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Li, Qiying
Department of Advanced Information Technology, Ph.D. Student

Furukawa, Hiroshi
Department of Advanced Information Technology

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Distribution of WLAN Access Points in a City and its Suburb and Prediction of System Capacity

Qiying LI* and Hiroshi FURUKAWA**

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Abstract: Explosive spread of wireless local area network (WLAN) access points in a global range makes this class of wireless system to be one of the best alternative ways to access internet. This paper investigates how many WLAN access points (APs) are distributed in real world and estimates system capacity if they are operated as a single system. The results indicate that the WLAN has a potential to achieve significant high system capacity compared to the existing cellular systems.

Keywords: Wireless LAN, Access point, Position estimation, Throughput, System capacity

1. Introduction

Wireless local area network (WLAN) access points (APs) based on IEEE802.11a/b/g specifications are widely used to connect the internet in home and office[1),2)]. In addition, portable gaming/audio/media devices with WLAN module have been also utilized as a means to access the internet. Generally, APs in home and an office room provide internet services for limited users in specific areas. Based on the radio propagation characteristics in WLAN, it is connectable to APs in the nearest buildings from outside. Therefore, if the existing APs are utilized as a common wireless communication infrastructure to access the internet, the efficient use of radio spectrum is highly expected because additional installation of APs that interfere with the existing ones can be avoided and consequently it is expected to achieve efficient use of the radio spectrum. Based on the fact that the coverage area from each AP is about 50 meter and it indicates that each AP constructs so-called pico-cell, it is expected that the WLAN system achieves the significant increase of system capacity compared to the existing cellular systems.

The purpose of this paper is to investigate how many wireless LAN APs are distributed in real world and estimate system capacity if they are operated as a single system. Although communication signals of respective APs are basically encrypted so as not to be hacked by others, it is possible to make them be shared among those who agree to the share. Those agreed people can access to someone else's AP subject to sharing their encryption key and strict authentication.

For this purpose, we investigate the distribution of APs in the downtown and residential areas of Fukuoka-city as typical examples. To estimate the position of AP we measure the received power of the beacon signals transmitted from each AP, because it is difficult visually to find the APs in home or buildings from outside. In this paper, we propose a method to estimate the position of APs based on the above measurements. Using this method, we clarify the distribution of APs in the downtown and residential areas of Fukuoka-city in Japan. The IEEE802.11 based WLAN employs the carrier sense multiple access with collision avoidance (CSMA/CA)[3)] as media access (MAC) protocol which affects the system capacity. In this paper, we also propose a simple method to evaluate the system capacity of the WLAN system with CSMA/CA protocol in multi-cell environments. Using the proposed evaluation method, we clarify achievable system capacities of WLAN system in three areas of Fukuoka-city.

2. Estimation of Access Point Position

2.1 Algorithm of position estimation

The received power of beacon signals from a target AP is measured at around the AP. Positions of respective measurement points are also measured by the Global Positioning System (GPS). Position of the target AP can be estimated by a maximum likelihood (ML) method using the above measurement data. The details of the proposed position estimation of APs are described below. Let $\mathbb{O}_i$ and R_i [dB] be the i-th measurement position and the received signal (relative) power measured at the i-th position, respectively. By weighting $\mathbb{O}_i$ with R_i, the center of gravity $\mathbb{C}$ with respect to the observation positions is given as

* Department of Advanced Information Technology, Ph.D. Student
** Department of Advanced Information Technology

$$\mathbb{C} = \frac{R_1 \cdot \mathbb{O}_1 + R_2 \cdot \mathbb{O}_2 + R_3 \cdot \mathbb{O}_3 + \ldots + R_M \cdot \mathbb{O}_M}{R_1 + R_2 + R_3 + \ldots R_M} \quad (1)$$

where M denotes the number of measurement points. In order to reduce computation time, We limit area to be searched in the ML position estimation to X square meter (Xm^2) and $\mathbb{C}$ is used as center of the square.

