Wireless Signal and Information Tracking Using Fuzzy Logic

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Abstract. Over the last decade, many commercial and government organizations as well as university campuses have deployed WLANs such as IEEE 802.11b. This has fostered a growing interest in location-based services and applications. Fuzzy logic can be applied to evaluate the behaviour of Wireless Local Area Networks (WLAN) received signal strength (RSS) and as well as to retrieve the location-aware information according to the preference of user. The behavior study of WLAN signal strength is a pivotal part of WLAN tracking analysis. Previous analytical model has not been addressed effectively for analyzing how the WLAN infrastructure affected the accuracy of tracking. In this paper, we first propose a novel fuzzy spatio-temporal topographic model. We applied the Nelder-Mead (NM) method to simplify our previous work on fuzzy color map into a topographic (line-based) map. Secondly, we propose a location-aware information retrieval application that travelers access the application with Apple's iPhones which also identify the user current location. We demonstrate our idea with 17,000 restaurants in Hong Kong and make use of fuzzy logic to return the favorable dinning place search result according to the user's preference. Our result shows that the new analytical model can provide a detail and quantitative strong representation of WLAN RSS.

Keywords: Wireless tracking, Topographic mapping, Fuzzy logic, Wi-Fi signal strength, iPhone.

1 Introduction

Wireless Local Area Networks (WLAN) tracking analysis is a crucial part for deploying the efficient indoor positioning system. The analytical models can be used to visualize the distribution of signal and help to improve the design of positioning systems, for example by eliminating installation of WLAN access points (APs) and shortening the sampling time of WLAN received signal strength (RSS) in location estimation. Recent research on WLAN RSS analytical model [1] and [2] are based on the accuracy of positioning systems and proximity graphs, such as Voronoi diagram, clustering graph. They assume the distribution of the RSS is in Gaussian and pair wise. Some research works [2], [3], and [4] ignores the radio signal properties. Such assumptions may ignore or distort the real behavior of RSS and provides inadequate and inaccurate RSS analysis.

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The fuzzy visualization map concepts widely applied in other fields, such as temperature, rainfall and atmosphere. Topographic mapping has been also highly recognized as a comprehensive method to visualize geographical information, such as the reflectance of slope and terrain. NM method also is used in many other fields such as data mining [5] and antenna optimization [6]. Fuzzy, topographic and NM modelling could well be applied to modelling in WLAN RSS analytical model.

In this paper, we first propose a novel analytical model that provides a visualization of the RSS distribution. We make use of the Nelder-Mead (NM) method to simplify our pervious works on the multi-layer fuzzy color model [7] to topographic (line-based) model. We develop a topographic model as analytical tools for evaluating and visualizing where the RSS is denser and clustering different RSS in different topographic level.

Secondly, we propose a location-aware information retrieval system that travelers access the system with Apple's iPhones. We apply fuzzy logic to search for the dinning place according to the preference of the user. We also extend iPhone's positioning features into indoor environment with our previous work of Wi-Fi positioning [7],[8]. Our system could be used in the entire area of Hong Kong city (1,104 km^2) with more than 17,000 restaurants. The restaurant information includes types of food, price, name, latitude, longitude of the restaurant and ratings from users. The entire set of database is retrieved and updated from [9]. Figure 1 shows the interface of our location-aware Application using Apple's iPhone.

The proposed analytical model offers two benefits. First, it serves as a quicker reference and efficient analysis tool. Second, it can provide a detail and quantitative strong representation of WLAN RSS. The iPhone application offers four benefits. First, our iPhone application provides a hybrid, accurate and effective positioning across indoors and outdoors. Second, it provides more flexibility to the user and provide recommendations of the restaurant according to the distance, user's preferred price and food type. Third, the database is remotely connected from [9] which user can rate, access and update the restaurant information through internet. Finally, it is user-friendly with full mobility.

