A Dynamic Channel Assignment Method Based on Location Information of Mobile Terminals in Indoor WLAN Positioning Systems

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***Abstract*—In this paper, we propose a dynamic channel assignment method that utilizes location information of mobile terminals to calculate the optimal channel scheme in indoor WLAN positioning systems. Our method could achieve two goals: (a) the optimal channel scheme can guarantee a maximum throughput of overall wireless network. (b) terminals can communicate and be located simultaneously in our system.**

By taking advantage of positioning system, we can know the location of terminals, and such location information can be used to optimize network capacity through assigning appropriate channels. Assigning different channel to neighbouring APs is not only for optimizing network capacity, but also for improving the positioning accuracy due to that it can immigrate the interference among APs and receive accurate signal strength.

To confirm its effectiveness, we evaluate our approach by simulation. We compare our method with the single, random, and static methods and the LCCS method. The results illustrate that the throughput of our channel assignment method is higher than other methods.

***Index Terms*—dynamic channel assignment, location information, communication, positioning, throughput.**

I. Introduction

802.11-based wireless access is a widely used technology in public hot spots such as university campus, airports, coffee bars, and hospitals, etc. A typical development of it in recent years is WLAN (Wireless Local Area Network) of Wi-Fi by which mobile terminals can access wireless networks smoothly through a WLAN AP (Access Point) [1]. However, with the extensive establishment of WLAN environment in public facilities, radio wave interference among APs has become a severe problem.

On the other hand, as wireless networks rapidly gained popularity, various service that is based on context-aware of ubiquitous has been changing our daily life. As an essential part of context-aware service, positioning technologies are important for improving convenience of context-aware software. The most well-known positioning system is GPS (Global Positioning System), which is widely used in vehicles and mobile phones etc. However, a major problem of conventional GPS is that it cannot achieve a satisfactory accuracy degree for users in indoor environment such as in buildings or underground [2]. Therefore, technologies like ultraviolet, RFID and WLAN are researched and developed for indoor positioning [3][4].

In our research, wireless APs are utilized as positioning devices since rapid development of WLAN provides a potential platform for positioning by APs. In a changing wireless network environment (such as airport), a dynamic channel assignment scheme is necessary to optimize wireless network capacity (throughput). Because the number and location information of mobile terminals are changing at any time, it is necessary that observing and knowing the situation of terminals periodically and changing channels of AP to be suit for wireless environment.

The foremost contribution of our research is that we are the first, to the best of our knowledge, using location information as a feedback, to dynamically assign channels to APs and to mitigate interference as well as improve network capacity. Utilizing our indoor positioning system, we can get the location information, and the final objective function is to maximize throughput of overall wireless network. To calculate throughput of wireless network, we use an estimate method according to medium contention principle of CSMA/CA with RTS/CTS [5]. In addition, besides improving network capacity, in the inspect of positioning, the estimate accuracy can also be improved by assigning different channels to APs due to that mobile terminals can receive more accuracy signal strength from different channels of APs.

We extend the description of our work as follows. Section II discusses related work. Section III introduces some technologies involved in our paper. Section IV defines the problem to be addressed and formalizes the problem. To verify the significance of channel assignment from the view point of communication and positioning, in section V, the throughput estimation used in our research is introduced, and a dynamic channel assignment is proposed to get the maximum network capacity according to location information of mobile terminals. Section VI evaluates the proposed method and compares with other methods. And in section VII, we introduce our positioning method in detail, and discuss the relationship between channel assignment and positioning accuracy. Section

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VIII concludes the paper and mentions future work.

II. Related Works

In the area of infrastructure-based 802.11 WLANs, channel assignment schemes have been widely discussed [6][7]. According to how often channel assignments are triggered, it can be classified into static methods and dynamic methods. Static channel assignment schemes are usually executed only once. Once the action is done, the channels are used for a long time. While dynamic channel methods can change the channel of APs periodically according to the situation of wireless network. It is obvious that dynamic methods are better than static methods for performance of network in a changing environment.

The work in [8] is a static method. It discusses the problems of channel assignment as well as AP placement simultaneously, and proposes an approximate solution with ILP (Integer Linear Programming). By adjusting the number of mobile terminals connected to APs, it evaluates network performance such as throughput. The main purpose is to find out optimized (minimized) AP locations from AP candidate points while considering a channel assignment method with a maximized throughput.

The work in [9] also employs a static channel assignment method. However, to investigate the fairness issue of channel assignment in resource sharing among mobile terminals, the authors propose a close-to-optimal approach called *patching algorithm*, which is better than exhausting searching with respect to time complexity. Furthermore, the work proposes a probability-based throughput an estimation method. However, to evaluate throughput performance, the authors compare the method with other throughput evaluation standard. Due to the difference standard between calculation methods, it is difficult to illustrate that the method outperforms others.

The work in [10] proposes a distributed, self-configure channel assignment scheme for uncoordinated WLANs. Core feature of this work is *client-assisted*, which means that APs are assisted with feedback from clients for gathering adjacent devices' traffic information. Since WLAN becomes uncoordinated and independently managed with high AP density, a dynamic channel assignment method becomes important. Different form [10], our work collects and utilizes location information to improve the performance of network.