In this paper, we propose a method to estimate position of AP based on the above measured information. **Figure 1** illustrates basic idea of the AP position estimation, where we consider X square meter (Xm^2) area whose center place is $\mathbb{C}$. The measurement points $\mathbb{O}_i$ are placed along the observer walking route. The square area is divided into several subareas and the center position of the j-th subarea is denoted as $\mathbb{P}_j$. Assuming that the signal is transmitted from AP located in $\mathbb{P}_j$ and measured at the i-th measurement position $\mathbb{O}_i$, the received signal power $\tilde{R}_{j,i}$ can be calculated using a ray tracing method[3]. The details of the ray tracing method employed in this paper are explained in the next subsection. The basic idea to estimate AP position in the proposed method is to compare the actual received signal power with the calculated ones using the ray tracing. In the proposed ML estimation method, the square error between estimation R_i and $\tilde{R}_{j,i}$ is given as

$$e_j = \frac{1}{M} \sum_{i=1}^{M} (R_i - \tilde{R}_{j,i})^2 \quad (2)$$

The objective of the proposed ML algorithm is to find j so as to minimize e_j.

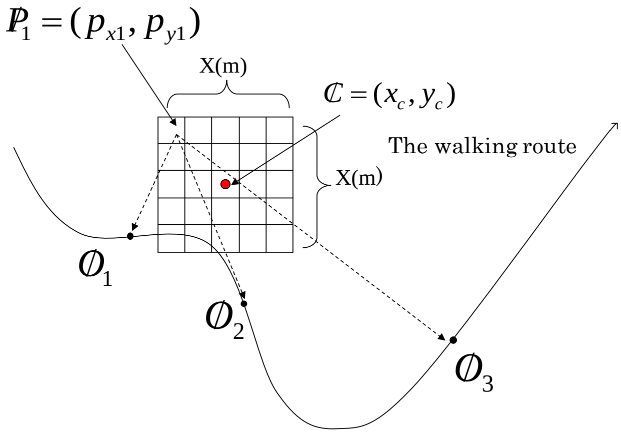


Fig. 1 Illustration to explain the proposed AP position estimation algorithm.

2.2 Experiments for estimation accuracy evaluation

We need to assess accuracy of estimated AP positions by the proposed method. For this purpose, the actual position of the known APs is compared with the estimated one and the error between them is evaluated.

The experiment steps are described as follow.

(1) Position of an AP is measured by the GPS. To reduce the measurement error caused GPS receiver, we obtain 360 measurements of GPS signal and these data are averaged. Let the averaged position of AP denote P_c.

(2) Walk around the target AP as in **Fig.1** and measure the received beacon signal power. The position of the measurement points are measured by GPS receiver. Similarly to (1), 100 measured data samples are averaged to reduce the error caused by GPS receiver.

(3) The position of the AP is estimated with the proposed method. The estimated position is denoted as P_e.

(4) Difference between P_e and P_c is delected as an error, i.e. $e = |P_c - P_e|$.

(5) The estimation error is calculated for the other APs located in different positions, while the same experiments as (1)-(4) is continued. The estimation errors are measured at 100 different positions.

The data are measured at Ito-Campus of Kyushu University. The transmission power is 17dBm. The received power is calculated using ray launching method[3]. The ray launching method is one of ray tracing techniques to trace the ray propagation route from the transmitter. The principle of the ray launching method is explained in **Fig.2**. In the ray launching method, the receiver extracts the traced routes only when the ray propagates to the observation area near the receiver. We use as software EEM-RTM[7] for the above calculations.

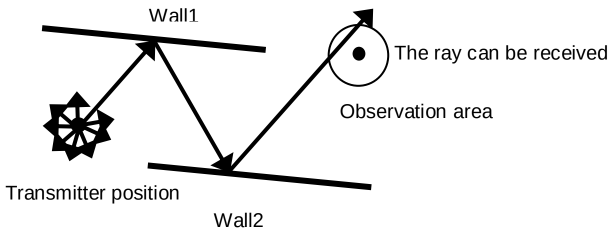
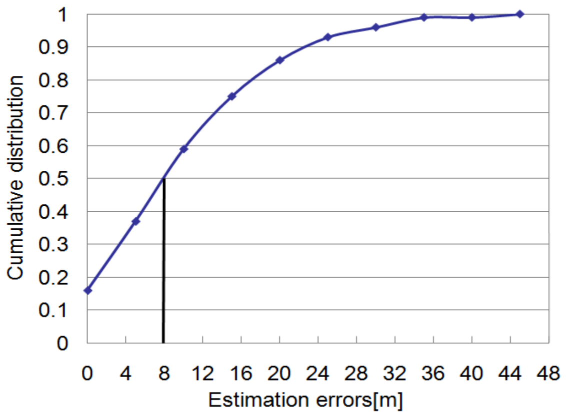


Fig.2 Ray launching method.