The rest of this paper is organized as follows: Section 2 presents the topographic model design. Section 3 describes the iPhone application implementation. Section 4 describes the fuzzy membership function of distance and price. Section 5 presents the experimental setup of large scale site RSS surveying in 9.34 hectare campus area over 2,000 access points. Section 6 discusses the analysis result of obstacles, human bodies and WLAN APs location. Finally, Section 7 offers our conclusion and future work.

2 Topographic Model Design

The basic idea of topographic model is to plot a curve connecting minimum points where the function has a same particular RSS value. The sets of APs are known as topographic line nodes. Topographic line nodes are the APs residing on the topographic lines around contour region. In this section, we introduce the major operations of topographic model including propagation-based algorithm, fuzzy membership function in our previous work [7], topographic line node measurement, Nelder-Mead method and topographic model generation.

Fig. 1. Proposed Location-aware Application using Apple's iPhone

2.1 Propagation-Based Algorithm

The propagation-based algorithm [10] which is used to calculate the RSS as follows:

$$r_i(d_{i,k}) = r_0(d_0) - 10\alpha \log_{10}(d_{i,k}) - wallLoss \qquad (1)$$

where $D = \{d_1...d_n | d_i \in \Re^n\}$ is a set of locations, $R = \{r_1...r_n | r_i \in \Re^n\}$ is a set of sampling LF vector respect to known d_i, α is the path loss exponent (clutter density factor) and $wallLoss$ is the sum of the losses introduced by each wall on the line segment drawn at Euclidean distance $d_{i,k}$.

2.2 Fuzzy Membership Function

In this subsection, our fuzzy membership function has been published in [7] and we will make use of it. Nonetheless, for completeness in the following we briefly describe.

Using fuzzy logic, the proposed model offers an enhanced LF hyperbolic solution that maps the RSS from a 0 to 1 fuzzy membership function. Instead of using a numeric value, the fuzzy logic determines the RSS as "strong", "normal" and "weak".

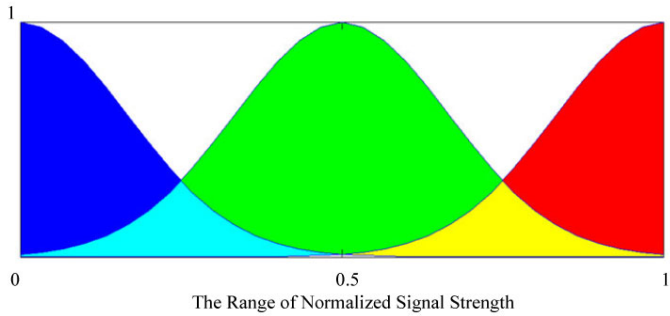


Fig. 2. Fuzzy membership graph for RSS

The normalization distribution is used to represent the fuzzy membership functions.

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{(\alpha-\mu)^2}{2\sigma^2}} \tag{2}$$

where $p(x)$ is the probability function, x is the normalized RSS, σ is the standard deviation of normalized signal normalized strength in a region, μ is the mean of signal strength in a region. The WLAN network is fully covered for the whole campus.

The membership function of term set, $\mu\,(\mathrm{RSSDensity}) = \{\mathrm{Red, Green, Blue}\}$. Red means the signal strength density is high, green means the signal strength is medium and blue means the signal strength density is low. The fuzzy set interval of blue is [0, 0.5], [0, 1] is green and [0.5, 1] is red.