In addition, location information has also been used in other types of network such as Wireless Sensor Network (WSN). The work in [11] proposes a method to obtain location information by using Echo State Networks (ESNs). The experimental results show that a good accuracy of the prediction can be achieved in a small WSN by configuring the ESNs. Different from it, we pursue positioning accuracy and optimized network capacity by dynamic channel assignment in WLAN. It is commonly desirable to get more accurate positioning with RSSI in indoor environment. However, the propagation conditions are hardly predictable due to the dynamic nature of RSSI. The work in [12] proposes an automatic virtual calibration method before location procedure that does not require human intervention. The highlight is that it can be periodically performed by the wireless channel conditions. Indeed, accurate location information can be used in many applications of network area as well.

III. Involved Technologies

WLAN can work in infrastructure mode or ad-hoc mode, where one of the primary difference between them lies on how APs are connected. In infrastructure mode, APs are connected to each other with wired link to form backbone network. In ad-hoc mode, APs interconnect through single/multiple hop wireless links to the backbone. To guarantee communication of wireless links among single/multiple hop, the same routing's APs must be assigned to a single channel. Therefore, channel assignment is a more important issue in infrastructure mode than in ad-hoc mode. It should be pointed out that infrastructure mode is discussed in our work.

A. 802.11g Channel Specification and 802.11k Protocol

Based on specification, 802.11 mainly consists of 802.11b/g and 802.11a. In this work, we only discuss the specification of 802.11g. The ISM (Industrial, Scientific and Medical) band of 802.11g contains 11∼14 channels. As shown in Fig.1, there are only 3 non-overlapping channel in 802.11g (namely, channel 1, channel 6 and channel 11) [13]. We utilize three non-overlapping channels in this paper.

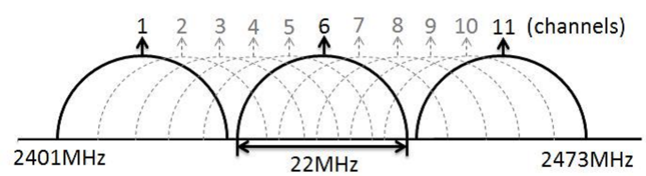

Fig. 1. 802.11g Channel Specification in 2.4GHz.

IEEE 802.11k was established to transfer and measure information of adjacent APs [14]. According to 802.11k, AP channels and other information can be periodically transmitted along with beacon. By this mechanism, APs can clear the channel assignment information of neighborhood. Therefore, 802.11k is useful for the development of channel assignment problem. In our research, channel and location information can be gathered according to this protocol.

B. Data Rate (network throughput) of 802.11b/g

According to IEEE802.11g standard specification, data rate can be automatically selected by connection quality. As shown in Fig.2, IEEE802.11g works in 2.4MHz with a maximum raw data rate of 54Mbps. The data rate is changed according to signal quality and network environment. In this paper, we assume that change of data rate is only related with distance between APs and terminals.

Transmission range of APs or terminals can be divided into communication range and interference range. If packets are sent/received between APs and terminals, they have to be

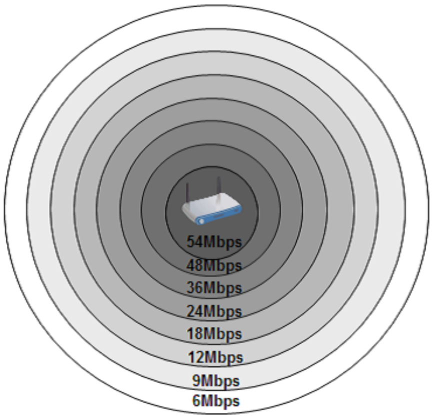

Fig. 2. Data Rate of 802.11g.

located in a mutual communication range. Medium contentions occur if APs or terminals are in the mutual interference range. The received sensitivity thresholds of the two ranges are defined by APs' hardware [15].

To determine communication range and interference range in our work, the range of data rate 24Mbps is defied as communication range of APs. The minimum sensitivity (MIN_{sen}) of 24Mbps is -74dBm. To get the transmission distance of 24Mbps, transmission loss (T_{loss}) need to be calculated by the equation

$$T_{loss} = P_t - MIN_{sen} + G_t \quad (1)$$

Where transmission power P_t is 10dBm, transmitting antenna gain G_t is 0, and MIN_{sen} is -74dBm here. Hence, we can get the T_{loss} as 84dB when minimum sensitivity is -74dBm.

We calculate the transmission distance by free space propagation loss equation as follows.

$$T_{loss} = 20log(4\pi d/\lambda) \quad (2)$$

where d is transmission distance which we need to calculate, wavelength λ is 0.06m in 5GHz. The transmission distance is calculated on 76m as communication radius. Similarly, we define the range of data rate 6Mbps as interference range of APs. The interference radius can be calculated on 193m. These results are utilized in section VI.

