Wireless LAN Access Point Deployment and Pricing with Location-Based Advertising

Cheng Zhang*, Zhi Liu†§, Bo Gu‡§, Kyoko Yamori¶§, and Yoshiaki Tanaka‖§
*Department of Computer Science and Communications Engineering, Waseda University, Tokyo, 169-0072 Japan
†Department of Mathematical and Systems Engineering, Shizuoka University, Shizuoka, 432-8561 Japan
‡Department of Information and Communications Engineering, Kogakuin University, Tokyo, 192-0015 Japan
§Global Information and Telecommunication Institute, Waseda University, Tokyo, 169-8555 Japan
¶Department of Management Information, Asahi University, Mizuho-shi, 501-0296 Japan
‖Department of Communications and Computer Engineering, Waseda University, Tokyo, 169-8555 Japan
Email: cheng.zhang@akane.waseda.jp, liu@shizuoka.ac.jp,
bo.gu@cc.kogakuin.ac.jp, kyamori@alice.asahi-u.ac.jp, ytanaka@waseda.jp

***Abstract*—In order to improve the quality of service (QoS) for mobile users (MUs) and save investment cost for deploying new cellular base station, mobile network operators (MNOs) are deploying wireless local area network (LAN) access points (APs) to offload MU's traffic from cellular network to wireless LAN. However, offloading too much traffic from cellular network may impair MNO's profit since the cellular network price is higher than that of wireless LAN, whose price is low or even zero. Therefore, how to deploy wireless LAN APs to offload traffic without impairing MNO's profit is a critical problem for MNOs. As far as the authors understand, existing studies about deployment of wireless LAN APs do not consider MNO's profit and are usually in a heuristic manner. In this paper, we study the location-based advertising (LBA) leveraged wireless LAN deployment, where MNO may also collect revenue by selling LBA service in different locations to advertisers. We formulate MNO's profit maximization problem by considering different MU's demand in different locations, wireless LAN price for MUs, and revenue from LBA service. Extensive simulations are conducted to validate our analytical results.**

***Index Terms*—wireless LAN, mobile data offloading, profit maximization, location-based advertising**

I. Introduction

The demand for mobile data traffic is increasing quickly. According to the report from Cisco Systems, Inc. [1], monthly global mobile data traffic will be 49 exabytes by 2021, while it was 7.2 exabytes/month at the end of 2016. But, capacity of mobile network is growing much slower than that of demand for mobile traffic from MUs, which is a crucial problem for MNO. New communication technologies such as 5G can help provide larger wireless network capacity [2], but updating existing infrastructure is costly and time-consuming. Microeconomics methods such as time-dependent pricing [3][4] have been proposed to alter MUs' usage pattern, which can shift peak traffic demand to non-peak traffic demand, but these methods are complicated and difficult to be implemented. Another option is deploying complementary network such as wireless LAN to offload MNOs' traffic and increase MNO's network capacity. This option is cheap and wireless LAN APs can be deployed rapidly.

Mobile data offloading is being supported by new industrial standards like the 3GPP Access Network Discovery and Selection Function (ANDSF) standard [5] and Hotspot 2.0 [6], which shows that the wireless LAN technology is integrating with cellular technology. It is expected that wireless LAN technology will take an important part in the 5G systems.

Deploying wireless LAN APs has been an attractive approach to alleviate MNOs' cellular network congestion and reduce MNOs' cost as well. MNOs ought to reap the profit from the huge mobile data demand. However, it is reported that one of the largest Chinese MNO has suffered from profit falls even for huge mobile traffic increase [7]. The reason is that traditional methods to deploy wireless LAN APs in a heuristic manner do not consider MNO's profit. This poses a question: *How to deploy wireless LAN APs to maximize MNO's profit?* Deploying more wireless LAN APs can reduce MNO's cost and offload more traffic from cellular network to wireless LAN APs. But, the offloaded traffic may generate less or no revenue for the MNO, which results in profit (note that profit = revenue - cost) loss for MNO. Existing works on mobile data offloading concentrated either on cost reduction effect of wireless LAN data offloading from MNOs' perspective [8][9], or on maximization of MUs' fulfilment from MUs' perspective [10][11][12] [13], without considering MNO's profit maxmization problem.