For the blue region, we substitute $\sigma = 0.5$, $\mu = 0$.

$$\mu_{Blue}(0 < x < 0.5) = \frac{2}{\sqrt{2\pi}} e^{-2x^2} \tag{3}$$

For the green region, we substitute $\sigma = 0.5$, $\mu = 0.5$.

$$\mu_{Green}(0 < x < 1) = \frac{2}{\sqrt{2\pi}} e^{-2(x-\frac{1}{2})^2} \tag{4}$$

For the red region, we substitute $\sigma = 0.5$, $\mu = 1$.

$$\mu_{Red}(0.5 < x < 1) = \frac{2}{\sqrt{2\pi}} e^{-2(x-1)^2} \tag{5}$$

Figure 2 shows the fuzzy membership function. X-axis represents the normalized signal strength from 0 to 1 (from -93dBm to -15dBm). The width of membership function depends on the standard deviation of the RSS. The overlap area will be indicated by mixed colors. We can use different colored regions to represent the WLAN RSS distribution. Conceptually we define a spatio-temporal region as follows:

Assume that B is a finite set of RSS vector belonging to a particular color region, where $B = \{b_1...b_n | b_i \in \Re^n\}$, i.e., $b_i \in S$, $\forall S \in R$, and $\forall S \in [l, u]$, where l is the lower bound of fuzzy interval and u is a upper bound of fuzzy interval. To analyze the distribution surfaces S, there always exists a spatio-temporal mapping, $q : B \to S$.

$$q(x) = \int_S h(x)b(S)dS, \tag{6}$$

where $h(x)$ is the characteristic function of S, i.e.,

$$h(x) = \begin{cases} 1, x \in S \\ 0, x \notin S \end{cases} \tag{7}$$

and $b(S)$ is a weight function that specifies a prior on the distribution of surfaces S. We can explicitly define $b(S)$ by (1). By (3), (4), (5), (6), and (7), the RSS distribution can be illustrated.

2.3 Topographic Node

Each topographic node consists of three components and can be expressed as $< l, d, g >$, in which l represents topographic level, d represents the locations of Wi-Fi received signal, g represents the gradient direction of the RSS distribution. The spatial data value distribution mapped into the (x, y, l) space, where the co-ordinate (x, y) represents the location and $l = f(x, y)$ describes a function mapping from (x, y) co-ordinates to level l. The gradient vector g denotes the direction of RSS where to degrade in the space. The gradient vector can be calculated by:

$$g = -f'(x, y) = \left(\frac{\Delta f}{\Delta x}, \frac{\Delta f}{\Delta y}\right)^T \tag{8}$$

$$S = \frac{B - W}{2} \tag{9}$$

2.4 Nelder-Mead Method

The Nelder-Mead (NM) method is a commonly used nonlinear optimization algorithm for finding a local minimum of a function of several variables has been devised by Nelder and Mead [11]. It is a numerical method for minimizing an objective function in a many-dimensional space. Instead of using (1) and (2), we estimate the location by NM method.

First, we collect the location fingerprint, r with an unknown location (x, y). We define $f(n) = |n - r|$, where n is any location fingerprint. Second, we select three location fingerprints (LFs) to be three vertices of a triangle.

We initialize a triangle BGW and function f is to be minimized. Vertices B, G, and W, where $f(B)$ is the smallest value (best vertex), $f(G)$ is the medium value (good vertex), and $f(W)$ is a largest value (worst vertex). There are 4 cases when using NM method. They are reflection, expansion, contraction and shrink. We recursively use NM method until finding the point which is the local minimum (nearest) in B, G, W that they are the same value.

