Traffic-Aware Access-Points Deployment Strategies for VANETS

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Abstract. Using WLAN-hotspots to provide access to mobile users has proven its feasibility and interest in many cases such as mesh and vehicular networks. Nevertheless, VANETs are still looking for deployment strategies that would ensure a maximum data exchange and a well balanced access. The high mobility and density of users and the impossibility to provide a full coverage make such requirements a hard challenge.

In this paper we make a quick review of the commonly used deployment schemes and show their limits regarding real VANETs constraints. We analyze the deployment problem taking into account the vehicular density and the resulting contention problem. We formalize the problem and provide a centrality-based deployment aiming a global service-access optimization and a p-center based deployment aiming fairness as a second objective. We evaluate through simulation the performance of our proposed schemes and show their efficiency and benefits in comparison to other deployment strategies.

Keywords: VANET · AccessPoint deployment · Coverage problem

1 Introduction

VANET is best known for V2V (vehicle-to-vehicle) communications; Nevertheless, many recent studies revealed the importance of V2I (vehicle-to-infrastructure) communication not only as a gateway to external resources (internet access, content sharing...) but also as an indispensable support for V2V communication. The Drive-Thru-Internet [1] was one of the first projects which evoked and demonstrated the feasibility of such communication even at high speed. Thenceforth, many projects showed the benefits of using V2I communication in many application field such as traffic congestion monitoring, accident tracking, Geo-Routing support and many others [2]. Developing dedicated deployment strategies becomes hence essential.

In this paper we provide an overview of, so far, proposed deployment strategies for VANETs. We show that most of them reveal to be ineffective since neglecting the contention problem caused by vehicular density.

In the second part we introduce a novel view of the coverage problem for VANETs and define more accurate and effective deployment objectives.

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The third part of this paper, introduces a composed model which takes into account vehicular density and traffic load followed by a detailed analysis to address both global optimization and fairness requirement. We show through theoretical analysis that the deployment problem could be reduced to an evolved form of centrality-based classification for the global optimization and a complex form of the *p-center* problem [3] for the fairness consideration. Based on this model, we develop two deployment strategies aiming at efficiency and fairness.

Finally, we evaluate in paragraph 4 the performance of our deployment schemes and show that they perform significantly better than random deployment and other centrality-based strategies, confirming hence the theoretical analysis.

2 Overview of Deployment Strategies

Many ITS projects have integrated the use of access points [2,4] to provide internet access or any kind of sharing and communication services, unfortunately without any care for the choice of their location and the impact it could have on the efficiency and validity of their results.

Several works have progressively tried to address the VANET access-point deployment problem. Using open Wifi, was a starting point for such efforts [4,5]. Many works used then the intuitive idea of placing APs on intersections as to improve the number of covered vehicles [2,6,7].

A better and deeper understanding of the role of infrastructure on application level pushed researchers then to develop application-oriented schemes such as those presented in [8] and [9]. In the first work [8], a cooperative downloading scenario was intended. The deployment aimed at maximizing the potential for collaboration among vehicles i.e., the probability of meeting between downloader and prospective carriers of information. In the second work [9], AP-positions were selected with regards to the benefit (i.e. time saving), vehicles may gain from the knowledge of real-time road traffics.

Works [6] and [10] formulated the problem in a more abstract way. The first work [6], formulates the problem as a Maximum Coverage Problem (MCP) [11], so as to maximize the number of vehicles that get in contact with deployed access points. The second work [10] tries to ensure a regular contact opportunity at maximal pre-configured distance. A deployment provides a so-called 'α-coverage' of distance α if any path in F (set of paths) is covered by at least one access point. The authors modeled the problem as a vertex multicut problem whose solution corresponds to the sought after access point locations.

Despite the importance of all these efforts, most of them are reducing the coverage notion to a simple meeting opportunity (for vehicles) [6–9] or even to a belonging-test (to streets which are then considered to be well covered!) [10,12,13]. In spite of the idea of [12] and [13] to account for the distance, the relative position and the time spent in contact with the access point in order to get a better evaluation of the quality of the *opportunity* metric, we think that considering any "contact" with an access point as an 'opportunity' to establish an appropriate communication is unfortunately untrue in VANET conditions.

It is well known that the wireless channel is shared among all participants and could be even inaccessible in contention scenarios. Such a deployment scheme is hence only relevant and valuable in low density environments.

The problem was thus reduced to a simple geographical coverage by having overlooked the traffic load and the vehicular density and the resulting contention they may cause in such type of communication.