There are few works on wireless LAN AP deployment problem. E. Bulut et al. in [14] proposed to deploy wireless LAN AP in places with high data demand and maximize the total offload traffic from cellular network. C.S. Wang et al. in [15] tried to deploy wireless LAN APs for MU to provide high quality ubiquitous communication by considering coverage rate, budget and capacity fulfil rate. Both [14] and [15] failed to consider that offloading traffic from MNO's cellular network may also reduce MNO's revenue. R. Prasad et al. in [16] aimed at finding a set of optimal gateways deployment in a cellular wireless LAN environment to minimize network installation cost. T. Wang et al. in [17] studied the problem of deploying wireless LAN APs that can provide continuous wireless services for MUs, and two problems were formulated to maximize the continuous MUs' coverage and minimize the

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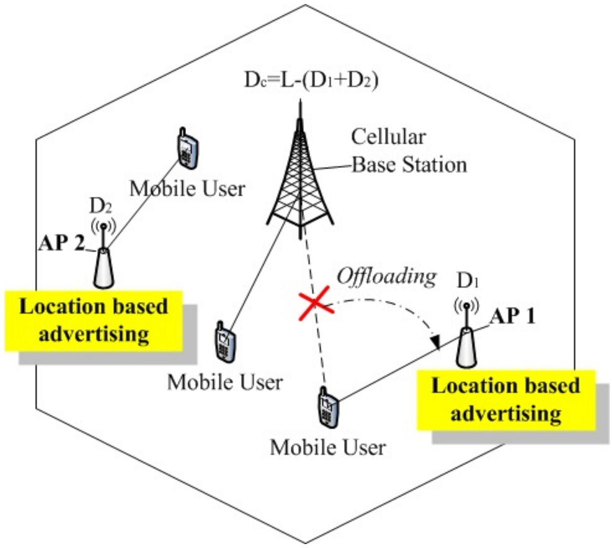

Fig. 1. Illustration of proposed model: In an area, MNO's cellular base station provides wireless service, and there are wireless LAN AP 1 and AP 2 are deployed at location 1 and 2. MNO can deploy location based advertising at location 1 and 2 by wireless LAN AP 1 and AP 2. The corresponding offloaded traffic (or demand for wireless LAN) are D_1, D_2; the demand for cellular network is the difference between the total MUs' expected demand in the area (L) and total amount of traffic that has been offloaded ($D_1 + D_2$), which means that $D_c = L - (D_1 + D_2)$.

wireless LAN APs deployment cost. Both [16] and [17] failed to consider the profit loss problem again. One recent work by K. Poularakis et al. in [7] studied the wireless LAN APs deployment problem to maxmize MNO's profit. Unfortunately, [7] adopted a unrealistic demand function, and the offloaded traffic for wireless LAN AP becomes infinity when wireless LAN AP price approaches to zero, failing to capture the status of the real-world.

On the other hand, location-based advertising (LBA) is a new form of advertising that integrates mobile advertising with location-based services [18]. MNOs know the specific location of their deployed wireless LAN APs. Therefore, it is possible for MNO to provide location-specific advertisements at each wireless LAN AP and collect revenue from advertisers.

In this paper, we study the location-based advertising leveraged wireless LAN AP deployment. We consider both the traffic offloading for MUs and the cost of wireless LAN APs deployment, and adopt LBA for MNO.

The main contributions of this paper are summarized as follows:

Firstly, the impact of wireless LAN APs deployment on the MNO's profit is analyzed, while MNO collects revenue from LBA. We not only consider offloading data for MUs, but also consider the possible revenue loss for MNO from data offloading.

Secondly, an analytical solution has been achieved for the MNO's profit maximization problem and extensive simulations have been conducted to validate our theoretical analysis.

The organization of the rest of the paper is as follows. Section II illustrates the related work. Section III formulates the MNO's profit maximization problem. Section IV presents analytical solution for MNO' profit maximization problem. Section V illustrates the simulation and results. Finally, we conclude this paper in Section VI.

II. System Model

We consider a certain area as shown in Fig. 1. MNO's cellular network covers the whole area with price $p_c > 0$ (yen/GB) and cost h_c (yen/GB). Wireless LAN APs can be deployed in M candidate locations in the area. And the set of locations is denoted as $\mathcal{M} = \{1, 2, ..., M\}$. The are two kinds of cost for wireless LAN APs: (1) the deployment cost g_m (yen/GB), $m \in \mathcal{M}$ and (2) the serving cost h_w (yen/GB). The price of wireless LAN is denoted as $p_w \geq 0$ (yen/GB).

