Research on Neighboring APs Discovery Methods in PnP WLAN

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\textbf{Abstract}—To overcome the disadvantage in traditional manual configuration method for WLANs, such as the high configuration and maintenance cost and low efficiency of system performance, we propose the Plug-and-Play (PnP) of Multi-mode APs that APs auto-configure themselves based on the network environment. In order to implement the PnP, the Multi-mode AP must obtain its neighboring APs' configuration and environment information. Existing neighboring APs discovery method can not provide the precise neighboring APs information to satisfy the requirement of PnP of AP. In this paper, we propose three kinds of neighboring AP discovery and information exchange methods, which are passive discovery method, active discovery method and station assistant discovery method. Using these three neighboring AP discovery methods, AP can discover all neighboring APs and obtain needed information. We further propose two whole process flows, which combine three discovery methods in different manner, to achieve different goal. One process flow is to discover the neighboring AP as fast as possible, called fast discovery process flow. Another one is to discover the neighboring AP with minimal interference to neighboring APs, called the minimal interference process flow. The efficiency of the two process flows is shown in the simulation results.

\textbf{Index Terms}—Plug-and-Play, WLAN, APs discovery, auto-configuration

I. INTRODUCTION

During the past years, the IEEE 802.11 wireless local area networks [1] have been widely deployed to access Internet in universities, offices, hotels, airports and other public places because of its convenience of deployment, low cost and high-rate data transmission capability. However, with the deployment of a large number of APs, the problem of configuration and maintenance of APs also arises. At present, the configuration and maintenance of APs are implemented in manual method, which is only effective for the configuration of few numbers of APs. But the feature of WLAN is that the radio coverage area of AP is small and the number of APs needs to be configured is often large in one deployment. The manual method greatly increases the cost of both the configuration and maintenance of the WLANs system and usually can not get better configuration results which lead to low efficiency in performance.

The PnP of APs, which means that APs auto-configure themselves based on the network environment, is a effective solution to this problem and is also is an important development trend for next generation wireless access networks [5] [6]. The PnP of APs provides a mechanism to configure APs in an automated manner so that no or least configuration and maintenance work have to be performed manually. It can reduce the cost of configuration and deployment and improve the system performance.

To implement the PnP of APs, the APs should be able to support neighboring AP discovery, dynamic working channel selection and dynamic load balance etc. In this paper, we focus on the neighboring AP discovery, which is the basic to implement the PnP of APs. Only obtaining the precise information of both neighboring APs and the radio environment, AP can select the most suitable working channel to implement the PnP of itself. To the best of our knowledge, existing neighboring AP discovery method, which allows the AP to get neighboring AP information through OAM, can not provide the precise neighboring APs information to satisfy the requirement of PnP of AP. So it needs a new neighboring AP discovery technology.

In this paper, we propose three kinds of neighboring AP discovery methods, which are passive discovery method, active
discovery method and station assistant discovery method. The AP can discover all neighboring APs and obtain needed information by using these three methods. We simulate the interference to working cells by using three neighboring AP discovery scheme simultaneously. The simulation results show that the interference of our proposed scheme to working cells is small. AP can discover all neighboring APs on condition of not decreasing the performance of neighboring APs basically.

The rest of this paper is organized as follows. In Section II, we provide a brief description of neighboring AP information list. Active discovery method, passive discovery method and station assistant discovery method are introduced in Section III, Section IV and Section V, respectively. Then in Section VI, we describe the whole process flow. Simulation results are given in Section VII. Finally, the last section concludes the paper.

II. NEIGHBORING AP INFORMATION LIST

In this paper, we classify AP into two types. AP that initiates the neighboring AP discovery is called the new AP (nAP). Other APs are called the old AP (oAP).

The neighboring APs of an AP are defined as the APs that have overlapping radio coverage area with it. Each AP has a neighboring AP information list that saves all the needed neighboring AP information. AP obtains the information of neighboring APs using three neighboring AP discovery methods and saves them in this list. The structure of neighboring AP list is shown as follows:

<table>
<thead>
<tr>
<th>Neighboring AP MAC address</th>
<th>Neighboring AP channel</th>
<th>Neighboring AP Load</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

III. ACTIVE DISCOVERY METHOD

In active discovery method, the nAP initiates the neighboring AP discovery flow and broadcasts the Active Probe Request frame periodically. The oAPs which are within the radio coverage of the nAP receive the Active Probe Request frame, and respond to the nAP via the wired backbone. At last, the nAP adds the information of the oAPs to its own neighboring AP information list. A typical scenario of Active Discovery Method is shown in Figure 1:

![Figure 1 Active Discovery Method](image)

A. The Frame Formats

In active discovery method, we define two kinds of frames to exchange information between nAP and oAP. The frame formats are described in this subsection.