In a recent study, F.MA et al. [14] attempted to address the contention problem by proposing a modeling that prohibits simultaneous communications of neighboring nodes and evaluates the proposed deployment strategy based on the aggregate throughput instead of a simple metric. In spite of this important step towards a consistent and coherent modeling of the deployment problem, we think that a more abstract and application-independent model should be used. In fact the last work gets around the problem of contention by presenting a model which prohibits concurrent communications. Apart from pure dissemination-oriented scenarios, where access points broadcast application-related information to vehicles, concurrent communications do exist and do affect the average throughput of the whole system and should be therefore taken into account instead of being pushed aside.

In the next paragraph we will redefine the concept of coverage for VANETs and formalize the problem in such a way to take into account the key factors contributing to the fulfillment of a valuable deployment scheme.

3 The Coverage Problem

The above presented approaches may be relevant in download direction (dissemination scenarios) where density does not much affect the overall data transfer. They are, however, unsuitable for upload scenarios and could even be counterproductive because they do not take interference and contention problem into account. In the rest of our work, we will thus consider the difficult side of the problem namely the optimization of the deployment with regard to the upload direction.

In the following, we present a model which focuses on this aspect and allow us to move from a loose metric 'the contact opportunity' to a very precise metric "the data volume" and from global scenarios to two tailored scenarios with different constraints.

Definition 1. *A trip t, is a Set of successively connected edges; so for a graph G(V, E) representing the roads plan,* $t = \{e_i; e_i \in E\}$ *We note thereby the set of predefined considered trips as* π*.*

Definition 2. *A deployment provides a maximum coverage, if the average data volume (in the uplink direction) is maximized (global optimisation) for the overall considered trips or if possible for each considered trip (fairness consideration).*

This new formulation of the problem reveals the importance of vehicle traffic and data traffic incorporation in the deployment problem. In order to take these factors in consideration, we propose the following modeling:

1. We are considering a predefined set of trips denoted by π (where π_{AB}^k, is the k^{th} considered trip between A and B).
2. A set of candidate deployment positions is given, denoted S_{AP}
3. We consider an average vehicle traffic of γ_{AB}^k veh/sec on each trip π_{AB}^k.
4. We consider an average data traffic load of λ packets/s for each vehicle.
5. We are only considering traffic in the uplink direction (V2I).

The first assumption reflects the fact that vehicle-traffic is usually a mixture of vehicle flows driven by origin to destination paradigm [15,16]. The third point applies different traffic arrival rates for the considered trips which truly maps the real state on roads. As it is stated by the last assumption, we will focus on the uplink traffic as it fully accounts for the contention problem we are trying to address.

Based on these assumptions, the following definitions and theorems will lead us to formalize the problem and to define valuable objective functions.

Lemma 1 (Average Density). *Let $\eta(i)$ denote the average number of vehicles in the range of access point (i). Applying little's law and summing the different traffics of vehicles passing through (i), we get the following result:*

$$\eta(i) = \sum_{\pi_{AB}^k, i \in \pi_{AB}^k} \frac{2r}{v_i} * \gamma_{AB}^k \tag{1}$$

r being the radius of the communication zone and v_i the average vehicle velocity within the communication zone of (i).

The traffic load generated by each vehicle being equal to λ packets/s, the total offered load for an access point (i) is then defined as:

$$\lambda_i^{Total} = \lambda * \eta(i) \tag{2}$$

Theorem 1. *$\mathcal{TH}(i, v)$ being the effective throughput offered to a vehicle v in the range of the access point (i), $\mathcal{TH}(i, v)$ depends only on the access point position (under constant vehicular density in its communication zone).*

Proof. Bianchi [17] showed that the effective throughput per vehicle $\mathcal{TH}(i, v)$ depends only on the total offered load and the number of contending stations. Or, the total offered load for an access point (i), noted λ_i^{total}, depends only from the position of that access point (Eq. 2) and of the average number of contending vehicles in its range. This last one depends in our case also only on the access point position (lemma 1); So the average effective throughput depends only on the access point position. We note it for simplicity $\mathcal{TH}(i, v) = \mathcal{TH}_i$.

Hence, knowing the vehicle traffic, we can deduce the effective throughput for each candidate access point position (formally [17,18], experimentally or by simulation as we did). The corresponding vector (to S_{AP}) is noted $\mathcal{TH}_{AP}$.