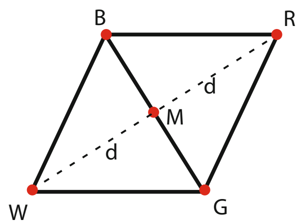


Fig. 3. Reflection Using the Point R

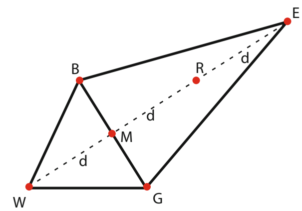


Fig. 4. Expansion Using the Point E

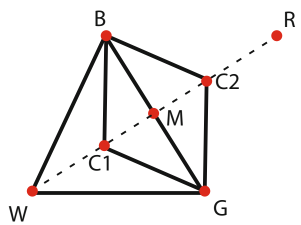


Fig. 5. Contraction Using the Point C

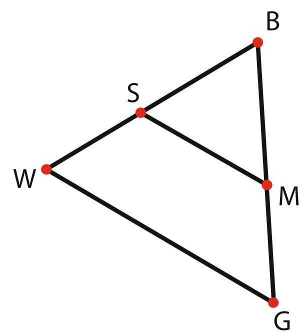


Fig. 6. Shrink toward B

The midpoint of the good side is

$$M = \frac{B+G}{2} \tag{10}$$

Reflection using the Point R. The function decreases as we move along the side of the triangle from W to B, and it decreases as we move along the side from W to G. Hence it is feasible that function f takes on smaller values at points that lie away from W on the opposite side of the line between B and G. We choose the point R that is obtained by "reflecting" the triangle through the side BG. To determine R, we first find the midpoint M of the side BG. Then draw the line segment from W to M and call its length d. This last segment is extended a distance d through M to locate the point R (See Figure 3). The vector formula for R is

$$R = M + (M - W) = 2M - W \tag{11}$$

Expansion Using the Point E. If the function value at R is smaller than the function value at W, then we have moved in the correct direction toward the minimum. Perhaps the minimum is just a bit farther than the point R. So we extend the line segment through M and R to the point E. This forms an expanded triangle BGE. The point E is found by moving an additional distance d along the line joining M and R (See Figure 4). If the function value at E is less than the function value at R, then we have found a better vertex than R. The vector formula for E is

Table 1. Nelder-Mead Method Procedure

```
IF f(R)<f(G), THEN Perform Case (i) {either reflect or extend}
ELSE Perform Case (ii) {either contract or shrink}

BEGIN {Case(i)}                 BEGIN {Case(ii).}
IF f(B)<f(R) THEN               IF f(R)<f(W) THEN
  replace W with R                replace W with R
ELSE                            ENDIF
  compute E and f(E)
  IF f(E)<f(B) THEN             compute C = (W + M)/2
    replace W with E            or C = (M + R)/2 and f (C)
  ELSE                          IF f(C)<f(W) THEN
    replace W with R              replace W with C
  ENDIF                         ELSE
ENDIF                             compute S and f(S)
END {Case (i)}                    replace G with M
                                ENDIF
                                END {Case (ii)}
```

$$E = R + (R - M) = 2R - M \tag{12}$$

Contraction using the Point C. If the function values at R and W are the same, another point must be tested. Perhaps the function is smaller at M, but we cannot replace W with M because we must have a triangle. Consider the two midpoints C_1 and C_2 of the line segments WM and MR, respectively (see Figure 5). The point with the smaller function value is called C, and the new triangle is BGC. Note. The choice between C_1 and C_2 might seem inappropriate for the two-dimensional case, but it is important in higher dimensions.

$$C_1 = \frac{M - W}{2} \tag{13}$$

$$C_2 = R - \frac{M - W}{2} \tag{14}$$

Shrink toward B. If the function value at C is not less than the value at W, the points G and W must be shrunk toward B (see Figure 6). The point G is replaced with M, and W is replaced with S, which is the midpoint of the line segment joining B with W.

2.5 Topographic Model Generation

We generate topographic model based on our previous work [7] and NM algorithm. We apply NM method to a many-dimensional RSS distribution space problem to simplify the fuzzy color map down to a contour (line-based) map.