C. Medium Access Control (CSMA/CA with RTS/CTS)

At present, 802.11g is widely used in WLAN environment. According to communication protocol of WLAN, CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) is the 802.11 mechanism of MAC layer [5]. However, it cannot avoid collision problem such as hidden terminal problem and multiply simultaneous terminal requests. Therefore, the RTS/CTS handshake-based MAC is proposed. In our research, RTS/CTS is involved when discussing *Potential Restrainer* to estimate throughput in subsection V-A. As shown in Fig.3, the two terminals (i.e., t_1 and t_2) are in the communication range of *ap*, and they may not know the mutual existence of each other. The general access procedure of RTS/CTS is as follows.

1) Terminal t_1 wants to send data through accessing *ap* by sending a message RTS (Request To Send).
2) After receiving RTS, *ap* sends a receipt message CTS (Clear to Send). The CTS can be detected by other communication devices such as t_2 that are in the interference range of *ap*. And all devices except t_1 and *ap* must keep silence until the confirmation message ACK (Acknowledgment) is received by *ap*. Of course t_1 will wait for a period if *ap* is busy.
3) t_1 then obtains an authorization to send data to *ap*. On the contrary, t_1 can also receive data from *ap*.
4) When this data transmission finishes, *ap* sends ACK to all the other devices in its interference range, informing that they could now send RTS messages. *ap* becomes idle again and waits the next RTS from terminals such as t_1 or t_2.

We can summary the above access procedure as four-way handshakes of RTS-CTS-DATA-ACK. To avoid the situation that t_1 and t_2 send RTS messages simultaneously, *ap* waits a random time, and the terminal whose RTS is received first can send data. According to the principle, when *ap* sends CTS, terminals in the interference range of *ap* can be restrained, hence we analyze four types of Potential Restrainers in subsection V-A .

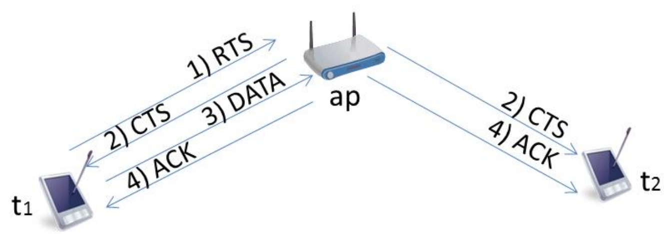

Fig. 3. CSMA/CA with RTS/CTS.

IV. Modeling

A. Overview

Based on the technologies mentioned in the previous section, we model our problem and restrictions by mathematical formulas. Meanwhile, since our solution must satisfy the requirements of both positioning and communication, we summary some assumptions/preconditions made in this work as follows:

(a) To achieve the goal of positioning, every terminal must be able to observe in its interference range three APs at least.
(b) To satisfy the requirement of communication, every terminal must be able to connect with an AP for communication that is in its communication range.
(c) The APs, whose coordinates are known beforehand, can be placed as a regular or irregular deployment in a test field .
(d) Every device (AP or terminal) has only one Network Interface Card (NIC), and thus, the channel of AP used

for communication is the same as the channel of AP used for positioning .

B. Problem Formulation

We first define some core concepts – the sets AP and T of APs and Terminals, respectively, that are used in the work.

The set of APs: $AP = \{ap_i \mid i = 1, 2, ..., m\}$, where each ap_i is an AP.

The set of Terminals: $T = \{t_j \mid j = 1, 2, ..., n\}$, where each t_j is a terminal.

Based on the three non-overlapped channels of 802.11b/g, we consider that each ap can be assigned to a channel k ($k \in \{1, 6, 11\}$), and thus the set AP is divided into three subsets AP_k, where each $ap \in AP_k$ is assigned to channel k and $\forall k, k'$ ($\in \{1, 6, 11\}$), $AP_k \cap AP_{k'} = \Phi$ and $\cup AP_k = AP$.

Since each AP is assumed to have one interface merely and thus an AP only works with one channel. In addition, all APs are assigned to a channel k, where $k \in \{1, 6, 11\}$. The distance between an AP ap_i and a terminal t_j can be calculated by a function $D(ap_i, t_j)$ or $D(t_j, ap_i)$.

As mentioned in subsection III-B, every AP or terminal has an interference range and a communication range. We use R and r ($R \geq r$) to denote the corresponding radius respectively. To judge whether a terminal t_j is located in the interference range of ap_i, we define the function $ATR(t_j,\ ap_i)$ as follows.

$$ATR(t_j,\ ap_i) = \begin{cases} 1 & if\ \ D(t_j,\ ap_i) \leq R \\ 0 & otherwise \end{cases} \tag{3}$$

where $i \in \{1, 2, ..., m\},\ \ j \in \{1, 2, ..., n\}$.

Next, we use NR_j to denote the number of APs that are in the interference range of terminal t_j.

$$NR_j = \sum_{i=1}^{m} ATR(t_j,\ ap_i) \tag{4}$$

where $i \in \{1, 2, ..., m\},\ \ j \in \{1, 2, ..., n\}$.