Based on this estimation, we can now calculate the average data volume per km $\mathcal{NB}(\pi^k_{AB})$ that could be sent from a vehicle taking a Trip π^k_{AB} from A to B through a set of chosen access-points noted AP:

$$\mathcal{NB}(\pi^k_{AB}) = \frac{1}{|\pi^k_{AB}|} \sum_{i \in AP} (\mathcal{TH}_i * \frac{2r}{v_i}) * \chi_{\pi^k_{AB}}(i)$$

$$\text{with} \quad \chi_{\pi^k_{AB}}(i) = \begin{cases} 0 \text{ if i} \notin \pi^k_{AB} \\ 1 \text{ if i} \in \pi^k_{AB} \end{cases}$$

This formulation reflects the simple fact that a vehicle will have the opportunity to send data through each access point belonging to the trajectory of its trip from A to B assuming an effective throughput of $\mathcal{TH}(i)$ along the communication zone. This value is then normalized over the trip length (noted $|\pi^k_{AB}|$).

We can now define the average data volume per km that can be successfully sent by a vehicle taking a trip on the network as $\mathcal{NB}(F)$:

$$\mathcal{NB}(F) = \sum_{p \in \pi} \frac{\gamma_p}{\gamma_{total}} * \mathcal{NB}(p) \text{ with } p = \pi^k_{AB}. \tag{3}$$

where γ_{total} represents the total arrival rate for the whole network (all considered trips: $\gamma_{total} = \sum_{p \in \pi} \gamma_p$. This average is obtained by considering the vehicle traffic rate for each trip.

The deployment problem being now well formalized, we can henceforth tackle the optimization problem. In the following two sections, we investigate the global optimization version and the fairness version of the deployment problem.

3.1 Global Optimization

In this section the following problem is considered: given a set of candidate access-point positions S_{AP}, we are looking for the optimal subset of p positions AP^* that maximizes $\mathcal{NB}(F)$.

Theorem 2. *The optimal set of* p *positions that maximizes* $\mathcal{NB}(F)$ *is the set having the maximal group betweeness centrality.*

Proof. According to equation (3)

$$\begin{aligned} \mathcal{NB}(F) &= \frac{1}{\gamma_{total}} \sum_{p \in \pi} \{ \frac{\gamma_p}{|p|} \sum_{i \in AP} (Th_i * \frac{2r}{v_i}) * \chi_p(i) \} \\ &= \frac{1}{\gamma_{total}} \sum_{p \in \pi} \frac{\gamma_p}{|p|} \{ \sum_{i \in AP} \mathcal{C}_i * \chi_p(i) \} \end{aligned} \tag{4}$$

with $\mathcal{C}_i = Th_i * \frac{2r}{v_i}$ which only depends on the access point position (Theorem 1 and r being constant).

The obtained form (Eq. 4) corresponds to a scaled group betweeness centrality [19] defined in its simplest length-scaled form [20] for a subset $G \in V$ as

$$C_B(G) = \sum_{s,t \in V} \frac{1}{dist(s,t)} \frac{\sigma(s,t|G)}{\sigma(s,t)}$$

where the numerator $(\sigma(s,t|G))$ counts the number of shortest $(s,t) - paths$ containing any vertex of G as an inner vertex.

In our case, paths are restricted to the set π and not limited to shortest paths, so group betweeness can be written in a more general weighted form:

$$C_B(G) = \sum_{p \in \pi} \frac{\gamma_p}{|p|} \chi_p(G) \quad \text{where } \chi_p(G) = \begin{cases} 1 \text{ if p contains any vertex of G} \\ 0 \qquad\qquad \text{otherwise} \end{cases}$$

This formulation reflects the social consideration that connections of the group to other members are counted once. This is in our case not true, as each member (access point) contributes to the group by its own connection (represented by C_i in our model) even to the same client.

We can hence extend the group betweeness definition by redefining:

$$\chi_p(G) = \sum_{i \in G} C_i * \chi_p(i) \quad \text{with } \chi_p(i) = \begin{cases} 1 \text{ if i belongs to p} \\ 0 \quad \text{otherwise} \end{cases}$$

Finally we obtain : $C_B(AP) = \sum_{p \in \pi} \frac{\gamma_p}{|p|} \sum_{i \in AP} C_i * \chi_p(i)$ which corresponds to $\mathcal{NB}(F)$ confirming hence Theorem 2.

The next theorem will allow us to shift toward individual betweeness to avoid the complexity of group betweeness algorithms which are difficult to scale [21].