First, we select three LFs to be three vertices of a triangle: $\boldsymbol{B}$, $\boldsymbol{G}$ and $\boldsymbol{W}$, where $\boldsymbol{B}$ is a location with high RSS (best vertex), $\boldsymbol{G}$ is a location with medium RSS

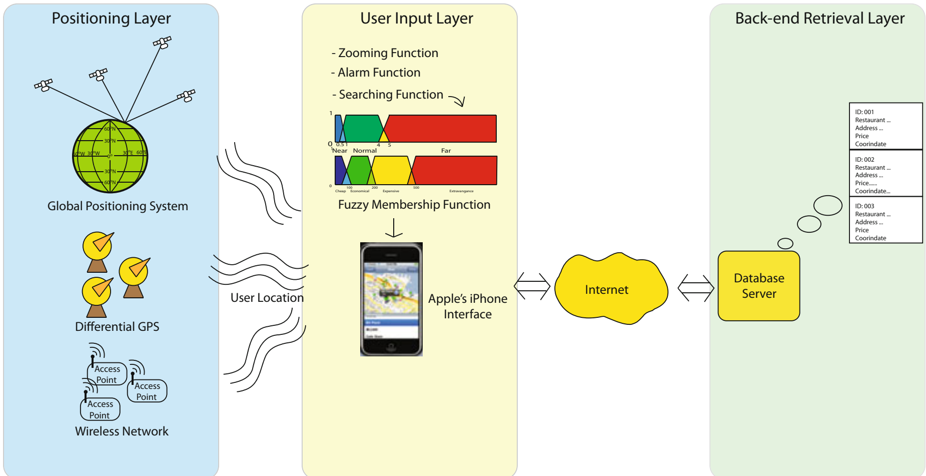


Fig. 7. System overview of location-aware information retrieval system using Apple's iPhone

(good vertex), and $\boldsymbol{W}$ is a location with the low RSS (worst vertex). The location vector of RSS at x_k,y_k use in function, $N(x,y)$. We use (1) to define $N(x,y)$. There are 4 cases when using NM method. They are reflection, expansion, contraction and shrink. We recursively use NM method until finding the point which is the local minimum in $\boldsymbol{B}$, $\boldsymbol{G}$ and $\boldsymbol{W}$ that they are the same value. Table 1 summarizes the procedure.

A contour function is then used to plot a curve connecting minimum points where the function has a same particular value. We normalize the minimum value between 0 and 1, and the contour line is 0.1 in each level.

3 iPhone Application Implementation

In this section, we introduce how our location-aware information application to be implemented. Figure 7 describes the system overview. There are three main layers in our application.

The first layer is the positioning layer. We use hybrid positioning technology to locate the user. iPhone 3GS has already included the features of DGPS. We further extend the positioning functions into indoors by Wi-Fi positioning techniques. In most of the cases, when the user stays in outdoor environment, DGPS would be used to estimate the user's location. When the iPhone cannot receive satellite signal or received satellite signal is very week, the proposed system will automatically turn to Wi-Fi positioning. The second layer is the user input layer which reads users' query, displays the restaurant information and identify the location in the Google map. We implement our system using iPhone as front-end user interface. iPhone is a touch device that it can easily control the zooming function of the map. We also implement alarm functions to remind and provide suitable choices of restaurants according to users' preference. The third layer is the back-end retrieval layer. This layer includes a location-aware database server

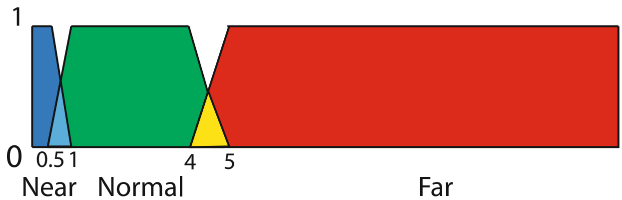


Fig. 8. Fuzzy membership graph for distance

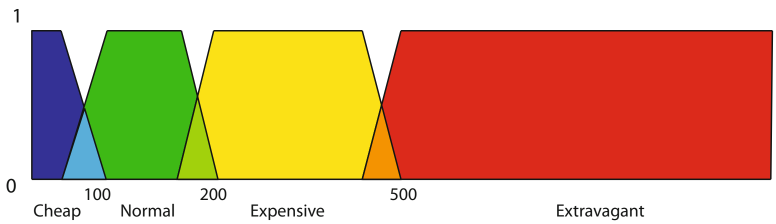


Fig. 9. Fuzzy membership graph for price

which stores the name, address, price, type and global co-ordinate of 17,000 restaurants. The database is updated and connected from [9].