Similarly, to judge whether a terminal t_j is located in the communication range of ap_i, we define the function $ATC(t_j,\ ap_i)$ as follows.

$$ATC(t_j,\ ap_i) = \begin{cases} 1 & if\ \ D(ap_i,\ t_j) \leq r \\ 0 & otherwise \end{cases} \tag{5}$$

where $i \in \{1, 2, ..., m\},\ \ j \in \{1, 2, ..., n\}$.

Next, we use NC_j to denote the number of APs that are in the interference range of terminal t_j.

$$NC_j = \sum_{i=1}^{m} ATC(t_j,\ ap_i) \tag{6}$$

where $i \in \{1, 2, ..., m\},\ \ j \in \{1, 2, ..., n\}$.

We formulate the two assumptions/preconditions (a) and (b) mentioned in subsection IV-A as follows. Note that we denote them as "Restriction 1" and "Restriction 2", respectively, for illustration simplicity in the algorithm in subsection V-B.

Restriction 1 (on Positioning): The basic condition for positioning is that there are at least three APs in the interference range of any terminal t_j. So we describe the assumption as follows.

$$\forall j, \qquad NR_j \geq 3. \tag{7}$$

where $j \in \{1, 2, ..., n\},\ \ k \in \{1, 6, 11\}$.

Restriction 2 (on Communication): Every terminal must be able to connect with a AP for communication. To satisfy this, it is required that at least one AP is in the communication range of the terminal, which can be described as follows.

$$\forall j, \qquad NC_j \geq 1. \tag{8}$$

where $i \in \{1, 2, ..., m\},\ \ j \in \{1, 2, ..., n\}$.

In fact, there may exist multiple APs in the communication range of a terminal. So we define a set $H_j = \{ap_i \mid D(t_j, ap_i) < r\}$. The element APs of set H_j are those that can communicate with terminal t_j in their communication range.

For providing wireless broadband, terminals are required to connect their nearest AP which is selected from the AP set H_j. The function $Q(t_i, ap_j)$ is used to define this issue.

$$Q(t_j,\ ap_i) = \begin{cases} 1 & ap_i \in H_j \wedge (\forall i'\ \ (ap_{i'} \in H_j \wedge i' \neq i) \\ & \quad \rightarrow D(ap_i, t_j) \leq D(ap_{i'}, t_j)) \\ 0 & otherwise \end{cases} \tag{9}$$

If ap_i is the nearest AP to t_j, the value of function $Q(t_i, ap_j)$ is 1, otherwise it is 0. In brief, one terminal can only work in a channel, and this channel must be taken both communication and positioning into account simultaneously.

V. A PROPOSAL OF DYNAMIC CHANNEL ASSIGNMENT

A. A Throughput Estimation Method

In our research, we estimate terminal throughput according to data rate and the number of potential restrainers. We assume a WLAN environment without interference and obstacle, and that APs have no delay in switching communication from one terminal to another.

We imagine that there are one terminal and one AP merely in an ideal environment. If the terminal is in the area of 54Mbps of 802.11g, we consider that the throughput of this terminal is 54Mbps. On the other hand, if the number of terminals increases, the phenomenon of Medium Access Contention Constraints (MACC) [13] happens obviously. In this paper, we estimate throughput of overall network by considering accumulation of potential restrainers. Therefore, we analyze four types of potential restrainers for an arbitrary terminal t_1 that communicates with AP ap_1.

Type1: As shown in Fig 4(a), mobile terminals in the interference range of t_1 are considered as restrainers of type1. If mobile terminals near to t_1 are in its interference area, potential MACC happens directly. The number of potential type1 restrainers is denoted by RST_1, where in Fig 4(a), r_1 and r_2 are such restrainers.

Type2: Different from type1, mobile terminals, which are in the interference range of ap_1 that connects with terminal t_1, are considered as restrainers of type2.

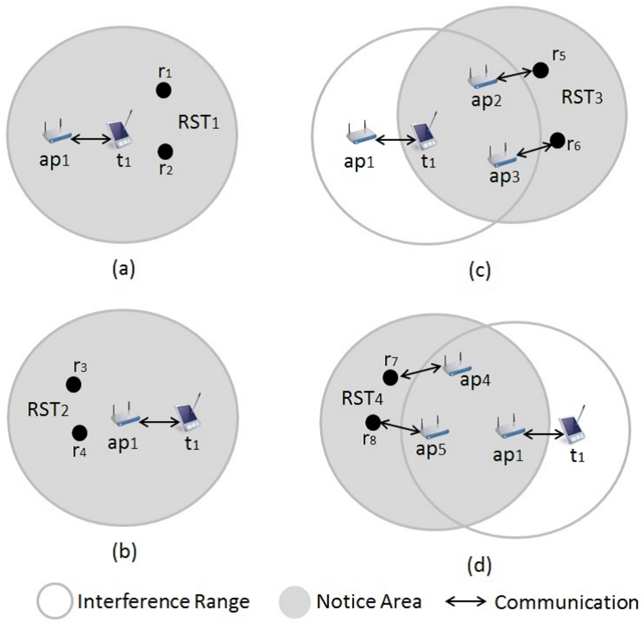

Fig. 4. Four Types of Potential Restrainers.