A variable $y_m \in \{0, 1\}$ is defined to show whether a wireless LAN AP is deployed at location $m \in \mathcal{M}$ or not. If $y_m = 1$, a wireless LAN AP is deployed at location m, and if $y_m = 0$, a wireless LAN AP is not deployed at location m. The MNO makes wireless LAN APs deployment decision for all M candidate locations. The following vector $\mathbf{y}$ in Eq. (1) shows MNO's wireless LAN APs deployment decision for all M locations.

$$\mathbf{y} = (y_1, ..., y_M) \tag{1}$$

$\mathcal{M}_y \subseteq \mathcal{M}$ is the subset of locations that have been deployed with wireless LAN APs, which means that $y_m = 1$, $\forall\, y_m \in \mathcal{M}_y$.

The demand for wireless LAN AP m is expressed as follows in Eq. (2)

$$D_m(\mathbf{y}, p_w) = (D_m^0 - \gamma_m p_w) y_m \tag{2}$$

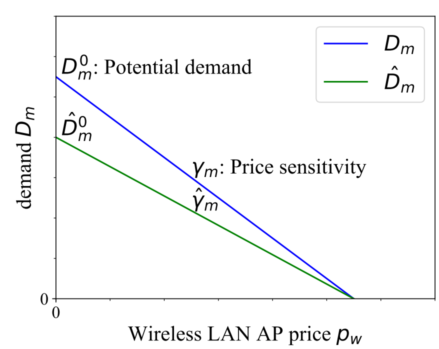

Fig. 2. Wireless LAN AP demand function.

D_m^0 is the potential demand (traffic) MUs would like to offload to wireless LAN AP at place m when the wireless LAN AP price is zero. This parameter reflects the popularity of the location. The more popular the location m is , the larger the D_m^0 is. This parameter can be obtained by analyzing the historical traffic data in the corresponding candidate location. $D_m(\mathbf{y}, p_w)$ is a function that decreases with p_w. γ_m is the price sensitivity of wireless LAN AP demand at place m. Larger γ_m means that the demand decreases faster when wireless LAN AP price increases. Please note

TABLE I
NOTATIONS SUMMARY.

Notation	Description
p_c	cellular network price.
h_c	cellular network cost.
p_w	wireless LAN price.
h_w	wireless LAN cost.
$\mathcal{M}$	set of M candidate locations to deploy wireless LAN APs.
g_m	deployment cost for wireless LAN AP at location m, $m \in \mathcal{M}$.
y_m	$y_m \in \{0, 1\}$, $y_m = 1$ indicates wireless LAN AP is deployed at location m, while $y_m = 0$ indicates wireless LAN AP is not deployed at location m, $m \in \mathcal{M}$.
$\mathbf{y}$	$\mathbf{y} = (y_1, ..., y_M)$
$\mathcal{M}_y$	$\mathcal{M}_y \subseteq \mathcal{M}$ is the subset of locations that have been deployed with wireless LAN APs, which means that $y_m = 1 \ \forall \ y_m \in \mathcal{M}_y$.
D_m^0	the potential demand for wireless LAN AP at location m.
γ_m	the price sensitivity of wireless LAN AP demand at location m.
$D_m(\mathbf{y}, p_w)$	the demand for wireless LAN AP at location m.
D_c	the demand for cellular network.
L	MUs' total expected demand for the area.
α_m	MNO's unit advertisement price at location m.

that when $p_w = 0$, $D_m(\mathbf{y}, 0) = D_m^0$, and when p_w is large enough, $D_m(\mathbf{y}, p_w)$ decreases to zero. This is different from the unrealistic demand model in [7]. L denotes MUs' total expected demand within the area, which can also be obtained from historical traffic analysis. Then, the demand for MNO's cellular network is expressed as follows in Eq. (3).

$$D_c(\mathbf{y}, p_w) = L - \sum_{m \in \mathcal{M}_y} D_m(\mathbf{y}, p_w) \tag{3}$$

It is the difference between MUs' total expected demand and the total offloaded traffic to wireless LAN APs.