Figure 3 shows the cumulative distribution as a function of the estimation error. As in **Fig.3**, median error between the actual position and estimated one is 8 meter. This result shows that proposed method superior to methods mentioned in paper 8) that estimating error are several tens of meters. Based on the fact that the coverage area from the transmitter in WLAN is about 50

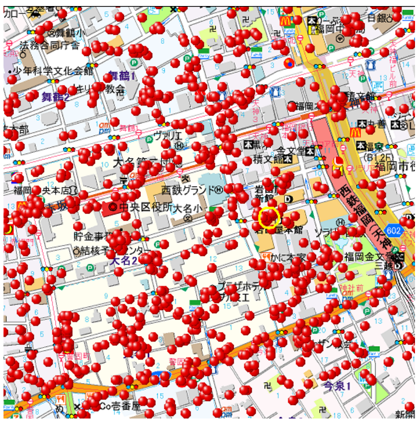


meter, we can see that the proposed method achieves enough accuracy to estimate the position of APs.

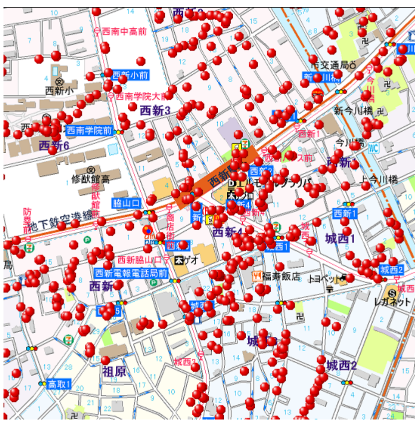
Fig. 3 Cumulative distribution of estimation error.

2.3 Position estimation of APs in Fukuoka city

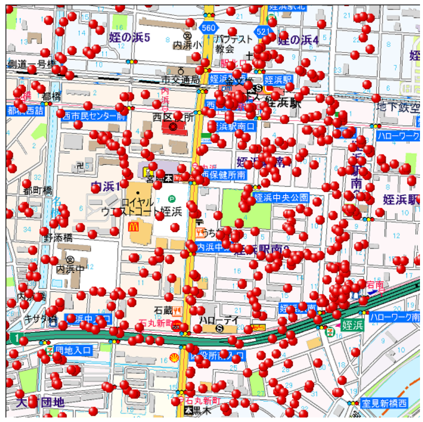
Figure 4 shows the distribution of AP positions estimated by the proposed method and the data sampled in Sep 2007. Estimated areas



(a) Tenjin-area



(b) Nishijin-area



(c) Meinohama-area

Fig .4 Distribution of APs in 3 areas of Fukuoka.

Table 1 Distribution of APs in 3 areas.

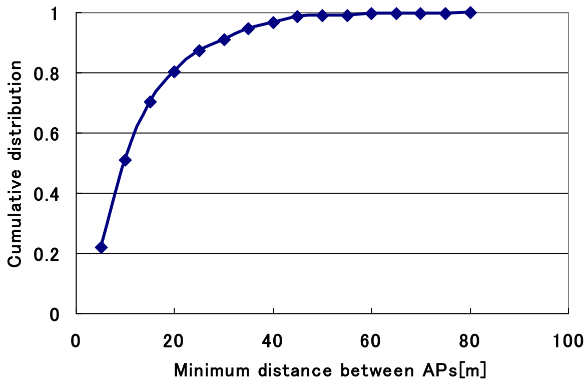
Areas	Number of 11a APs	Number of 11b APs	Number of 11g APs
Nishijin	80	32	309
Tenjin	105	102	450
Meinohama	54	82	430

Table 2 The minimum distances between APs in 3 areas.