Potential MACC also happens in this case. The number of potential type2 restrainers is denoted by RST_2, where in Fig 4(b), r_3 and r_4 are such restrainers.

Type3: As shown in Fig 4(c), mobile terminals, which communicate with those APs that are not ap_1 but also in the interference range of t_1, are considered as restrainers of type3. According to the principle of CSMA/CA with RTS/CTS, MACC occurs between those terminals and t_1. The number of potential type3 restrainers is denoted by RST_3, where r_5 and r_6 are such restrainers.

Type4: As shown in Fig 4(d), mobile terminals, which communicate with those APs that are in the interference range of ap_1, are considered as restrainers of type4. Similar to type3, MACC also occurs between those terminals and t_1. The number of potential type4 restrainers is denoted by RST_4, where r_7 and r_8 are such restrainers.

Based on these types of potential restrainers, the function of calculating throughput for an arbitrary mobile terminal $t \in T$ can be defined as follows, where $t_j \neq t$:

$$TH(t) = \frac{DR(t)}{\sum_{j=1}^{n} RST(t, t_j)} \tag{10}$$

where

$$RST(t, t_j) = \begin{cases} 1 & \text{if } t_j \text{ is the potential restrainer of } t \\ 0 & \text{otherwise} \end{cases} \tag{11}$$

$DR(t)$ is the data rate of t which is calculated by the RSSI received from its connecting AP. In this work, we converse it to the transmission distance between AP and terminal. According to Equation (1), (2) and the data rate of 802.11g as shown in Fig.2, transmission distance can be calculated. For terminal t, the number of all potential restrainers can be represented by $\sum_{j=1}^{n} RST(t, t_j)$. Function $RST(t, t_j)$ is used to check whether terminal t_j is the potential restrainer of t.

Therefore, the function of calculating throughput for overall terminals can be defined as:

$$\sum_{j=1}^{n} TH(t_j) \tag{12}$$

B. The dynamic channel assignment method

As mentioned in our former work [16], channel assignment can also improve the throughput of wireless network. In that work, we have proposed a static channel assignment method for improving network capacity. However, it cannot deal well with a dynamic environment of mobile terminals. According to the throughput estimation method in subsection V-A. Terminals' throughput has relationship with location of terminals due to counting the number of potential restrainers. Considering the advantage of our positioning system, an optimal wireless network capacity could be achieved by dynamically reassigning channels through utilizing collected terminal-assisted information (especially, location information). The system can check the number and location of terminals periodically, calculate the potential restrainers for each terminals, and finally, find out the maximum throughput of overall terminals by periodic channel assignment. The advantage of dynamic channel assignment is that WLAN can always keep high network capacity for users (mobile terminals).

Pseudo code of the proposed algorithm is described as follows.

Dynamic Channel Assignment Algorithm

```
Initialization:
  All aps are assigned to channel 1;
  MAX_TH = Σ_{j=1}^{n} TH(t_j); //  t_j is terminal.

Optimization:
  Exhaustively search for any possible combinations of aps' channels
  in a time interval
   {
    If (Restriction 1 && Restriction 2)
      Calculate throughput TH of this channel combination;
      If (TH > MAX_TH )
        MAX_TH = TH;
    }

Output:
  The channel assignment when MAX_TH;
  The value MAX_TH.
```

Initially, according to the location information of terminals, APs are assigned to an optimal channel scheme by an exhaustive enumeration. As the terminals move, the status of WLAN also changes. The algorithm is executed periodically to calculate the location and throughput of terminals. By the way, for every possible combination of *aps*' channel scheme, it is necessary to check whether each channel assignment satisfies both Restriction 1 and Restriction 2 simultaneously.

VI. Evaluation and Analysis

A. *Simulation Parameters*

In this section, we evaluate our proposal by simulation. To confirm its effectiveness, we compare it with:

1) The single and random methods.
   By the single method we mean the method in which all APs are assigned to the same channel. By the random method we mean the method in which APs select three isolated channel randomly.
2) The static method.
   By the static method we mean once a channel is assigned it cannot be changed by the environment.
3) The LCCS method (Least Congested Channel Search) [17]. Traditionally the LCCS method means each AP scans all available channels and chooses the one used by the least number of associated devices. In this paper, LCCS can only select channels from channel 1, channel 6, and channel 11.

TABLE I
The Simulation Parameters

Simulation Parameters	Value
Service Area Size	315×315 meter
Number of APs	11
Number of Terminals	14
Channel Set	{channel 1, channel 6, channel 11}
The Employed 802.11 Specify	802.11g
Radius of Communication	76 meter
Radius of Interference	190 meter

As shown in Table I, we test our simulation in a 315×315 meter test area. 11 APs are fixed as mesh shown as Fig.5(a), in which the vertical distance and horizontal distance for neighborhood APs are 63 meter. The number of terminals is 14 and location is changed randomly. As time passes, dynamic channel assignment is executed at each time interval. For comparison, we test 10 time intervals (10 cases) to calculate throughput for each experiment in our paper. The radiums of communication and radius of interference are set as 76 meter and 190 meter, respectively. We test some cases under the specification of 802.11g, and only three isolated channels can be used in our paper.