MNO provides LBA at each deployed wireless LAN AP since he knows specific location of the wireless LAN AP and corresponding user population. Obviously, different locations have different advertisement value for advertisers. Location with higher demand for wireless LAN AP has much higher advertisement value, and MNO can receive much more revenue from location with higher demand. α_m is denoted as MNO's unit advertisement price at location m, $m \in \mathcal{M}$, for advertisers. MNO's revenue from LBA at location m is denoted as in Eq.(4).

$$\pi_m^a = \alpha_m D_m(\mathbf{y}, p_w) \tag{4}$$

Please note that MNO's revenue from LBA at location m is proportional to the demand for wireless LAN AP m. Here we do not consider the strategic interactions between MNO's advertisement price α_m and demand from advertisers as our previous work [19]. It is assumed that there are many advertisers are interested in LBA of MNO, and advertisers are "price-taker" [20]. Actually, there is a *two-sided market* [21] among MNO, MUs and advertisers. MNO's wireless LAN AP is the platform, and MUs are on one side, while advertisers are on the other side. While the number of MUs on one side is affected by the number of advertisers on the other side through MNO's decision on wireless LAN AP price, the number of advertisers are also dependents on the number of MUs. In this paper, we primarily concentrate on the MNO's deployment decision of wireless LAN APs in different locations for mobile data offloading, while considering a revenue source from advertisers. In future work, we may formulate a two-sided market model, and consider how advertisers' demand for LBA of MNO changes with MNO's advertisement price and the number of MUs in wireless LAN.

III. MNO's Profit Maximization Problem

The MNO's profit is expressed as follows in Eq. (5).

$$\begin{aligned}\Pi(\mathbf{y}, p_w) = &\sum_{m \in \mathcal{M}_y} \Big((p_w - h_w) D_m(\mathbf{y}, p_w) - g_m\Big) \\ &+ \sum_{m \in \mathcal{M}_y} \pi_m^a \\ &+ (p_c - h_c) D_c(\mathbf{y}, p_w)\end{aligned} \tag{5}$$

The first part of MNO's profit is from deployed wireless LAN APs, it is the summation of profit from locations deployed with wireless LAN APs ($\mathcal{M}_y$). The second part of MNO's profit is from LBA. Please note that we assume that the cost for MNO to deploy advertisement is zero, then MNO's profit from advertisement is the summation of revenue from all locations with LBA. The third part of MNO's profit is from cellular network.

The objective of MNO is to maximize its profit by setting optimal wireless LAN APs deployment decision vector $\mathbf{y}$ and the wireless LAN APs' price p_w.

Problem 1: MNO's profit maximization problem is defined as follows in Eq. (6).

$$\max_{\mathbf{y}, p_w} \Pi(\mathbf{y}, p_w) \tag{6}$$

$$s.t. \quad p_w \geq 0 \tag{7}$$

$$y_m \in \{0, 1\}, \forall m \in \mathcal{M} \tag{8}$$

It is assumed that MNO's cellular network price p_c is externally determined, and we do not optimize the cellular network price p_c here. This assumption is reasonable because the cellular network price p_c is determined by the MNO's quality of service (QoS), and also is the result of price competition with other MNOs [3][4]. We also assume MNO's advertisement price α_m is externally determined. However, we will evaluate how MNO's profit changes with different advertisement prices in section V.

IV. Analytical Solution

In this section, an analytical solution for Problem 1 is given, which shows how to set optimal price of wireless LAN AP and how to deploy AP in each candidate location. The following Proposition 1 shows the solution for Problem 1.

Proposition 1: The optimal solution of **Problem 1** can be found in polynomial-time. And the optimal wireless LAN AP price is as follows.

$$p_{\mathrm{w}}^* = \frac{D_m^0}{2\gamma_m} + \frac{1}{2}(h_{\mathrm{w}} + p_{\mathrm{c}} - h_{\mathrm{c}} - \alpha_m) \tag{9}$$

The optimal wireless LAN APs deployment policy $\mathbf{y}^*$ is determined by the following Eq.(10)

$$y_m^* = \begin{cases} 1 & \text{if } \left[\frac{(D_m^0)}{2\sqrt{\gamma_m}} + \frac{\sqrt{\gamma_m}}{2}(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m)\right] \geq \sqrt{g_m} \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