4 Fuzzy Modeling for Distance and Price

Usually, human is sensible to some abstract concepts, such as far away, near, cheap or expensive. In this section, we make use of fuzzy logic to represent the distance and price. Fuzzy membership functions are used to represent the distance between the restaurant and the user location. The membership function of term set is $\mu(Distance) = \{Near, Normal, Far\}$. Figure 8 shows the fuzzy membership graph which X-axis represents the distance in kilometers and Y-axis represents the fuzzy membership from 0 to 1.

Similarly, fuzzy membership functions could be used to represent the price. $\mu(Price) = \{Cheap, Normal, Expensive, Extravagant\}$ is the membership function of term set. Figure 9 shows the fuzzy membership graph which X-axis represents the price in Hong Kong dollars and Y-axis represents the fuzzy membership from 0 to 1. The trapezoid function is used to represent the fuzzy membership functions of the distance and the price.

5 Experimental Setup

In this section, we describe experiment setup in 9.34 hectare campus area. We use the same setting as used in [12], [13], [1], [14], [10], [15] and [16]. RSS site survey measurement will be in The Hong Kong Polytechnic University (PolyU) campus. The approximate total area of the campus is 9.34 hectare. A standard laptop computer equipped

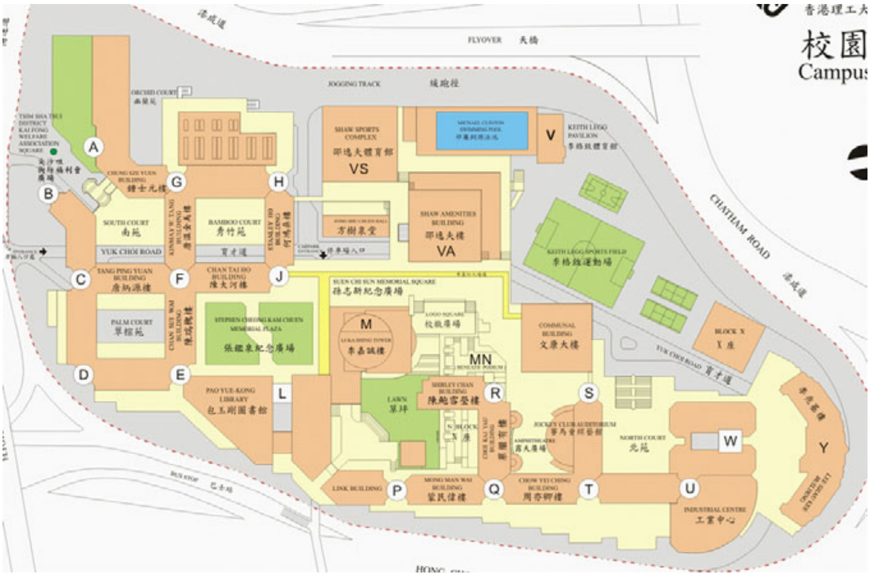


Fig. 10. The site plan for PolyU Campus with 27 buildings

with an Intel WLAN card and client manager software was used to measure samples of RSS from access points (APs) of PolyU campus.

There are basically 26 buildings from Core A to Core Z and 7 extra buildings with WLAN access. Each core building is covered by at least 13 APs. The received signal sensitivity of the WLAN card also limits the range of the RSS to be between -93 dBm and -15 dBm. Nevertheless, the highest typical value of the RSS is approximately -30 dBm at one meter from any AP. The sampling schedule is to collect the RSS data every 5 seconds. The vector of RSS data at each location forms the location fingerprint with around 20 RSS elements in the vector. Total 27 locations of measurement are chosen in the campus. Figure 10 show the 27 locations site plan. The radio channels used for each AP are channel 1, 6, and 11 respectively. The sampling will be taken with two periods of time, (7:30am-9:30am (leisure) and 4:30pm - 6:30pm (busy)). From [1], the presence or absence of people in the building significantly affects the RSS values. The duration of sampling was 2 weeks with total 12 days (from Mon to Sat). In mean while, temperature, weather, sampling time and humidity were recorded. The total number of RSS samples would be 12 days X 4 directions X 27 buildings X 20 APs X 2 times = 51,840.

