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The Deployment of Multiple Infrastructures in Vehicular Networks

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Abstract

Deploying roadside access points (APs) or infrastructures can improve data delivery. However, a solution that tries to cover every point in an entire road network with APs (a full coverage) is not very practical due to prohibitive deployment and operational costs. In this paper, we used a new Infrastructure, i.e., WiFi to Mesh (W2M), which used to improve the performance of vehicular internet. Through analyze the heterogeneity of function between AP and W2M, including coverage area, we propose an infrastructures deployment strategy for Vehicular Internet which is supported by a variety of infrastructures. In particular, we used a new metric, called Contact Opportunity, such a metric is closely related to the quality of data service that a mobile user might experience while driving through the system. We then present an efficient deployment method of APs and W2Ms that maximizes the worst case contact opportunity with the minimum cost. The problem of finding an economic deployment of APs and W2Ms that is depends on the quality of service (QoS) turns out to be NP-hard. The efficiency of our strategy is demonstrated via simulations using data from real-world road networks.

Keywords: *AP; W2M; Vehicular Network; QoS; minimum cost*

1. Introduction

Wireless vehicular networks have recently received increasing attention and a wide spectrum of existing applications have been envisioned, such as driving safety [1] and content sharing [2]. Two vehicles can communicate with each other when their distance is smaller than the communication range. Recent study shows that the duration time for a moving vehicle encountering a fixed point can be as short as 10 seconds on average [3]. Vehicles are moving fast, this makes the network topology dynamic and changing quickly over time. It is often difficult to find a connected path between any pair of vehicles in a vehicular network.

Mobile networks incur higher delays and more frequent disconnections than tethered networks. While a complete and robust infrastructure is necessary to support applications most sensitive to delay, such as VOIP, many applications from environmental monitoring [4] to software updates, email, and instant messaging can tolerate longer delays and intermittent connectivity. However, the lower the delay, the greater the number of applications the network can support.

An infrastructure of roadside units or access points (APs) has become ubiquitously available in urban areas [5, 6]. Roadside APs can communicate with passing vehicles, store and forward data packets. Roadside APs are usually connected via a wired network (*e.g.*, Internet). It has been widely accepted that such an infrastructure can improve data delivery in vehicular networks.

Although large deployments of WLANs can be used to provide high data-rate services over large areas, the cost becomes prohibitive due to the sheer number of access points (APs)

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required, the cost becomes prohibitive due to the sheer number of access points (APs) required [7]. For instance, to cover a 2km x 2km area in Mountain View, Google needed to deploy 400 access points [8] to barely provide coverage at the base data rate. Installing wired base stations connected to the Internet can lower delays; but they require costly installation of power and wired network connectivity—these costs can be as high as US$5,000 per base station [9]. In addition to the deployment cost, the maintenance and management complexity has led to abandonment or scaling back of several WLAN projects from San Francisco to Philadelphia [10]. While a complete and robust infrastructure is necessary to support applications most sensitive to delay.

To resolve these questions, in [9], with the purpose of improve the performance of wireless vehicular networks, it introduced a new Infrastructure-Assisted, *i.e.*, W2M, which combined with Mesh and WiFi communication technology. The device not only takes the advantage of Short-range, high-bandwidth technology of WiFi, but also accesses the long-range, low-bitrate radios technology of Mesh. The buses communicate with each other over TCP connections using WiFi radios. When a bus comes within WiFi range, the two exchange data over a TCP connection until the contact with W2M ends. The relay node stores those packets, waits for another transit bus, and then exchanges packets with that bus, propagating packets from mobile node to mobile node (see Figure 1). This WiFi to mesh infrastructure cost less than $ 100, in addition, we have built these nodes from the same solar-powered boxes as the relays. This saves the cost of connecting the access points to the Internet, but requires a minimum density to maintain a connected topology.

In this paper, we will find solutions to these problems which aim to obtain good results on the theoretical analysis fully integrated with theoretical analysis, algorithms, experimental verification, and other technical means. At the same time, the paper makes a meaningful exploration for research of vehicle networks and performance optimization in the heterogeneous network.

