costs for only 1.4% increase in the number of covered vehicles is not reasonable.

C. Empirical evaluation of the layout of roadside units

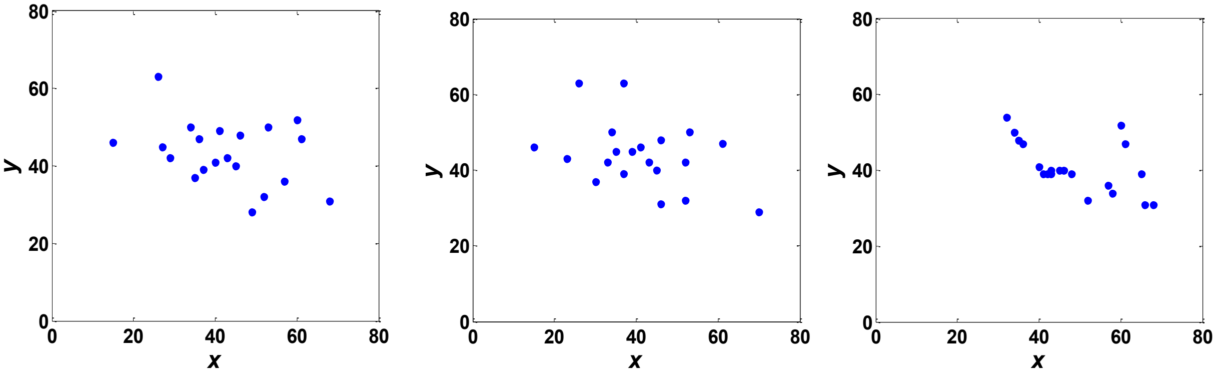
In this experiment, we have fixed the number of roadside units η=20. Thus, we are covering 0.2% of the 10 thousand available urban cells. We also consider the minimal connection duration t_{min}=20s. Figs. 5(a)-5(c) demonstrate the localization of the roadside units deployed accordingly to (respectively) CTB, FPF, and KP strategies. Since the urban cell [45, 40] presents the higher traffic, it is selected by all three strategies. Recall that KP selects cells in decreasing order of traffic density. Thus, Fig. 5(c) shows the top-20 most popular urban cells, and we notice that areas of high traffic are interconnected.

On the other hand, Figs. 5(a) (CTB) and 5(b) (FPF) present a more dispersed selection of urban cells, allowing that vehicles traveling outside very popular routes also receive coverage in some points. Finally, we also notice that CTB replaces some urban cells from FPF in order to incorporate the criterion of connection duration (inexistent in FPF).

VIII. Conclusion

This work presents a novel problem formulation for designing the infrastructure for vehicular networks. Basically, we propose a deployment strategy that provides guarantees in terms of minimal connection duration for a given share of vehicles. We represent the road network in a grid-like structure by partitioning the city into a set of $\psi \times \psi$ urban cells, and then we devise the proposed strategy (CTB).

We rely on the realistic mobility trace of Cologne, Germany [4], and we use the strategies FPF [5] and KP [6] as baselines. FPF works based on the migration ratios between urban cells and maximizes the number of distinct vehicles experiencing at least one connection to roadside unit. On the other hand, KP deploys roadside units in the most popular urban cells of the city. Our simulation results demonstrate that



(a) CTB (b) FPF (c) KP

Figure 5. plots the layout of 20 roadside units in the grid representing the road network of Cologne, Germany. Fig. 5(a) shows the layout according to CTB. Fig. 5(b) presents the proposed layout by FPF, while Fig. 5(c) indicates the layout proposed by strategy KP. Although we have partitioned the road network into a 100x100 grid, here we plot only the first 80x80 cells in order to zoom the figure for highlighting distinctions among the three strategies.

the CTB strategy achieves its goals in terms of selecting better urban cells for providing the coverage when compared to FPF and KP.

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References

[1] H. Hartenstein and K. Laberteaux, *Vehicular applications and inter-networking technologies*. Wiley-Blackwell, 2010.

[2] C. M. Silva, B. M. Masini, G. Ferrari, and I. Thibault, "A Survey on Infrastructure-Based Vehicular Networks," *Mobile Information Systems*, vol. 2017, Article ID 6123868, pp. 28–56, 2017.

[3] Y. Wu, Y. Zhu, and B. Li, "Infrastructure-assisted routing in vehicular networks," *2012 Proceedings IEEE INFOCOM*, 2012.

[4] http://kolntrace.project.citi-lab.fr/.

[5] C. M. Silva, W. Meira, and J. F. M. Sarubbi, "Non-intrusive planning the roadside infrastructure for vehicular networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 17, pp. 938–947, April 2016.

[6] O. Trullols, M. Fiore, C. Casetti, C. Chiasserini, and J. B. Ordinas, "Planning roadside infrastructure for information dissemination in intelligent transportation systems," *Computer Communications*, vol. 33, no. 4, p. 432–442, 2010.