Proof. By substituting Eq.(2), Eq.(3) and Eq.(4) into Eq.(5), we can express MNO's profit as follows.

$$\begin{aligned} \Pi(\mathbf{y}, p_{\mathrm{w}}) &= \sum_{m \in \mathcal{M}_y} \Big((p_{\mathrm{w}} + \alpha_m - h_{\mathrm{w}})(D_m^0 - \gamma_m p_{\mathrm{w}}) - g_m\Big) \\ &+ (p_{\mathrm{c}} - h_{\mathrm{c}})\Big(L - \sum_{m \in \mathcal{M}_y} (D_m^0 - \gamma_m p_{\mathrm{w}})\Big) \\ &= \sum_{m \in \mathcal{M}_y} \Big((p_{\mathrm{w}} + \alpha_m - h_{\mathrm{w}} - p_{\mathrm{c}} + h_{\mathrm{c}})(D_m^0 - \gamma_m p_{\mathrm{w}}) - g_m\Big) \\ &+ (p_{\mathrm{c}} - h_{\mathrm{c}})L \end{aligned} \tag{11}$$

The optimal condition for p_{w} is to let the first order differentiation equal to 0 as follows.

$$\frac{\partial \Pi(\mathbf{y}, p_{\mathrm{w}})}{\partial p_{\mathrm{w}}} = 0 \tag{12}$$

On the other hand, we have

$$\begin{aligned} \frac{\partial \Pi(\mathbf{y}, p_{\mathrm{w}})}{\partial p_{\mathrm{w}}} =& (D_m^0 - \gamma_m p_{\mathrm{w}}) + (p_{\mathrm{w}} + \alpha_m - h_{\mathrm{w}})(-\gamma_m) \\ &+ (p_{\mathrm{c}} - h_{\mathrm{c}})\gamma_m \\ =& D_m^0 - 2\gamma_m p_{\mathrm{w}} - \gamma_m \alpha_m + \gamma_m h_{\mathrm{w}} \\ &+ \gamma_m p_{\mathrm{c}} - \gamma_m h_{\mathrm{c}} \\ =& D_m^0 - 2\gamma_m p_{\mathrm{w}} + \gamma_m (h_{\mathrm{w}} + p_{\mathrm{c}} - h_{\mathrm{c}} - \alpha_m) \end{aligned} \tag{13}$$

Then, the wireless LAN AP price that maxmize MNO's profit is as follows.

$$\begin{aligned} p_{\mathrm{w}}^* &= \frac{D_m^0 + \gamma_m (h_{\mathrm{w}} + p_{\mathrm{c}} - h_{\mathrm{c}} - \alpha_m)}{2\gamma_m} \\ &= \frac{D_m^0}{2\gamma_m} + \frac{1}{2}(h_{\mathrm{w}} + p_{\mathrm{c}} - h_{\mathrm{c}} - \alpha_m) \end{aligned} \tag{14}$$

The MNO' profit can be expressed by subsituting Eq.(14).

$$\begin{aligned} &\Pi(\mathbf{y}, p_{\mathrm{w}}^*) = \\ &\sum_{m \in \mathcal{M}_y} \Big(\Big(\frac{D_m^0}{2\gamma_m} + \frac{1}{2}(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m)\Big)\Big(D_m^0 - \gamma_m p_{\mathrm{w}}\Big) - g_m\Big) \\ &+ (p_{\mathrm{c}} - h_{\mathrm{c}})L \end{aligned} \tag{15}$$

$$\begin{aligned} &= \sum_{m \in \mathcal{M}_y} \Big(\Big(\frac{D_m^0}{2\gamma_m} + \frac{1}{2}(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m)\Big) \\ &\Big(D_m^0 - \gamma_m\Big(\frac{D_m^0}{2\gamma_m} + \frac{1}{2}(h_{\mathrm{w}} - h_{\mathrm{c}} + p_{\mathrm{c}} - \alpha_m)\Big)\Big) - g_m\Big) \\ &+ (p_{\mathrm{c}} - h_{\mathrm{c}})L \end{aligned} \tag{16}$$