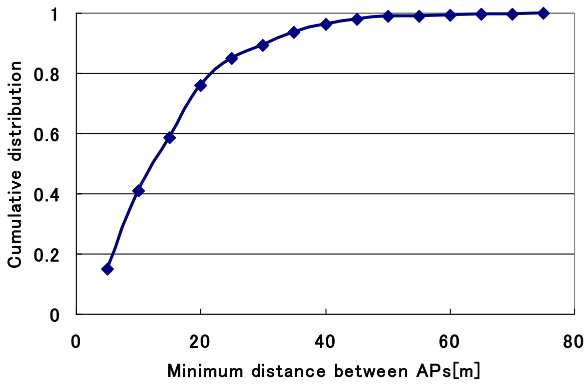
Areas	Average(m)	Median(m)	Standard deviation(m)
Nishijin	14.28	11.25	11.55
Tenjin	12.88	10	11.10
Meinohama	14.87	12.5	11.63

(Tenjin, Meinohama and Nishijin) are typical examples of downtown and residential areas in Fukuoka city: Tenjin is the largest downtown area in Kyushu; Nishijin includes both shopping and residential areas near the station and Meinohama is a residential town for those who mostly work in Tenjin downtown. The positions of APs are estimated in 1km square areas. From **Fig.4**, we can see that APs are inuniformly placed and the distribution of AP depends on the area. **Table 1** shows the number of APs based on IEEE802.11a/b/g in 3 areas of Fukuoka-city. **Table 2** shows the minimum distance between APs in each area, where average, median, and standard deviation are shown.

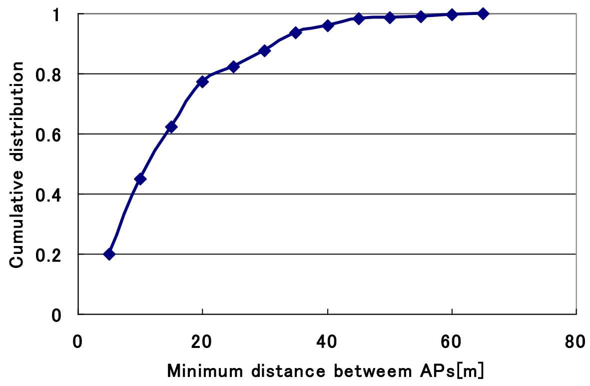
The minimum distance between APs is defined as the distance between an AP and the nearest neighbor of the AP. **Figure 5** shows cumulative distribution as a function of minimum distance between APs in three areas. From this figure, it can be seen that, in most cases, the nearest AP exists within 20 meter area from each AP. In addition, **Fig.4** also indicates that APs are crowdedly placed in each area. In fact, from **Table 2**, the average minimum distance between APs is about 15m even in Meinohama-area. In such an environment, APs are interfered each others, which will lead to significant throughput degradation. **Figure 6** shows distribution of APs over wireless channels in IEEE802.11b/g WLAN at 2.4GHz-band, where the total number of channels is 14 (c1-c14). As shown in this figure, we can see that the available channels concentrate on specific frequencies such as c1, c6, c7, and c11.



(a) Tenjin



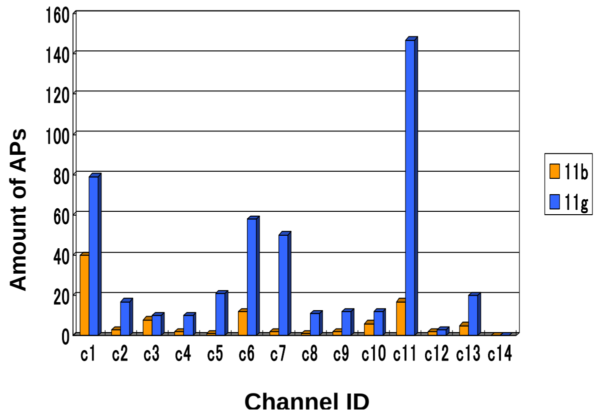
(b) Nishijin



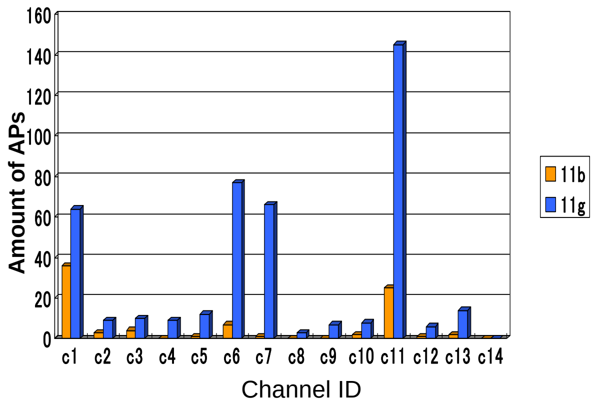
(c) Meinohama

Fig.5 Cumulative distribution of the minimum distance between APs.