Our main contribution in this work is to find an economic deployment method of APs and W2Ms that maximizes the worst case contact opportunity with the minimum cost.

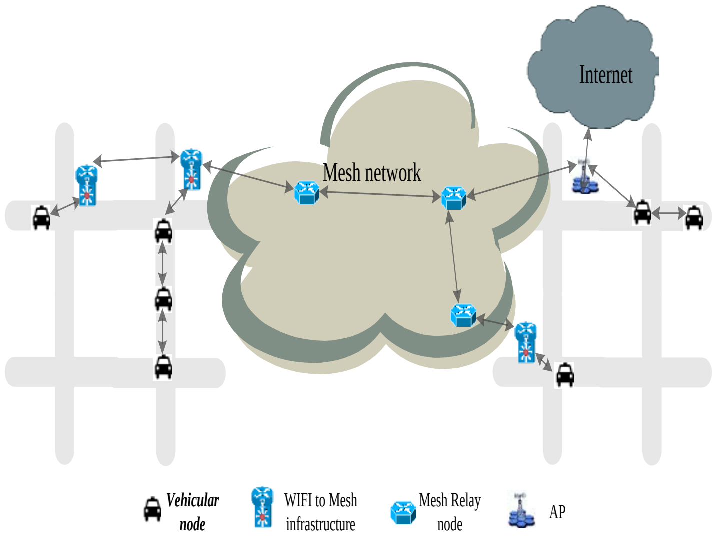

Figure 1. The Network Structure of VANET base on Various Types of Infrastructures

The rest of the paper is organized as follows. The next section reviews related work. In Section III, problem describes and analyzes. Evaluation results are presented in Section IV. The paper concludes in Section V.

2. Related Work

The deployment method of infrastructures is important to vehicular networks and a good deployment strategy which provides guarantee on transmission performance of network can reduce overhead. Nowadays, some researches about the deployment of WSN network nodes, such as sink nodes, base stations deployment, have been more mature. These studies that relate to the deployment strategy of sink nodes in WSN network were carried out for the static network scenarios. The sensor nodes will no longer move after randomly deployed. Meanwhile, network topology is unchanged.

Our problem can also be viewed as a coverage problem over geometric graphs. Coverage problems have been intensively studied with applications in various fields, including VLSI design [11] and the deployment of sensor networks [12, 13] and cellular networks. In [11], PTAS algorithms are provided to the problem of covering points by disks or squares and the dual problem of packing squares with applications in VLSI design and image processing. In [12], various coverage models in sensor networks have been studied, including a set of crossing paths, a set of discrete points, and covering a connected region in a belt region. Partial coverage of a 2-D region with statistical [14] or deterministic [13] guarantees have also been studied.

However, the study about multiple infrastructures deployment in a dynamic network environment, such as vehicle network, is still in its infancy. It has observed in [7] that put the contact opportunity as a quality of service of roadside WiFi network, which was used to measure the performance of a APs deployment. Informally, the contact opportunity for a given deployment measures the fraction of distance or time that a mobile user is in contact with some AP when moving through a certain path. It is a pity that it did not give a multiple infrastructures deployment strategy in a heterogeneous network.

In [15], put the access probability as the important index for service coverage performance. Actually, the stand or fall of network infrastructure deployment is directly related to the overall network performance and cost. For this reason, in [16], after formulated the coexisting problem of packet forwarding and buffer allocation as an optimization problem and show that it is a knapsack problem, they put the APs deployment as a next work.

With the purpose of improve the performance of wireless vehicular networks, it has been observed in [9] that adding the W2M infrastructure and Mesh Relay node in wireless vehicular networks will improve the network performance and reduce the cost. It is a pity that it did not give the infrastructure deployment scheme.

In summary, a few of existing studies have considered the multiple infrastructures deployment in a dynamic network environment with the minimum cost. The research that finding a minimum cost deployment of APs and W2Ms that is depends on the quality of service (QoS) of Vehicular Internet which is supported by a variety of infrastructures is still in its infancy. In this work, combining with the research achievements of literature [7] and [9], We then present an efficient deployment method of APs and W2Ms that maximizes the worst case contact opportunity with the minimum cost.