$$\begin{aligned} &= \sum_{m \in \mathcal{M}_y} \Big(\frac{D_m^0}{2\gamma_m} + \frac{1}{2}(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m)\Big)\Big(\frac{D_m^0}{2} - \\ &\frac{1}{2}\gamma_m(h_{\mathrm{w}} - h_{\mathrm{c}} + p_{\mathrm{c}} - \alpha_m)\Big) \\ &- \sum_{m \in \mathcal{M}_y} g_m + (p_{\mathrm{c}} - h_{\mathrm{c}})L \end{aligned} \tag{17}$$

$$\begin{aligned} &= \sum_{m \in \mathcal{M}_y} \Big(\frac{(D_m^0)^2}{4\gamma_m} - \frac{D_m^0}{4}(h_{\mathrm{w}} - h_{\mathrm{c}} + p_{\mathrm{c}} - \alpha_m) \\ &+ \frac{D_m^0}{4}(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m) + \frac{1}{4}\gamma_m(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m)^2\Big) \\ &- \sum_{m \in \mathcal{M}_y} g_m + (p_{\mathrm{c}} - h_{\mathrm{c}})L \end{aligned} \tag{18}$$

$$\begin{aligned} &= \sum_{m \in \mathcal{M}_y} \Big(\frac{(D_m^0)^2}{4\gamma_m} + \frac{D_m^0}{2}(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m) \\ &+ \frac{1}{4}\gamma_m(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m)^2\Big) - \sum_{m \in \mathcal{M}_y} g_m + (p_{\mathrm{c}} - h_{\mathrm{c}})L \end{aligned} \tag{19}$$

$$\begin{aligned} &= \sum_{m \in \mathcal{M}_y} \Big[\frac{(D_m^0)}{2\sqrt{\gamma_m}} + \frac{\sqrt{\gamma_m}}{2}(h_{\mathrm{c}} - p_{\mathrm{c}} - h_{\mathrm{w}} - \alpha_m)\Big]^2 \\ &- \sum_{m \in \mathcal{M}_y} g_m + (p_{\mathrm{c}} - h_{\mathrm{c}})L \end{aligned} \tag{20}$$

Therefore, the increase of MNO's profit when deploying a new wireless LAN AP at place m can be expressed as follows in Eq. (21)

$$\Delta\Pi_m = \Big[\frac{(D_m^0)}{2\sqrt{\gamma_m}} + \frac{\sqrt{\gamma_m}}{2}(h_{\mathrm{c}} - p_{\mathrm{c}} - h_{\mathrm{w}} - \alpha_m)\Big]^2 - g_m \tag{21}$$

It is obvious that wireless LAN AP m should be deployed at place m if and only if the following condition is satisfied.

$$\Delta\Pi_m \geq 0 \tag{22}$$

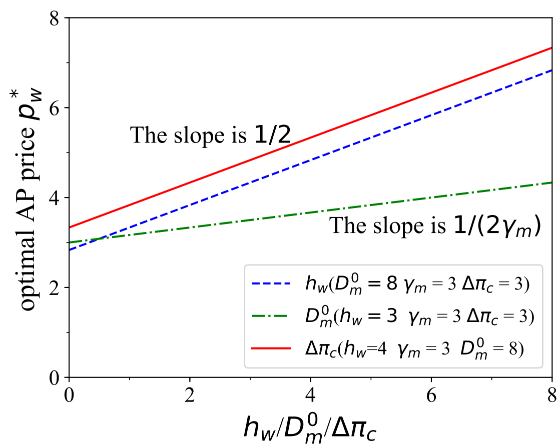

Fig. 3. Optimal prices p_{w}^* changes with different h_{w}, D_m^0, and $\Delta\pi_c$ ($\alpha_m = 0$).

Then we can induce the optimal wireless LAN AP deployment policy y^* will be

$$y_m^* = \begin{cases} 1 & \text{if } \left[\frac{(D_m^0)}{2\sqrt{\gamma_m}} + \frac{\sqrt{\gamma_m}}{2}(h_{\mathrm{c}} - h_{\mathrm{w}} - p_{\mathrm{c}} - \alpha_m)\right] \geq \sqrt{g_m} \\ 0 & \text{otherwise} \end{cases} \tag{23}$$

■

It is shown in Eq.(9) that the optimal wireless LAN price p_{w}^* is driven down by α_m, which is the advertisement price. This means that if MNO collects revenue from LBA, wireless LAN price for MU can be decreased. It is possible that the wireless LAN price is zero if the advertisement price is large enough. In this case, the demand for wireless LAN will be the largest D_m^0, this in turn makes the advertisement in the corresponding location attractive for advertisers.