B. *Scenarios and Analysis*

In the test area, APs are in fixed coordinations, while terminals move randomly. As a premise, we require that each terminal can obverse at least 3 APs. This is a requirement for considering positioning and communication simultaneously. Dynamic channel assignment can assign channels for APs periodically according to location information of terminals.

As mentioned in subsection VI-A, we compare our method in three scenarios.

1) Comparison with the single method and the random method.
   Terminals are deployed as two parameter of dispersed random (Fig.5(c)) and cluster random (Fig.5(d)). According to the result shown in Fig.6, The solid lines

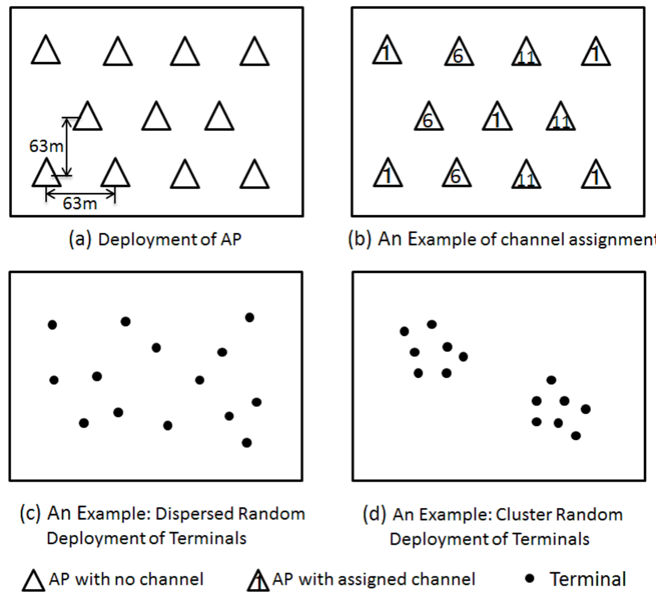

Fig. 5. Examples of APs/Terminals Deployment.

represent the result (throughput) of dynamic channel assignment method. The short dotted line represent the result (throughput) of random channel assignment method and the long dotted line represent the result (throughput) of single channel assignment method. Either dispersed random or cluster random appears our proposal is best solution for throughput. The single channel assignment method is most disadvantageous for throughput. The random channel assignment is in between the single method and our proposal. However, it is not stable scheme.

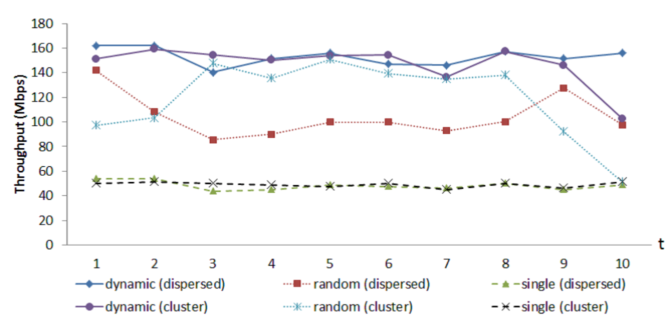

Fig. 6. Comparison with Single Method and Random Method.

2) Comparison with the static method. We also conduct the evaluation under dispersed random pattern and cluster random pattern. First, terminals are deployed as dispersed random pattern. As shown in Fig.7, initially, to obtain the maximum throughput, the dynamic method assign the optimal channel scheme for APs in the same way as the static method. However, as terminals are moving, the dynamic method is better than the static method obviously. The reason is that the dynamic

method can detect changes of network environment and tune channels of APs for optimal throughput.

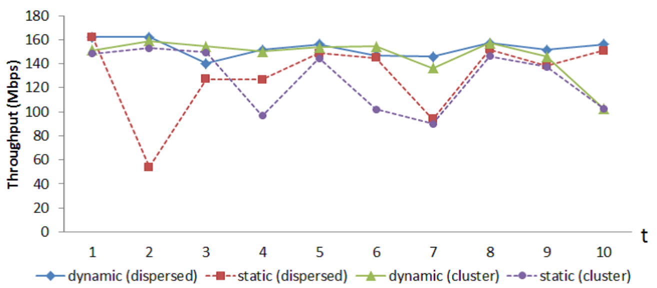

Fig. 7. Comparison with the Static Method (The Dispersed Pattern).

Second, terminals are deployed as cluster random pattern. Different from dispersed pattern, terminals centralized appear at some regions as cluster. We consider this scenario very likely to occur in shopping mall or stadium where persons gather together.

3) Comparison with LCCS.
We compare the dynamic method with LCCS in cluster random pattern and dispersed random pattern for terminals under 802.11g. In fact, LCCS is also a dynamic channel assignment method which changes channel scheme by the WLAN environment. According to the results shown in Fig.8, our proposal is better than LCCS on the whole.