Theorem 3. *The optimal set of* p *positions that maximizes* $\mathcal{NB}(F)$ *is the set of* p *positions with the highest betweeness centralities.*

Proof. Coming back to equation (4) and considering the maximum:

$$\begin{aligned} \max_{AP \subset S_{AP}} (\mathcal{NB}(F)) &= \frac{1}{\gamma_{total}} . \max_{AP \subset S_{AP}} (\sum_{p \in \pi} \{ \sum_{i \in AP} \frac{\gamma_p}{|p|} * \mathcal{C}_i * \chi_p(i) \}) \\ &= \frac{1}{\gamma_{total}} . \max_{AP \subset S_{AP}} (\sum_{i \in AP} \{ \sum_{p \in \pi} \frac{\gamma_p}{|p|} * \mathcal{C}_i * \chi_p(i) \}) \quad \text{commutative property} \\ &= \frac{1}{\gamma_{total}} . \sum_{k=0..\mathsf{p}} \max_{i_k \in S_{AP}} (\sum_{p \in \pi} \frac{\gamma_p}{|p|} * \mathcal{C}_{i_k} * \chi_p(i_k)) \quad \text{independance of the max operands} \end{aligned}$$

Fortunately, $\sum_{p \in \pi} \frac{\gamma_p}{|p|} * \mathcal{C}_{i_k} * \chi_p(i_k)$ corresponds to the weighted beetweeness of the node i_k in the graph π. So we can formalize as:

$$\max_{AP \subset S_{AP}} (\mathcal{NB}(F)) = \frac{1}{\gamma_{total}} . \sum_{k=0..\mathsf{p}} \max_{i_k \in S_{AP}} \{ \mathcal{CB}_\pi(i_k) \}$$

$\mathcal{CB}_\pi(i_k)$ being the centrality betweeness of node i_k regarding the graph π.

Hence, the optimal solution (which maximizes $\mathcal{NB}(F)$) corresponds to the positions with the highest betweeness centralities.

3.2 Fairness (Maximizing the Minimal)

In this section we consider the fairness side of the problem: given a set of candidate access-point positions, we are looking for the optimal set of p positions that maximizes the minimal achievable data transmission among all trips (paths) of the considered network:

$$\max_{AP \subset S_{AP}} (\min_{p \in \pi} \mathcal{NB}(p, AP))$$

Assuming D is the distance matrix $d_{ij} := [d(ap_i, p_j)]$ which associates to each access point ap_i its distance to the path p_j defined as:

$$d(ap_i, p_j) := \mathcal{NB}(p_j, ap_i) = \frac{1}{|p_j|} * C_i * \chi_{p_j}(ap_i)$$

Definition 3. *We define and consider the following objective function:*

$$\begin{aligned} center(AP) := \min_{p_j \in \pi} \mathcal{NB}(p_j, AP) &= \min_{p_j \in \pi} \sum_{i \in AP} \frac{1}{|p_j|} * C_i * \chi_{p_j}(i) \\ &= \min_{p_j \in \pi} \sum_{i \in AP} d(ap_i, p_j) \\ &= \min_{j=1,..,m} \sum_{i=1}^{n} d_{ij} * x_i \end{aligned} \tag{5}$$

n being the number of candidate access-point positions, m the number of paths to be covered and x_i the decision variable whether access point i is selected or not. Our deployment problem can be hence formulated as:

$$\max_{AP \in S_{AP}} center(AP) \qquad \text{subject to:} \begin{cases} 1. & \sum_{i=1}^{n} x_i \leq \mathsf{p} \\ 2. & x_i \in \{0,1\}\, i = 1..n \end{cases}$$

This category of problems is known in the literature as the *'p-center localization problem'* [3] which aims in its dual form to minimize the maximal distance of a set of p service points to a set of demand points. The only difference lies in the definition of the distance metric (The sum of all distances in our case, while it is aggregated to the minimal distance in the p-center problem).

The p-center problem being classified in the NP-Hard category [22], we use the p-center heuristic proposed in [23] as a basis to determine locally optimal positions. The two-stage heuristic (Algo.1) is adapted to take into account the above mentioned difference (the definition of the distance between a client and a set of service points and the corresponding objective function).

The first stage uses a greedy approach that looks for the 1-center solution in each iteration and updates iteratively the resulting objective function. The distance matrix is updated in such a way that each column represents the 'distance' of each path to the so far chosen access point group. The obtained set is then used in the substitution stage as a starter pack.