If we define $\Delta\pi_c = p_c - h_c$ as the MNO's unit profit from cellular network. The optimal wireless LAN AP price in Eq. (9) can be expressed as follows.

$$p_{\mathrm{w}}^* = \frac{D_m^0}{2\gamma_m} + \frac{1}{2}(h_{\mathrm{w}} + \Delta\pi_c - \alpha_m) \tag{24}$$

In Eq.(24), the term $\frac{D_m^0}{2\gamma_m}$ is determined by the demand from mobile users. Larger potential demand (D_m^0) and less price sensitive mobile users (γ_m) generate larger $\frac{D_m^0}{2\gamma_m}$; $\Delta\pi_c$ shows MNO's capability to generate profit through every cellular data bits. MNO with the larger $\Delta\pi_c$ also tends to set larger p_w for its wireless LAN AP.

V. Performance Evaluation

In this section, the performances of our proposed optimal wireless LAN APs deployment and optimal pricing algorithm are validated. We developed a python-based simulator for numerical analysis.[1]

We compare our *Optimal* wireless LAN AP deployment algorithm with two other algorithms: (i) *Baseline*: no wireless LAN AP is deployed and all the traffic is transmitted through MNO's cellular network; (ii) *Random*: the same number of wireless LAN APs as *Optimal* case are deployed randomly. The price of the corresponding wireless LAN APs is determined as that in Proposition 1.

TABLE II
Parameters in the simulation.

Parameters	Value
Target area	1000 m × 1000 m
M	100
MU density	12,000 per square mile (4,633 per square km)
L	33,456 GB/month
p_{c}	1,512 yen/GB
h_{c}	1,134 yen/GB
h_{w}	90 yen/GB
γ_{m}	0.2209 GB^2 / yen

A rectangular area of 1000 m × 1000 m is considered, and there are 100 candidate locations for wireless LAN APs deployment. The total MUs' expected demand L is assumed as 33,456 GB/month. The MNO's cellular network price p_{c} and cost h_{c} are assumed as 1,512 yen/GB and 1,134 yen/GB, respectively. The wireless LAN AP's serving cost h_{w} is assumed as 90 yen/GB. The price sensitivity of wireless LAN AP's demand γ_{m} is assumed as 0.2209 GB^2/yen. Please refer to Table II for the parameters and values[2] used in the evaluation.

We do not have the information of potential demand (D_m^0) for each wireless LAN AP candidate location. Here we uniformly extract 100 data from [20, 640] (GB / month). The 100 data are plotted in Fig. 4.

The wireless LAN AP deployment cost g_m is a key parameter to evaluate. We change g_m with different values to show how the number of deployed wireless LAN APs changes, how offloaded traffic changes, and how the MNO's profit changes under different deployment algorithms *Baseline*,

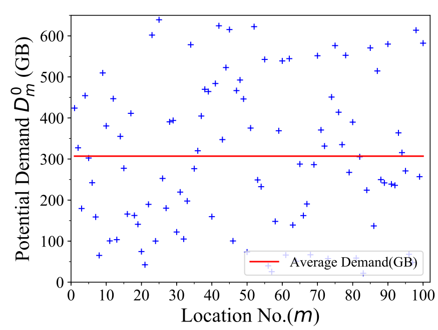

Fig. 4. Potential demand distribution of 100 locations: they are uniformly extracted from [20, 640] (GB / month).

[1]it can be fetched from the following URL link (https://github.com/aqian2006/WLANDeploymentWithLBA).

[2]the cellular price parameters' values in this table are formulated from the real pricing schemes of major Japanese MNOs and average monthly traffic statistical data of Ministry of Internal Affairs and Communications, MIC of Japan. (http://www.soumu.go.jp/johotsusintokei/field/data/gt010602.pdf)

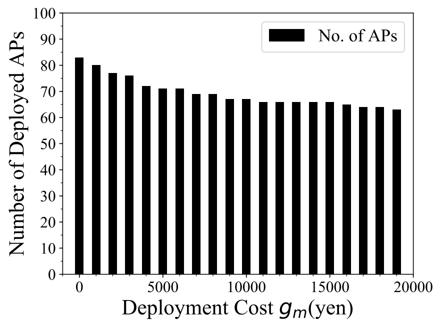

Fig. 5. The number of deployed APs with different AP's deployment cost.