6 Discussion and Analysis

In this section, we discuss the effect of the presence of human and LOS factor in our topographic model. There are three RSS features to be analyzed, LOS, the presence of human and RSS variation.

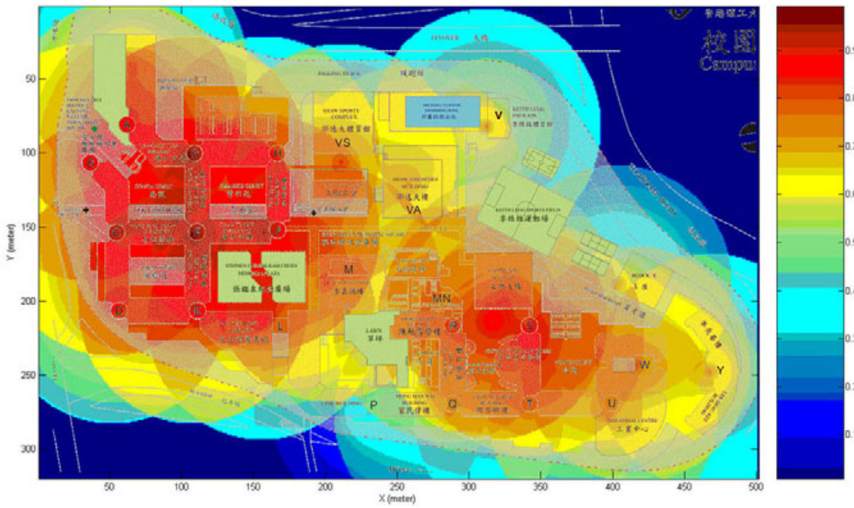


Fig. 11. Fuzzy RSS Distribution with the campus floor plan

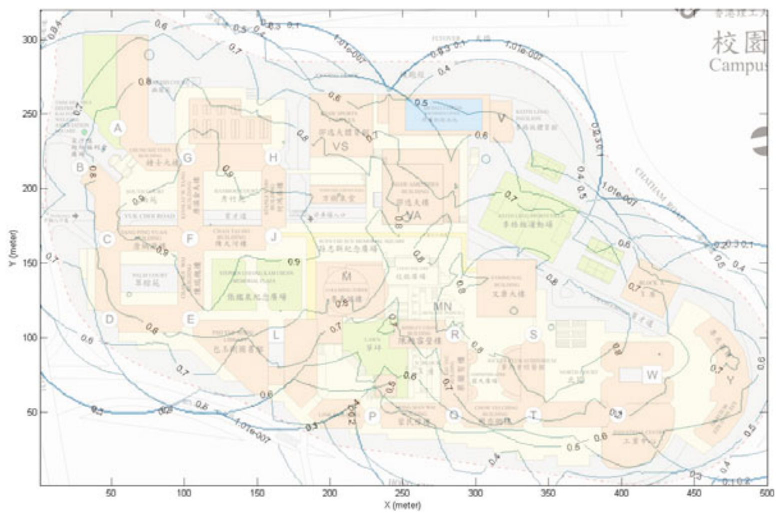
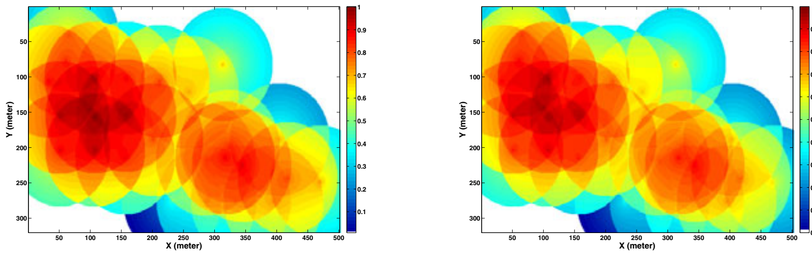