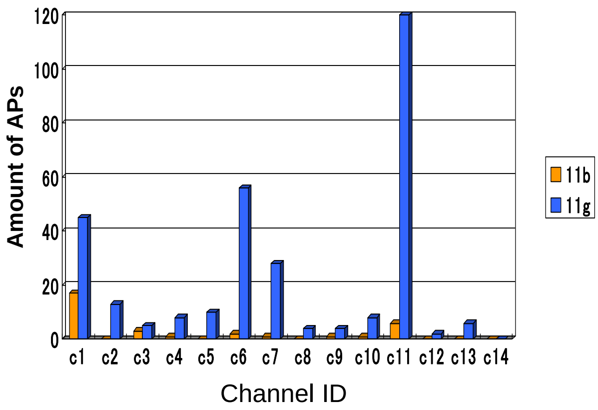
This interesting result can be explained as follows: person who is in changing of setting APs tends to assign a channel to respective APs so that the selected channel is the most less interfered one. The people's behavior results in autonomous channel segregation observed through the experiments.



(a) Tenjin



(b) Nishijin



(c) Meinohama

Fig.6 Allocated channel distribution in 11b/g standard APs.

3. Estimation of System Capacity

IEEE802.11 WLAN system employs CSMA/CA based MAC protocol which enables to transmit packets so as to reduce the probability of collision occurrence. In CSMA/CA based system, current channel status is sensed before the start of packet transmission. If transmissions from other APs are detected by carrier sensing, the transmitter stops sending packets and thus packet collisions can be mitigated. In CSMA/CA based system, the transmission is stopped whenever the measured interference power exceed a given threshold level, called CCA-threshold.

3.1 Estimation method of system capacity

In this paper, we define system capacity as the sum of the achievable maximum throughput in All APs located within 1km square measurement areas. To improve accuracy of system capacity estimation, precise modeling of interference is required.

The maximum throughput per cell without interference (i.e. in single cell environment) is given in **Table 3**[3),4)], where the maximum bearer rate and MAC throughput denote the maximum data rate in physical layer and the maximum actual throughput in UDP level for pear-to-pear communication, respectively. Length of UDP payload is 1472[Octet][3)].

Next, we consider actual maximum throughput per cell in multi-cell environment. In this paper, we introduce the successful packet transmission/reception probability $P_{success}$ as a new measure to calculate the throughput performance. This measure is used to express the throughput degradation caused by inter-cell interference. In addition, the transmission failure caused by hidden terminal problem and the standby-status in CSMA are also reflected in the probability $P_{success}$.

The probability of the standby status occurrence $P_{CCAsense}$ is given as the carrier detection probability. The probability of the hidden terminal occurrence is given as the probability of packet collision occurrence $P_{collision}$. Thus, the probability $P_{success}$ can be obtained as

$$P_{success} = (1 - P_{CCAsense})(1 - P_{collision}) \quad (3)$$

Table 3 The maximum MAC throughput of 802.11 WLAN.

Standard	Maximum Bearer Rate(Mbps)	Maximum MAC Throughput(Mbps)
802.11b	11	6
802.11g	54	22
802.11a	54	30

Using the $P_{success}$ in Eq.(3), the actual achievable maximum throughput per AP is given as

$$\begin{aligned} \mathrm{T_{cell}} &= \mathrm{T_{max\ mac}} \times P_{success} \\ &= \mathrm{T_{max\ mac}} \times (1 - P_{CCAsense})(1 - P_{collision}) \end{aligned} \quad (4)$$

where $T_{max\ mac}$ is the maximum MAC throughput given in **Table 3**.

Assuming that the offered load is high enough to evaluate T_{cell}, the system capacity can be given as the sum of T_{cell} achieved by all APs within each area. Since terminals are randomly distributed in a cell, we assume that position of terminals is fixed to the same position of AP for simplicity of discussion. Under this assumption, both uplink and downlink interference happens from position of APs. The throughput T_{cell} in each cell can be evaluated by obtaining $P_{CCAsense}$ and $P_{collision}$ and substitute them for Eq.(4).