- **Active Probe Request Frame**
  
  The Active Probe Request frame, which is extended from the Probe Request frame defined in the IEEE 802.11 [1], is used by nAP to initiate the neighboring AP discovery. We add action field and scan-completed neighboring AP field in the Probe Request frame. The frame format is shown in Figure 2.

![Figure 2 Active Probe Request frame](image)

   Table 2 Action subfield

<table>
<thead>
<tr>
<th>Meaning</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Probe Request Frame</td>
<td>0</td>
</tr>
<tr>
<td>Station Assistant Probe Request Frame</td>
<td>1</td>
</tr>
<tr>
<td>Station Request Frame</td>
<td>2</td>
</tr>
<tr>
<td>Reserved</td>
<td>3-255</td>
</tr>
</tbody>
</table>

   The scan-completed neighboring AP field, which is shown in Table 4, is used to indicate the neighboring APs that the nAP has already obtained all information needed. The neighboring AP number indicates the number of neighboring AP MAC address subfield. The neighboring AP MAC address subfield is used to identify the neighboring APs’ MAC address that the nAP has already obtained all information needed.

![Figure 3 Active Probe Response Frame](image)

   Table 4 Scan-completed Neighboring AP field

<table>
<thead>
<tr>
<th>Neighboring AP Number</th>
<th>Neighboring AP MAC Address 1</th>
<th>...</th>
<th>Neighboring AP MAC Address n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octet:</td>
<td>1</td>
<td>...</td>
<td>6</td>
</tr>
</tbody>
</table>

- **Active Probe Response Frame**
  
  The Active Probe Response frame is used by oAP to report the related information, such as load etc., to nAP via the wired backbone. The frame includes MAC address, BSSID and load of oAP.

![Figure 4 Flow of Active Discovery Method](image)

B. The Flow of Active Discovery Method

Figure 4 shows the process flow of the active discovery method.
The nAP broadcasts the Active Probe Request frame periodically. After receiving the Active Probe Request frame, the oAP checks if its MAC Address is contained in the scan-completed neighboring AP field. If contained, which means that the nAP has obtained all needed information of this oAP, the oAP ignores this request and does not respond to the nAP. Otherwise, the oAP responds the Active Probe Response frame to the nAP via the wired backbone. After receiving response, the nAP updates its neighboring AP information list.

IV. PASSIVE DISCOVERY METHOD

In passive discovery method, the nAP listens to the channel and receives beacon frames of the neighboring APs. Then the nAP deals with beacon frame according to the data in neighboring AP list.

A. The Frame Formats

The Beacon frame does not include all the information that the nAP need. In order to get information needed, the nAP uses passive probe request/response frame to exchange data with oAP via the wired backbone.

B. The Flow of Passive Neighboring AP Discovery

Figure 6 shows the process flow of the passive discovery method. After receiving the beacon frame of oAP, the nAP checks its own neighboring AP list to check if all information of this oAP has already been added to the list. If all information of oAP has already been in the list, the nAP ignores the beacon frame. Otherwise, the nAP updates its neighboring AP list and adds the information of oAP to its list. Then the nAP sends request to the oAP. The oAP responds information to the nAP. Then nAP updates the information of the oAP in its neighboring AP list.

V. STATION ASSISTANT DISCOVERY METHOD

In some case, two neighboring APs have overlapping area, but they can not communicate with each other directly as shown in Figure 7. In order to deal with this case where both passive discovery method and active discovery method are ineffective, we bring forward the station assistant discovery method. The stations in the overlapping area can receive the frames from both of these two APs simultaneously. We use these stations to discover the neighboring APs.

A. The Frame Formats

As seen in Figure 7, the nAP broadcasts the Station Assistant Probe Request frame periodically. The stations, which receive the request frame, send a request to their associated APs to inform the oAP. Finally oAP responds information back to the nAP via the wired backbone.

A. The Frame Formats

In this subsection, we describe the frame formats of Station Assistant Probe Request frame and Station Request frame and Probe Response frame.

- Station Assistant Probe Request Frame
The frame format of the Station Assistant Probe Request frame is the same as that of the Active Probe Request frame, as shown in Figure 2. The Action field is set to 1 in the Station Assistant Probe Request frame.

- **Station Request Frame**
  The Station Request frame, which is extended from the Probe Response frame defined in the IEEE 802.11 [1], is used by stations to inform the associated AP about the neighboring AP discovery request.

- **Probe Response frame**
  The frame format of the Probe Response frame is the same as that of the Active Probe Response frame, as shown in Figure 3.