Algorithm 1. P-center adapted Heuristic

Greedy phase : 1-Center

1: Pick the access point ap^* that maximizes the objective function: $Center(ap^*) = max_{ap_i \in S_{AP}} Center(ap_i)$ (the column that has the largest minimum)
2: Modify the distance matrix by setting $d(ap_i, p_j) = d(ap_i, p_j) + d(ap^*, p_j) \quad \forall i, j$
3: Repeat until obtaining an initial set of p points.

Substitution Phase

4: Let p_{min} be the least served path.
5: Pick the, not yet selected, access point ap^+ which improves at most p_{min}.
6: Look for an access point ap^- to be replaced, such that the objective function get not decreased $Center(AP \cup\ ap^+\ \setminus\ ap^-) \geq center(AP)$.
7: If none found goto 5 Else replace ap^- with ap^+ and Goto 4

The second stage, tries to improve the performance for the less served routes (paths) by exchanging access points, one-by-one, until no movement of single access-points can improve the objective function.

The two-stage heuristic provides a locally optimal solution. Better results can be surely achieved using globally optimal solutions built on different exhaustive p-center heuristics and algorithms [23,24].

4 Performance Evaluation

4.1 Access-Points Throughput Estimation

To evaluate the performance of the proposed deployment schemes, we estimated in a first stage the effective throughput $\mathcal{TH}(i, v)$ offered to a vehicle v with a constant speed v_i in the range of an Access point (i) under constant density conditions. According to theorem 1, this value depends only on the vehicular density within the communication zone.

Simulation scenarios consist of an access point placed on the side of a rectilinear road. Vehicles have been injected on each trip with a fixed inter-arrival rate ranging from $2s$ to $200s$ and a fixed average speed ranging from 2.5 to $15m/s$. A CBR traffic transmitting 1250 Byte packets at a $10Mb/s$ rate has been configured on each vehicle (to ensure a maximum load). The simulator OMNET++ was configured to use the 802.11b protocol with a communication range of about $300m$ (802.11b was employed with the idea of using the widely deployed and freely accessibles Wifi Access-Points. The simulation can be, however, straightforward extended to dedicated norms for VANETs namely the 802.11p).

In Figure 1, we show the average successfully transmitted data per vehicle for different speeds ($10..15m/s$) and different inter-arrival times. The number of packets successfully received by the AP reaches its maximum for an inter-arrival-rate of about $60s$ which corresponds to a communication with no concurrent vehicles ($60s * 10m/s = 600m$ inter-distance).

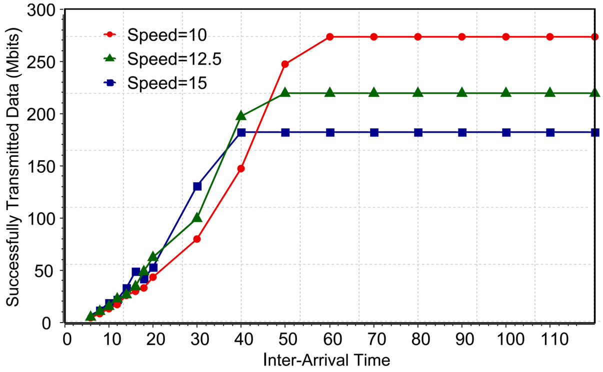

Fig. 1. Successfully Transmitted Data per Vehicle According to Inter-Arrival

The left part of the figure shows the negative impact of a high arrival rate (vehicular density) on the transmission, confirming our evaluation of deployment strategies made in paragraph 2. The speed has no direct impact on the quality of transmission but only on the duration of communication phase, which explains the constant gap between the three scenarios in the latter phase ($> 60s$).

4.2 Effective Throughput

To evaluate the proposed deployment strategies, we simulated a vehicular traffic over a $35km$ x $40km$ road-network using the SUMO simulator. Microscopic models implemented by SUMO are Krauss' car-following model [25] and Krajzewiczs lane-changing model [26] which faithfully mimic realistic driver's behavior. The macroscopic model is based on an O/D matrix [origin to destination paradigm], forming a set of about 90, randomly chosen, paths (denoted as π).