3. Problem Description and Analysis

In general, we would like to have an economic deployment of APs and W2Ms that is able to serve mobile users moving through a road network with guaranteed performance in terms of some intuitive metric such as contact opportunity. To this end, we used a performance metric that is closely related to average throughput for roadside APs and W2Ms deployment. We will find an efficient deployment method of APs and W2Ms that maximizes the worst case contact opportunity with the minimum cost

3.1. System Model

The road network will model as a connected geometric graph, where the points that road centerline segments and road intersections meet regard as vertices and edges represent road centerline segments that connecting road intersections. For a curved road segment, we introduce artificial road intersections at corners, so that each edge represents a straight line segment. Without loss of generality, the road network graph is assumed to be undirected.

We assume that A is a set of known candidate locations in the 2D region covering the road network where APs or W2Ms can be deployed. Associated with each candidate location $a\in A$, there is a fixed cost $w_a^A\in R^+$ for installing an AP at a, and a fixed cost $w_a^w\in R^+$ for installing a W2M at a. The coverage region of AP and W2M respectively are C_a^A, C_a^w. If existing a candidate location $b\in A$ that only suitable for installing W2M, then, $w_b^w=+\infty$, otherwise, $w_b^A=+\infty$.Because of equipment cost and the way of power supply, the communication ability of AP is stronger than W2M, *i.e.*, $C_a^A\supseteq C_a^w$. The coverage regions C_a^A, C_a^w, for each $a\in A$, partition the road network graph into smaller segments called sub-segments. Figure 2 shows a road network with two roads (lines) and two candidate locations with coverage regions shown as disks that partition the roads into sub-segments such as *ab*, *bc*, *cd*, *de*, *ef*, *gh*, *gi*, *etc*. Sub-segments such as *ab* can be concluded from the Figure 2. It will be completely covered or not completely covered.

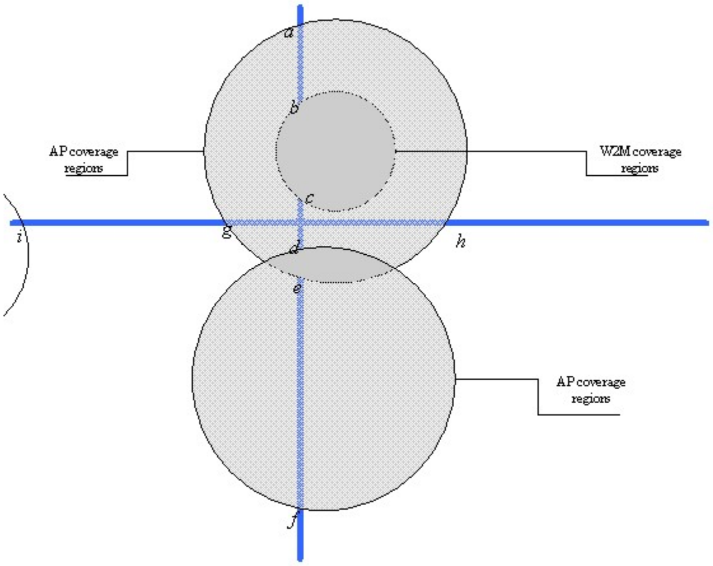

Figure 2. A Road Network with Two Roads and Three Candidate Locations with Coverage Regions Shown as Disks that Partition the Roads into Sub-segments such as ab, bc, cd, de, ef, gh, gi, etc

Let L denote the set of all the sub-segments in a road network graph. For each $l\in L$, $d(l) \in R^+$ denote the length of the corresponding road centerline segment. For any deployment consists of two parts:1) the deployment of APs, $S_A\subseteq A$;2) the deployment of W2Ms, $S_w\subseteq A$.