### B. The Flow of Station Assistant Neighboring AP Discovery

Figure 9 shows the process flow of the station assistant neighboring AP discovery method. The nAP broadcasts the Station Assistant Probe Request frame periodically. After receiving the Station Assistant Probe Request frame, the station checks if the MAC address of its associated AP is contained in the scan-completed neighboring AP field. If the MAC address is contained, the station ignores this request. Otherwise, the station send station request frame to inform its associated oAP. Then oAP response probe response frame to nAP via the wired backbone. Based on the information received, the nAP modifies its own neighboring AP list.

### VI. THE OVERALL PROCESS FLOW

The feature of three kinds of neighboring AP discovery methods is different According to the analysis. The passive discovery method and active discovery method have the same neighboring APs discovery coverage, but the interference to the neighboring AP is smaller than that of active discovery method. The mean discovery time of passive discovery method is larger than that of active discovery method. The interference to the neighboring AP of station assistant discovery method is larger than that of passive discovery method. But discovery coverage of it is larger than that of passive discovery method. According to these feature, we propose two kinds of whole process flows for different goals. One is fast discovery process flow. Other is minimal interference process flow.

#### A. Fast Discovery Process Flow

The goal of fast discovery process flow it to discover the neighboring AP as fast as possible to save the discovery time. The nAP uses the active discovery method, passive discovery method and station assistant discovery method simultaneously. The nAP switches in each available channel one by one and stays in each channel for a period of time. The nAP discovers neighboring APs using three methods in each channel and obtains the needed neighboring AP information. The nAP saves the information of neighboring APs into its neighboring AP list. The diagram of this process flow is shown in Figure 10.

#### B. Minimal Interference Process Flow

The fast discovery flow can discover all neighboring AP as fast as possible, but the influence to the neighboring AP is great. In order to reduce the influence to the neighboring AP, we propose another process flow – minimal interference process flow. According to the feature of three discovery methods, we firstly use passive discovery method to discover the neighboring AP. After delaying T seconds, the nAP uses the station assistant discovery method to discover other neighboring APs that can not be discovered by using passive discovery method. The stations, which associate to the APs that are discovered by using passive discovery method, need not respond the station assistant probe request. Therefore, the interference to the neighboring AP is reduced. The whole process flow is shown in Figure 11. The nAP switches in each available channel one by one. In each channel, the nAP firstly uses the passive discovery method to discover neighboring APs. Then, after delaying T seconds, the nAP uses the station assistant discovery method to discover
other neighboring APs.

![Flowchart](image)

**VII. SIMULATION RESULTS**

In this section, we simulate the fast discovery process flow and minimal interference process flow to compare the performance of them. The network structure of simulation is shown in Figure 12. In the simulation, the beacon interval is set to 0.02 seconds and the broadcast interval of active request frame and station assistant request frame of nAP is set to 0.008 seconds. The Delay T is set to 0.5 second.

Figure 13 and Figure 14 show the comparison of system throughput between fast discovery and minimal interference. From the Figure 13, we can see that when the system load is light, the interference to the neighboring AP of two process flows is basically the same. But under heavy system load scenario, the fast discovery flow brings more interference to the neighboring AP than the minimal interference mode; The system throughput of fast discovery process flow is smaller than that of minimal interference, as shown in Figure 14.

Figure 15 shows the comparison of neighboring discovery time in two kinds of process flows. From the figure we can see that the fast discovery process flow uses less scan time than the minimal interference process flow.

The interference to neighboring APs of the minimal interference flow is smaller than that of fast discovery flow. Opposite, the minimal interference flow uses more time to discover all neighboring AP than that of fast discovery flow. The nAP can choose the process flow according to the scenario.

![Network Structure](image)

**Figure 12** Network structure

![Throughput Comparison](image)

**Figure 13** Comparison of throughput when system data source rate at 4Mbps

![Throughput Comparison](image)

**Figure 14** Comparison of throughput when system data source rate at 8Mbps
This paper proposes three kinds of neighboring AP discovery and information exchange methods, which are passive discovery method, active discovery method and station assistant discovery method. The AP can discover all neighboring APs and obtain information needed by using these three methods. We also propose two whole process flows, fast discovery process flow and minimal interference process flow. The simulation results show that the interference to neighboring APs of the minimal interference flow is smaller than that of fast discovery process flow. The time to discover all neighboring AP of minimal interference flow is longer than that of fast discovery process flow. The nAP can choose the process flow according to the scenario.

The Plug and Play of APs brings a huge question domain to heterogeneous WLAN networks. It is natural that there are numerous issues and open questions for further study to realize PnP of APs. One of the difficulties identified is that how to make the select the suitable working mode and channel. Another issue is how to optimize the oAPs when nAPs become their neighbors. Besides this, another direction for future work might be the realization of PnP of APs in the practical networks.

ACKNOWLEDGMENT

This work was supported in part by the NTT-DoCoMo Beijing communication Labs. The authors would like to thank the contributions of the colleagues from NTT-DoCoMo Beijing Labs.

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