First, we consider $P_{CCAsense}$ as the carrier detection probability which is given by

$$P_{CCAsense} = \frac{N}{N+1} \quad (5)$$

where N denotes the number of the interfering APs to the i-th one. After that, we consider the probability $P_{collision}$. In IEEE802.11 based system, CCI (Co-Channel Interference) immunity is defined as a metric that shows tolerance to interference. Assume that CCA and CCI denote CCA-threshold and CCI immunity, respectively. If RSSI (Received Signal Strength Indicator) level [dBm] of a channel is less than

CCA[dBm]-CCI[dB], the interference level is short enough and thus the channel is regarded as clear. If RSSI level of a channel exceeds CCA-threshold, the channel is regarded as busy and thus packet collision can be avoided. When RSSI measured by a cell satisfies the following relation then collision may happen[5).

$$\mathrm{CCA} - \mathrm{CCI} < RSSI < \mathrm{CCA} \quad (6)$$

It should be noted that parameters of CCA, CCI and RSSI in Eq.(6) are expressed by dBm, dB and dBm respectively.

In this paper, the cell satisfying the relation of Eq.(6) is called the collision cell. Assuming that the number of collision cells around the i-th cell is M, the probability of the collision occurrence is given as

$$P_{collision} = \frac{M}{M+1} \quad (7)$$

To estimate the number of the interfering cells and collision cells, it is required to estimate radio propagation characteristics between cells (APs). In this paper, the radio propagation characteristics and the received power are calculated by EEM-RTM. To improve the accuracy of calculations, we use digital map that contains the detailed information such as Top-view shape of buildings.

3.2 Parameters for evaluations

The transmission power is 17dBm. The maximum bearer transmission rates in IEEE802.11a/b/g are 54, 11, and 54Mbps, respectively. CCA threshold values in 11a/g and 11b are set to -94dBm and -62dBm, respectively. For simplicity of the evaluation of the maximum system capacity, 11b/g and 11a/b/g APs are counted as 11g and 11a, respectively. In ray tracing calculation with the EEM-RTM software, the maximum number of reflections is set to 6.

3.3 Evaluation results

Tables 4 and **5** show the system capacity and the average throughput per AP (system capacity divided by the number of AP) in three areas of Fukuoka-city. In these tables, we can see that 11a AP achieves higher throughput than 11g AP, because the number of 11a AP is less than that of 11g AP so that interference cases of 11a AP are less than 11g AP. In addition, the amount of attenuation in 11a signal transmission at 5.2GHz is higher than that in 11g transmission at 2.4GHz and thus the interference power is effectively mitigated. To clarify the impact of achievable system capacity in WLAN system against cellular systems, we compare it

Table 4 System capacity in 3 areas of Fukuoka-City.

Standard	Tenjin (Mbps)	Nishijin (Mbps)	Meinohama (Mbps)
11b	342.7	125.4	286.2
11g	5616.0	4455.8	5495.4
11a	2726.0	2160.0	1514.1
Total	8684.0	6741.2	7295.7

Table 5 Averaged throughput per AP.

Standard	Tenjin (Mbps)	Nishijin (Mbps)	Meinohama (Mbps)
11b	3.36	3.92	3.49
11g	12.48	14.42	12.78
11a	25.96	27.00	28.04

with 3.5G cellular system. We assume that achievable MAC throughput in 3.5G system under multi-cell environment is 1 Mbps per sector. Assuming that the radius of cell is 600m and the number of sectors is 3, the system capacity of 3.5G system is 2.7Mbps per 1km2. This throughput performance is achieved when the system bandwidth of 3.5G system is 5MHz. Thus, when we assume 3.5G system has the same bandwidth as the WLAN system, 10.6Mbps is achieved. When the achievable system capacity of APs is compared with 3.5G system, we can see that the WLAN in Tenjin-area achieves 500times higher system capacity than that of the existing 3.5G cellular system.

4. Conclusion

In this paper, we investigate how many Wireless LAN APs are distributed in real world and estimate system capacity if they are operated as a single system. We proposed a method to estimate the position of APs through measurements of the beacon signals sent from APs in downtown and residential areas of Fukuoka-city in Japan. We also proposed a simple method to estimate system capacity in the above areas. Using the proposed method, it was clarified that the estimated system capacity of the WLAN in 1 square Km area of Fukuoka-city is about 500 times higher than that of the existing 3.5G system. The results indicate that the WLAN has a potential to achieve significant high system capacity compared to the existing systems.

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