Let $L_c\subseteq L$ denote the set of sub-segments covered by S_A, S_w, that is, $L_c(S_A, S_w)=\{l\in L | l\in(\cup_{a\in SA} C_a^A)\cup(\cup_{b\in Sw} C_b^w)\}$. Let D denote the set of feasible deployment, $D=\{d_1^A, d_2^A, d_3^A\ldots d_n^A, d_1^w, d_2^w, d_3^w\ldots d_n^w\}$,with each element $d_i^A \in D$, means it is approved to installing an AP at a_i, $a_i \in A$, means it is $d_i^w \in D$ approved to installing an W2M at , $a_i\in A$, This can be concluded that $|D|=2|A|$. Associated with each element $a\in D$, there is a set of sub-segments, $C_a\subseteq L$, covered by AP or W2M and a fixed cost $w_a\in R^+$, so that, a subset of D, $M \subseteq D$, the set of sub-segments covered by M can be expressed as $L_c(M)=\{l\in L | l\in \cup_{a\in M} C_a\}$.

Table 1. Symbols Used in the System Model

A	The set of all candidate locations for deploying APs or W2M
D	The set of feasible deployment
w_a^A	The cost of installing an AP at location $a \in A$
w_a^w	The cost of installing an W2M at location $a \in A$
C_a^A	The coverage region of an AP deployed at $a \in A$
C_a^w	The coverage region of an W2M deployed at $a \in A$
L	The set of sub-segments
$d(l)$	The length of a sub-segment $l \in L$
$L_c(M)$	The set of sub-segments covered by $M\subseteq D$
P	The set of movements
L_p	The set of sub-segments constituting $p \in P$

We model a movement on a road network as a simple path on the connected geometric graph. We assume that there is a set of movements, denoted as P, P could be a set of shortest (or fastest) paths or a set of most frequently traveled paths. The P is given as part of the input to the deployment decision maker. The concrete definition of P is independent of our problem definitions and solutions, while the size of the set P impacts the computational complexity and performance guarantee of our solutions. For instance, such information can be learned from a road network database and historical traffic data. For each $p\in P$, let $L_p\subseteq L$ denote the set of sub-segments that constitute p.

3.2. Problem Statement

We now introduce a performance metric for roadside deployment that does not require any information about the dynamics of the system and was defined in [7]. Given a deployment $M \subseteq D$, the Contact Opportunity in Distance of a path $p\in P$, denoted as η_p^d, is defined as the fraction of distance on p that is covered by some AP or W2M in M ,Formally,

$$\eta_p^d(M) = \frac{\sum_{l\in L_p \cap L_c} d(l)}{\sum_{l\in L_p} d(l)}. \tag{1}$$

Given a budget B, we are looking for a deployment where the total deployment cost of the APs and W2Ms does not exceed the budget, and the minimum contact opportunity over all movements in P is maximized. Such a deployment provides a worst case guarantee. Formally, if we let $w(M)$ denote the cost of a deployment $M \subseteq D$, that is $w(M)=\sum_{a\in M} w_a$, the optimization problem becomes

$$\max_{M\subseteq D} \min_{p\subseteq P} \eta_p^d(M), \text{ subject to } w(M) \le B. \tag{2}$$

3.3. Approximation via Sub-modular Set Cover

In this section, we first show that problem (2) is an instance of a budgeted version of the sub-modular set covering problem first studied in [17] and recently extensively explored in [18] and hence allows an efficient bicriterion approximation [18].

To show that (2) can be reduced to the budgeted sub-modular set covering problem, we note that the set function η_p^d: $2^D \rightarrow [0,1]$ satisfies the following properties: (1) nondecreasing, i.e., $\eta_p^d(T_1) \le \eta_p^d(T_2) \le \eta_p^d(D)$ whenever $T_1 \subseteq T_2 \subseteq D$, (2) normalized, i.e., $\eta_p^d(\phi)=0$, and (3) sub-modular, i.e., for all $T_1 \subseteq T_2 \subseteq D$ and $a \in D/T_2$, $\eta_p^d(T_1 \cup \{a\}) - \eta_p^d(T_1) \ge \eta_p^d(T_2 \cup \{a\}) - \eta_p^d(T_2)$.