[7] K. Weeratunga and A. Somers, "Connected vehicles: are we ready? internal report on potential implications for main roads wa," 2015.

[8] B. Masini, A. Bazzi, and A. Zanella, "A survey on the roadmap to mandate on board connectivity and enable v2v-based vehicular sensor networks," *Sensors*, vol. 18, no. 7, p. 2207, 2018.

[9] Y. Liang, H. Liu, and D. Rajan, "Optimal placement and configuration of roadside units in vehicular networks," in *2012 IEEE 75th Vehicular Technology Conference (VTC Spring)*, pp. 1–6, May 2012.

[10] Y. Ni, J. He, L. Cai, J. Pan, and Y. Bo, "Joint roadside unit deployment and service task assignment for internet of vehicles (iov)," *IEEE Internet of Things Journal*, vol. 6, pp. 3271–3283, April 2019.

[11] H. Yang, Z. Jia, and G. Xie, "Delay-bounded and cost-limited rsu deployment in urban vehicular ad hoc networks," *Sensors*, vol. 18, no. 9, p. 2764, 2018.

[12] P. Patil and A. Gokhale, "Voronoi-based placement of road-side units to improve dynamic resource management in vehicular ad hoc networks," *2013 International Conference on Collaboration Technologies and Systems (CTS)*, 2013.

[13] B. Aslam, F. Amjad, and C. C. Zou, "Optimal roadside units placement in urban areas for vehicular networks," in *2012 IEEE Symposium on Computers and Communications (ISCC)*, pp. 000423–000429, July 2012.

[14] P. Li, Q. Liu, C. Huang, J. Wang, and X. Jia, "Delay-bounded minimal cost placement of roadside units in vehicular ad hoc networks," *2015 IEEE International Conference on Communications (ICC)*, 2015.

[15] J. Sanguesa, M. Fogue, P. Garrido, F. Martinez, J.-C. Cano, and C. Calafate, "A survey and comparative study of broadcast warning message dissemination schemes for vanets," *Mobile Information Systems*, vol. 2016, p. 18, 03 2016.

[16] K. Liu and V.-S. Lee, "Rsu-based real-time data access in dynamic vehicular networks," in *Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on*, pp. 1051–1056, Sept 2010.

[17] R. Bruno and M. Nurchis, "Robust and efficient data collection schemes for vehicular multimedia sensor networks," in *World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a*, pp. 1–10, June 2013.

[18] Y. Liu, J. Niu, J. Ma, and W. Wang, "File downloading oriented roadside units deployment for vehicular networks," *Journal of Systems Architecture*, vol. 59, no. 10, p. 938–946, 2013.

[19] C. M. Silva, F. A. Silva, J. F. Sarubbi, T. R. Oliveira, W. Meira Jr, and J. M. S. Nogueira, "Designing mobile content delivery networks for the Internet of vehicles," *Vehicular Communications*, vol. 8, pp. 45 – 55, 2017. Internet of Vehicles.

[20] X. Cao, Q. Cui, S. Zhang, X. Jiang, and N. Wang, "Optimization deployment of roadside units with mobile vehicle data analytics," in *2018 24th Asia-Pacific Conference on Communications (APCC)*, pp. 358–363, Nov 2018.

[21] Z. Wang, J. Zheng, Y. Wu, and N. Mitton, "A centrality-based rsu deployment approach for vehicular ad hoc networks," in *2017 IEEE International Conference on Communications (ICC)*, pp. 1–5, May 2017.

[22] C. M. Silva and W. Meira Jr, "An architecture integrating stationary and mobile roadside units for providing communication on Intelligent Transportation Systems," in *NOMS 2016 - 2016 IEEE/IFIP Network Operations and Management Symposium*, pp. 358–365, April 2016.

[23] A. B. Reis, S. Sargento, and O. K. Tonguz, "Parked cars are excellent roadside units," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, pp. 2490–2502, Sep. 2017.

[24] T. H. Luan, X. Ling, and X. S. Shen, "Provisioning qos controlled media access in vehicular to infrastructure communications," *Ad Hoc Networks*, vol. 10, no. 2, pp. 231 – 242, 2012. Recent Advances in Analysis and Deployment of IEEE 802.11e and IEEE 802.11p Protocol Families.

[25] V. Harigovindan, A. Babu, and L. Jacob, "Proportional fair resource allocation in vehicle-to-infrastructure networks for drive-thru internet applications," *Computer Communications*, vol. 40, no. 0, pp. 33 – 50, 2014.

[26] M. Fogue, J. Sanguesa, F. Martinez, and J. Marquez-Barja, "Improving roadside unit deployment in vehicular networks by exploiting genetic algorithms," *Applied Sciences*, vol. 8, p. 86, Sep 2018.