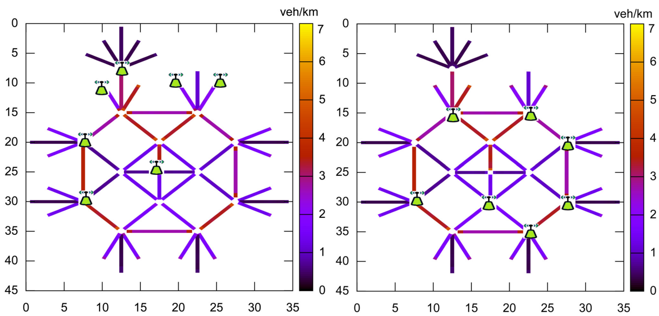

Fig. 2. Access Point Deployment Strategies (Global (left) Vs Fairness (right))

Vehicles have been injected with an average arrival rate of 1 vehicle each $200s$ on each path. Figure 2 illustrates the network topology, chosen to highlight the centrality of nodes as a key factor of our deployment strategy. Vehicular density varies up to $7veh/km$. At intersections, higher densities are obviously recorded.

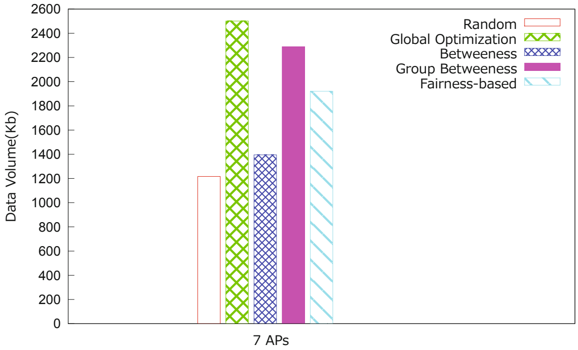

Fig. 3. Average Sent Data per Vehicle per km

Figure 3 evaluates the global approach by comparing the average amount of data successfully sent per vehicle per km according to five different deployment approaches: our approaches, denoted as *"Global"* and *"Fairness-based"* in addition to a betweeness, group-betweeness and a random based repartitions.

The 'global' approach presented in section 3.1 aiming to maximize $\mathcal{NB}(\mathcal{F})$ (the average data volume successfully sent per vehicle per km), achieves the best average value ie of $2,5Mb/km$ per vehicle. As stated in theorem 2 and 3 the 'global' deployment schema corresponds to a fine-parameterized form of the betweeness and group-betweeness centrality, which well explains the relative good performance achieved by these deployment approaches.

Fairness, being the second objective of our work, we evaluated and compared the fairness degree of the proposed deployment strategies reflected through the Jain's Fairness Index [27]. The Jain's Fairness Index of a data exchange vector $\mathcal{NB} = (\mathcal{NB}(p_1), ..., \mathcal{NB}(p_n))$ is given by:

$$\frac{(\sum_{i=1}^{n} \mathcal{NB}(p_i))^2}{n * \sum_{i=1}^{n} \mathcal{NB}(p_i)^2}$$

Intuitively, the Jain's Fairness Index of a data exchange vector is 1 if it is perfectly fair (i.e., vehicles realizes the same performances among all trips), and is 1/n if it is completely unfair (i.e., only one trips is covered all others are not).

Figure 4 shows that the fairness-based deployment outperforms indeed all other schemes and realizes a good performance by reaching an index of about 75% followed as expected by the group-betweeness approach, which favors as explained in 3.1 a collective behavior towards clients.

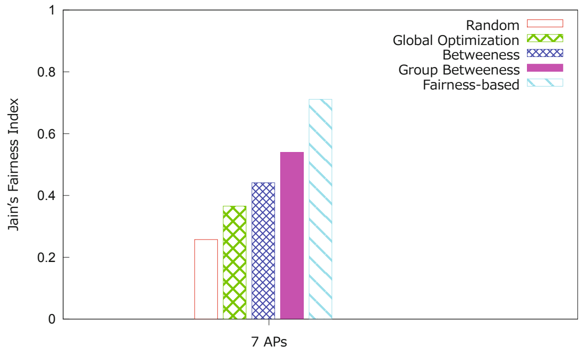

Fig. 4. Fairness Assessment for Deployment Strategies

5 Conclusion

In this article, we made a thorough review of classical coverage approaches and showed that these cannot be effective without taking into account the contention problem and without differentiating between download and upload directions.

Combining routes topology with both data and vehicle traffic, we proposed a consistent model and an accurate estimation of the average sent data among considered trips. Two objectives have been considered: maximizing the average successfully sent data and maximizing the minimal successfully sent data among different trips as a matter of fairness.

The analysis conducted us in the first case to a sophisticated form of betweeness centrality and in the second case to a complex form of the *p-center* problem. This led us to develop two deployment schemes, which demonstrated significant performance improvements in term of fairness and efficiency.

The simulation was performed using realistic mobility models and one of the most reliable simulators(SUMO). This should allow a straightforward application of our approaches on real maps and using even more realistic mobility traces.

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