Lemma 1. η_p^d is sub-modular.

Proof: For any $T_1 \subseteq T_2 \subseteq D$, $a \in D/T_2$, according to the formula of (1), there is

$$\eta_p^d(T_1+\{a\}) - \eta_p^d(T_1) = \frac{\sum\limits_{l\in L_p \cap (C_a \backslash L_c(T_1))} d(l)}{\sum\limits_{l\in L_p} d(l)} \tag{3}$$

In the same way:

$$\eta_p^d(T_2+\{a\}) - \eta_p^d(T_2) = \frac{\sum\limits_{l\in L_p \cap (C_a \backslash L_c(T_2))} d(l)}{\sum\limits_{l\in L_p} d(l)} \tag{4}$$

Since $T_1 \subseteq T_2$, $C_a/L_C(T_1) \supseteq C_a/L_C(T_2)$.
Therefore,

$$\eta_p^d(T_1 \cup \{a\}) - \eta_p^d(T_1) \ge \eta_p^d(T_2 \cup \{a\}) - \eta_p^d(T_2) \tag{5}$$

It follows that (2) is an instance of the budgeted sub-modular set covering problem, which does not have a polynomial time approximation algorithm unless P=NP as shown in [18] using a reduction from the hitting set problem. Fortunately, an efficient approximation can be achieved by relaxing both the requirement on the objective function and that on the budget. The first step of the solution framework proposed in [18] requires solving the following variant of the problem, which is interesting by itself: given a required minimum contact opportunity $Q \in [0, 1]$ over all the movements, find a deployment of minimum cost. Formally,

$$\min_{M\subseteq D} w(M), \text{ subject to } \min_{p\in P} \eta_p^d(M) \ge Q. \tag{6}$$

A binary search of $Q \in [0, 1]$ is then applied. For each Q, an instance of (6) is solved until a close to optimal solution to (2) is found. Although the budgeted version (2) is hard to approximate, the sub-problem (6) allows an efficient approximation since it can be reduced to the sub-modular set covering problem as follows [7]. Given Q, define:

$$\eta^d(M) = \sum_{p\in P} \min\{\eta_p^d(M), Q\}. \tag{7}$$

We note that η^d is also a sub-modular function since (a) $\min\{\eta_p^d(M), Q\}$ as a set function on D is sub-modular when η_p^d is sub-modular [19] and (b) the sum of sub-modular functions is sub-modular. Note that a subset $M \subseteq D$ is a feasible solution to (6) iff $\eta^d(M) = \eta^d(D) = |P|Q$. Therefore, (6) can be reformulated as a sub-modular set covering problem [19]:

$$\min_{M \subseteq D} w(M)\text{, subject to } \eta^d(M) = \eta^d(D)\,. \tag{8}$$