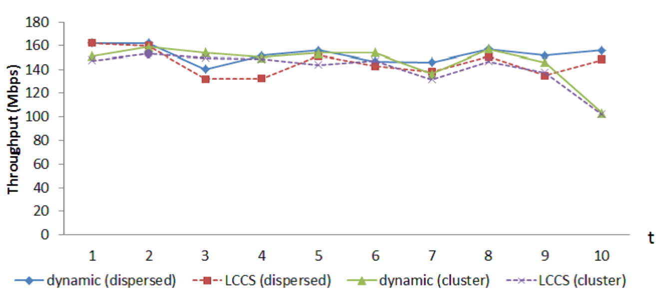

Fig. 8. Comparison with LCCS.

In brief, our dynamic method is better than other methods (single, random, static and LCCS) with respect to network throughput, although the advantage is not that obvious in some cases of cluster pattern.

VII. A Positioning method and A discussion about influence of positioning precision

Indoor positioning methods by WLAN can be divided into multilateration (trilateration) and scene analysis [18]. In general, there are various types of measurement of the signal from AP: time (TDoA [19] and TOA [20]) and signal [3][1]. For example, multilateration converses distance either by measuring the TDoA (Time Difference of Arrival) of a signal from three or more transmitters, or by measuring the distance according to propagation of signal. The time mode is suitable for using long distance such as GPS. Due to space limitation of indoor environment, it is difficult to reach the requirement of measuring time (or time difference of arrival) without special device. On the other hand, there is an advantage for signal mode that it estimates accuracy by RSSI of APs, while does not depend on special hardware. Terminals (mobile devices) detect signal strength from APs and calibrate the signal by certain approach [12].

In this section, we introduce the multilateration (trilateration) by RSSI used in our positioning system, and give a conclusion about influence of channel assignment on positioning precision. To get more accurate location information, inspired by work [12], we conduct calibration before positioning procedures. The calibration includes tuning parameters of the propagation model formula, deleting irregular signal strength, setting threshold value, and calculating average signal strength.

[1]There are some other types of classification, but we do not discuss them in this paper

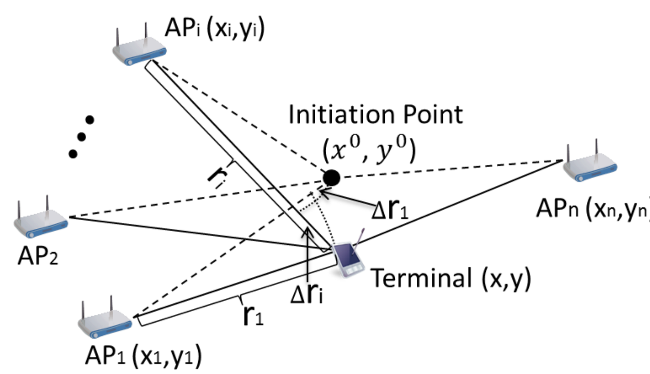

Fig. 9. Multilateration (Trilateration) Methods for Positioning.

A. The Location method in our research

We can measure the distance between transmitters (APs) and receivers (terminals) by RSSI and calculate coordinate by pythagorean theorem. For example, the distance between AP_i and terminal is r_i, the coordination of AP_i is (x_i, y_i), and the coordination of terminal is (x, y). r_i can be defined as

$$r_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} \quad (13)$$

Suppose the terminal that receives RSSI from AP_i is ss_i, the relationship between ss_i and r_i is

$$ss_i = P_{tx} - 20log_{10}f - 10\varphi log_{10}r_i + 28.0 \quad (14)$$

Formulas (13) and (14) can be combined into formula (15) as follows.

$$ss_i = P_{tx} - 20log_{10}f - 10\varphi log_{10}\sqrt{(x_i - x)^2 + (y_i - y)^2} + 28.0 \quad (15)$$

Where, P_{tx} is transmit power which can be regarded as 0 here, frequency f is 2450(Mhz). Constant term $-20log_{10}f +$

28.0 can be denoted as O, φ is an environment parameter. That is to say, formula (15) can be written as

$$ss_i = -10\varphi log_{10}\sqrt{(x_i - x)^2 + (y_i - y)^2} + O \quad (16)$$

By the way, to get more accurate location information, we tune the environment parameter φ of formula (16) in real indoor environment, and conduct calibration as mentioned above before transferring received signal strength to distance.