Fig. 12. Topographic RSS Distribution with the campus floor plan

6.1 Effect of LOS on RSS

Figure 11 and 12 show the effect of LOS in two major clusters of RSS. The two major centers of high intensity locate at F core and S core.

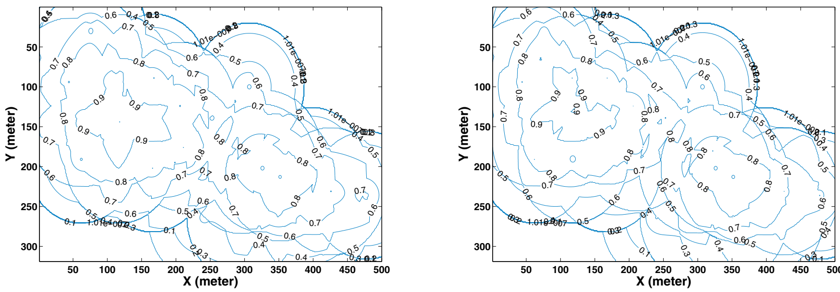
The distance between F core to S core buildings is around 600m apart. The RSS should be covered evenly. Moreover, between M core (Lee Ka Shing Tower) to R core buildings (Shirley Chan Tower), the RSS distribution is relatively low. The heights of



(a) In the leisure morning period

(b) In the busy evening period

Fig. 13. RSS Distribution in Fuzzy Analytical Model



(a) In the leisure morning period

(b) In the busy evening period

Fig. 14. RSS Distribution in Topographic Model

two buildings in M core and R core are around 80m and 70m respectively. The distance between M to R core is around 200m apart.

As we can see the topographic map in Figure 14(a) and 14(b), the slope of contour line from M core to R core is steep in the edge area, it means that the RSS is weaken quickly in the middle from M core to R core due to NLOS effects. For LOS conditions, RSS should fit into log-normal distribution. A multi-story building in a campus area will experience lower signal strengths within tall buildings due to the absence of LOS propagation.

6.2 Behavior Study on the Human's Presence

As the previous section mention, we collected the RSS data in 2 periods, one is in the morning leisure period (7.30am-9.30am) and the other is in the busy evening period (4:30pm - 6.30pm). We would like to observe the difference between two periods. Figure 13 and 14 show the difference RSS pattern which the RSS collect in the two different time slot. We can see that there is significant change of the RSS value. Figure 14(a) shows the topographic region in 0.9 level is larger than Figure 14(b). We can observe the slope on Figure 14(b) degrades larger than Figure 14(a). As a result, it verifies the effect of the user's presence can affect the mean of the RSS value.

7 Conclusions

In this paper, we propose NM optimized topographic model for RSS distribution. The new model provides quicker references and efficient analysis tool for improving the design of WLAN infrastructure to achieve localization accuracy. In our university site experiment, we provide a spatial analytical model for WLAN tracking in a campus. The fuzzy topographic RSS analytical map provides easier understanding of WLAN RSS pattern in a region. The usage of model can improve the efficiency usage of WLAN infrastructure substantially.

In the future, wireless communications and mobility service provision will be characterized by global mobile access (terminal and personal mobility), a high quality of service with full coverage, and intelligible and simple access to multimedia services for voice and video via one user single terminal. In this paper, we propose a location-aware information retrieval system. The system helps the user to find suitable dinning place and provides accurate and robust positioning. We could further extend our applications into other domains, such as hotel reservation, movie booking and shopping in fashion store.

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