Due to the η^d is sub-modular, (8) allows an efficient greedy approximation. See Algorithm 1(Figure 3). The P, D and the required contact opportunity Q are given as part of the input to the deployment decision maker. The algorithm starts with an empty set and in each iteration it picks and adds a new feasible deployment from D that is most cost effective until the required contact opportunity is achieved. This simple greedy procedure outputs a subset $M \subseteq D$, the cost of which never exceeds the cost of the optimal solution by more than a logarithmic factor [17]. In particular, by multiplying all η_p^d by 10^n for some n>2, η^d can be made an integer valued function without loss of much accuracy, then an approximation factor $\mu = O(1) + \ln(\max_{a \in D} \eta^d(a))$ can be achieved [7].

```
Algorithm 1 Minimum Cost Contact Opportunity
Input: D,P,Q
Output: D subset $M \subseteq D$
  1: M ← $\phi$;
  2: while $\eta^d(M) < \eta^d(D)$ do
  3:   Find $a \in D \setminus M$ that maximizes
           $\frac{\eta^d(M \cup \{a\}) - \eta^d(M)}{w_a}$;
  4:   $M \leftarrow M \cup \{a\}$;
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Figure 3. Minimum Cost Contact Opportunity

A binary search of $Q \in [0, 1]$ is then applied to solve (2).Let $B(Q)$ denote the total cost of a deployment that achieves Q computed by Algorithm 1. Staring at $Q = \min_{p \in P} \eta_p^d(D)$,that is the minimum contact opportunity when all the candidate locations are used, if $B(Q) > B$, a lower Q is selected. Otherwise, a higher Q is selected. The procedure continues until $B(Q_1) \leq B$ and $B(Q_2) > B$ for any Q_2: $Q_2 - Q_1 \geq \delta$, where δ can be adjusted to control the accuracy[7].

Given a budget B, such a binary search finds a subset $M \subseteq D$ that does not exceed the budget and has the minimum contact opportunity to be at least what an optimal solution with budget B/μ can achieve, that is,

$$\min_{p \in P} \eta_p^d(M) \geq \max_{T \subseteq D, w(T) \leq B/\mu} \min_{p \in P} \eta_p^d(T). \tag{9}$$

4. Evaluation

To study the performance of our approach, the road network of Hohhot was used in simulations. One performance metrics is considered, i.e., contact opportunity. As a result of the movements of buses has more social regularity and representative. The real vehicular traces from around 90 buses in Hohhot, China are used for simulations. To understand its performance, including the minimum cost under various contact opportunity, we will have a set of experiments that compare the preferment gap between merely deployment APs and deployment APs and W2Ms.

4.1. Simulation Settings

Figure 4 shows the road network used in simulations, where we only consider the largest connected component of the corresponding graph, which has 1229 road intersections and each of them is assumed to be a candidate location for deploying APs or W2Ms.

Figure 4. A Road Network Spanning a 16.7 km2 Region used in Simulations

To facilitate comparative study, we consider several infrastructure-assisted deployment types, *i.e.*, merely deployment APs (APs) and deployment APs, W2Ms (APs-W2Ms). The differences in minimum cost with different contact opportunities according to APs-W2Ms and APs will be measured and analyzed. In addition, the deployment algorithm will use our solution (opp).

- APs: covers the path in an entire road network only with APs, each candidate location $a \in D$.
- APs-W2Ms: covers the path in an entire road network with APs and W2Ms, each candidate location $a \in D$.

For compare the minimum contact opportunity in different deployment solutions, we consider several alternative algorithms. Then we will have a study about the differences in contact opportunity according to our solution (opp) and the other two deployment algorithms.

- Uniform Random Sampling (Rand for short): at each step randomly picks a new element from D as long as the total cost of the selected elements dose not exceeds the budget.
- Max-Min Distance Sampling (Dist for short):starts at a randomly selected location in D, and at each step finds a new element from D that maximizes the minimum graph distance (in terms of shortest paths) from the elements already selected, as long as the total cost of the selected elements does not exceed the budget.