According to calibrated signal strength, we can calculate the distance between APs and terminal. Of course, if a terminal can receive n AP's signal strength, n distances can be obtained as $r_1, r_2, ..., r_n$. So the coordination (APs and terminal) and distance between APs and terminal can be described as combined equations as follows.

$$\begin{cases} r_1 = \sqrt{(x_1 - x)^2 + (y_1 - y)^2} \\ r_2 = \sqrt{(x_2 - x)^2 + (y_2 - y)^2} \\ \quad\vdots \\ r_n = \sqrt{(x_n - x)^2 + (y_n - y)^2} \end{cases} \quad (17)$$

If we can solve the equations, the coordination of terminal (x, y) is obtained. However, since they are non-linear equations, it is difficult to use normal methods. The successive approximation method is used in our system. The main steps are introduced as follows:

1) An initiation value (x^0, y^0) is assumed as the coordination of terminal (x, y). (x^0, y^0) can be set to an arbitrary value.
2) The difference (Δr_i) of r_i and the distance between (x^0, y^0) and AP_i can be written as:

$$\Delta r_i = r_i - \sqrt{(x_i - x^0)^2 + (y_i - y^0)^2} \quad (18)$$

3) By utilizing Δr_i to update (x^0, y^0), the estimate coordination of terminals can be obtained. To solve the updated value (x^0, y^0) directly, the right-hand side of the equation (18) can be develop by the Taylor series expansion as follows.

$$\begin{cases} \Delta r_1 = \frac{\delta r_1}{\delta x}\Delta x + \frac{\delta r_1}{\delta y}\Delta y \\ \Delta r_2 = \frac{\delta r_2}{\delta x}\Delta x + \frac{\delta r_2}{\delta y}\Delta y \\ \quad\quad\vdots \\ \Delta r_n = \frac{\delta r_n}{\delta x}\Delta x + \frac{\delta r_n}{\delta y}\Delta y \end{cases} \quad (19)$$

The equations (19) can be expressed by a matrix equation as

$$\mathrm{G}\Delta\vec{l} = \Delta\vec{r} \quad (20)$$

where vector $\Delta\vec{l} = (\Delta x, \Delta y)^{\mathrm{T}}, \Delta\vec{r} = (\Delta r_1, \Delta r_2, \cdots, \Delta r_n)^{\mathrm{T}}$, and matrix G is

$$\mathrm{G} = \begin{pmatrix} \frac{\delta r_1}{\delta x} & \frac{\delta r_1}{\delta y} \\ \frac{\delta r_2}{\delta x} & \frac{\delta r_2}{\delta y} \\ \vdots & \vdots \\ \frac{\delta r_n}{\delta x} & \frac{\delta r_n}{\delta y} \end{pmatrix} \quad (21)$$

Because the number of unknowns is more than the number of equations, Least Squares Method is utilized to solve equation $\Delta\vec{l} = (\mathrm{G}^{\mathrm{T}}\mathrm{G})^{-1}\mathrm{G}^{\mathrm{T}}\Delta\vec{r}$.

4) Using the solution $\Delta\vec{l} = (\Delta x, \Delta y)^{\mathrm{T}}$ to update initial value (x^0, y^0) as $x^1 = x^0 + \Delta x$, $y^1 = y^0 + \Delta y$.
5) After updating (x^1, y^1), return to step 1), and repeated (step 1) ~ step 5)) until $(\Delta x, \Delta y)$ (error distance) becomes small enough and is acceptable. Finally (x^1, y^1), being as the estimate terminal coordinate, is output.

The problem of successive approximation method is that some solutions cannot converge. However since the main work of this paper is not on positioning method, these solutions are not to be considered.

B. A discussion: the relationship between channel assignment and positioning accuracy

The work in [21], reported that positioning precision is effected by channel interference among APs in indoor WLAN positioning. The investigation result indicated that the positioning accuracy heavily depends on channel interference. They compared different channel assignment schemes: ad-hoc, sequential, and orthogonal in experiments. ad-hoc channel assignment denotes that all APs are assigned to a single channel because APs can not communicate with each other if they use different channels in ad-hoc network. Sequential channel assignment means that APs are assigned to channels in ascending order (or in descending order) such as channel 1, channel 2, and channel 3, etc. Orthogonal channel assignment means that APs are assigned to channels with non-overlapping bandwidth. For example, channel 1, channel 6 and channel 11 are orthogonal channels in 802.11b/g. It is obvious that interference of ad-hoc channel assignment is most serious. The second is sequential channel assignment. Orthogonal channel assignment scheme is almost considered as no interference among APs. The experiment results shows that choosing an orthogonal channel assignment scheme could make location more accurate than others.

VIII. Conclusion

In this paper, we propose a dynamic channel assignment method based on location information of mobile terminals to optimize network throughput in WLAN positioning systems. We discuss the meaning of channel assignment in communication and positioning. According to results of simulation, our proposal, which can dynamically detect changes of WLAN environment, can achieve a better effect in throughput than other methods. In the area of positioning, because an effective channel assignment can immigrate the interference among APs, the positioning precision can be improved to some extent.

Therefore, channel assignment is not only good for communication, but also able to improve positioning precision. An accurate location information can play a positive feedback role for obtaining optimal network capacity by a dynamic channel assignment. Channel assignments can attain two objectives in communication and positioning.

We will confirm the relationship between positioning precision and channel assignment in quantitative through real environment experiments. Because ”to optimize network capacity by utilizing location information as a feedback” is the most important that the idea of this paper, we will apply this concept into other positioning systems to improve network performance.

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