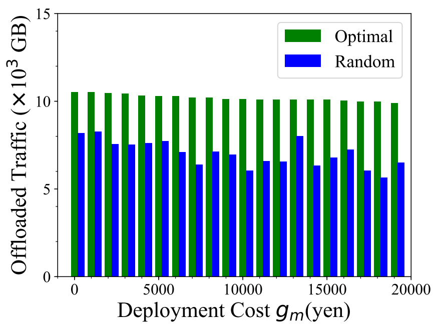

Fig. 6. Offloaded traffic comparison between proposed optimal algorithm and random algorithm.

Random and *Optimal*.

Fig. 5 shows that the number of deployed APs decreases with wireless LAN AP's deployment cost g_m. It shows that if the deployment cost is high, it not beneficial to deploy too many wireless LAN APs.

Fig.6 shows that the offloaded traffic of proposed optimal algorithm is much higher than that of the *Random* wireless LAN AP deployment algorithm.

Fig.7 shows the comparison of the profit from *Baseline*, *Random*, and *Optimal*. It can be seen that the profit of *Optimal* wireless LAN APs deployment algorithm is highest, and the profit of *Baseline* algorithm (No wireless LAN APs are deployed) is lowest. We can get some hints from this comparison: (a) deploying wireless LAN APs is much better

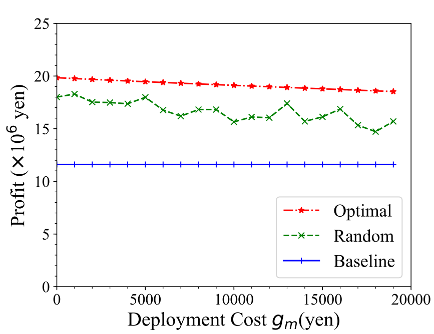

Fig. 7. Profit comparison with different deployment algorithms.

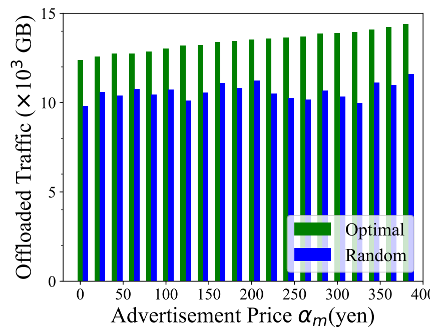

Fig. 8. Offloaded traffic comparison between *Optimal* optimal algorithm and random algorithm with different advertisement price (g_m = 10000 yen).

than no deployment of wireless LAN APs; (b) the optimal wireless LAN APs deployment algorithm improves MNO's profit.

The reason of the variation for Random algorithm in Fig.6 and 7 is that the wireless LAN APs at deployed randomly, and different locations have different demand, which will affect the traffic amount can be offload under different deployment cost (in Fig.6) and advertisement prices (in Fig. 7)

Fig.8 shows that the offloaded traffic of proposed optimal algorithm is much higher than that of the *Random* wireless LAN AP deployment algorithm when we fix deployment cost to 10000 yen. The offloaded traffic of proposed optimal algorithm increases with advertisement price α_m. The reason is that MNO can charge much lower wireless LAN price when MNO can collect revenue from LBA (see Eq.(9)), then much more demand for wireless LAN is generated.

VI. Conclusion

In this paper, we studied leverage location-based advertising for MNO to wireless LAN APs deployment, in which MNO collects revenue by selling LBA service to advertisers, while provides free or partial free wireless LAN APs for mobile users. We considered MNO's optimal wireless LAN APs deployemnt problem to maximize MNO's profit by using a generic traffic demand function to capture the traffic characteristics of a real network. An analytical solution has been obtained, and this solution can help decide the wireless LAN AP deployment on how to set the corresponding wireless LAN AP's optimal price, and how the advertisement price affect wireless LAN AP's optimal price and offloaded traffic. Extensive simulations have been conducted and the results show that the proposed wireless LAN APs deployment algorithm achieved highest profit for MNO.

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