4.2. Simulation Results

Figure 5 shows the minimum cost with different contact opportunities according to APs and APs-W2Ms in the vehicle network. With the growth of contact opportunity, both the minimum cost of APs and APs-W2Ms are rise. But the minimum cost of deployment APs and W2Ms is always less than merely deployment APs. As the above Figure shows, when our deployment method was used, the vehicle network produced a lower level of cost. This prove that add W2M infrastructure-assisted in vehicle network not only can improve the performance of service but also reduce the budget.

Figure 6 shows the gap of deployment cost between merely deployment APs and deployment APs-W2Ms with different contact opportunities. We found that when the contact opportunity is 0.75 or 0.85, the gap of minimum cost is lower than when the contact opportunity is 0.25 or 0.5. This is because, the coverage of W2M is limited, when the required contact opportunity is higher, we can only choose the AP to decorate, but when the required contact opportunity is lower, we can use some W2Ms to replace APs in Vehicular network then the cost can be reduced.

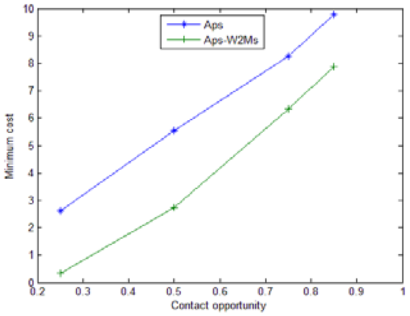

Figure 5. The Minimum Cost of APs and APs-W2Ms with Different Contact Opportunities

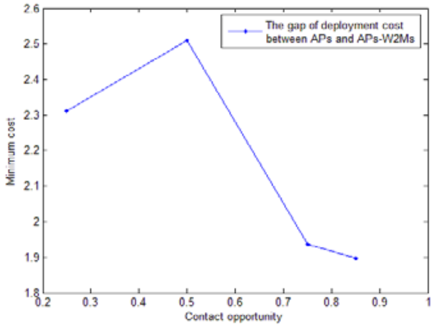

Figure 6. The Gap of Deployment Cost between APs and APs-W2Ms

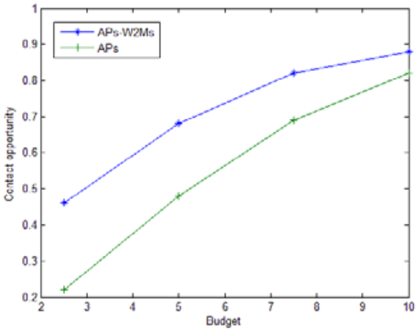

Figure 7. The Minimum Contact Opportunity with the BUdget between APs Deployment and APs-W2Ms Deployment

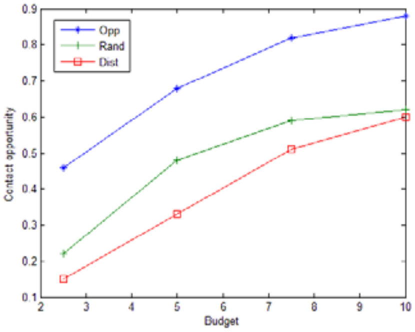

Figure 8. The Minimum Contact Opportunity (CO) Across all the Movements

Figure 7 shows the the minimum contact opportunity with different budget according to APs and APs-W2Ms in the vehicle network. From the graph, with the growth of budget, the opportunity of APs and APs-W2Ms are all improve. We can also conclusion that with the same budget, the minimum contact opportunity of APs-W2Ms is always higher than merely deployment APs. In addition, the gap of contact opportunity between APs and APs-W2Ms will be lower when we have enough cost .Facts prove that the deployment scheme based on a variety of infrastructures has larger advantages on performance compared with merely APs deployment.

Finally, Figure 8 shows the minimum contact opportunity with different budgets according to our solution (opp) and two baseline algorithms in the vehicle network. In this graph, Uniform Random Sampling and Max-Min Distance were used as the deployment solutions in vehicle network. As the graph shows, when our algorithm (opp) was used, with the same budget, the minimum contact opportunity with opp is always higher than other two algorithms. In addition, when the budget is more enough, our algorithm's performs were significantly better than the other two algorithm on minimum contact opportunity, the vehicle network produced a 20% higher level of minimum contact opportunity as compared to the use of Uniform Random Sampling and Max-Min Distance .

Experiments prove that add W2Ms infrastructure in vehicle network can effectively improve the service ability of network and reduce the cost of deployment .our algorithms have largest advantage on performance when a better configuration of AP's and W2M's locations is used. These results show that our algorithms adapt to the deployment of APs and W2Ms that is depends on the quality of service (QoS).

5. Conclusion

In this paper, we used a new Infrastructure, *i.e.*, WiFi to Mesh (W2M), which used to improve the performance of vehicular internet. Through analyze the heterogeneity of function between AP and W2M, including coverage area, we used a new metric, called Contact Opportunity, as a quality of service (QoS) for roadside WiFi network. We have investigated an efficient deployment method of APs and W2Ms that maximizes the worst case contact opportunity with the minimum cost. We demonstrated that the problem to finding a minimum cost deployment of APs and W2Ms that depending on the quality of service (QoS) of Vehicular Internet is NP-hard. The results prove that add W2Ms infrastructure in vehicle network can effectively improve the ability of network service and reduce the cost of deployment.

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