DeuceScan: Deuce-Based Fast Handoff Scheme in IEEE 802.11 Wireless Networks

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Abstract

The 802.11 IEEE Standard has been enabled low cost and effective LAN services (WLAN). It is widely believed that WLAN will become a major portion of the fourth generation cellular system (4G). The seamless handoff problem is very important design issue. The entire delay time of a handoff is divided into probe, authentication, and reassociation delay time, and the probe delay occupies most of the handoff delay time. Existing results investigate the fast handoff schemes to mainly reduce the probe delay. This paper presents a new fast handoff, called DeuceScan, scheme to reduce the probe delay for 802.11-based WLANs. A spatiotemporal approach is developed in DeuceScan scheme to utilize spatiotemporal graph to provide the spatiotemporal information for making better handoff decisions to exactly search for the next AP (access point). It efficiently reduces the MAC layer handoff latency. Our DeuceScan scheme is a pre-scan approach, and two factors of signal strength and variation of signal strength are both considered in our DeuceScan scheme. Finally, the simulation results illustrate our performance achievements in handoff delay time and packet loss rate, compared to existing fast handoff schemes.
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Chapter 1

Introduction

The 802.11 IEEE Standard has been enabled low cost and effective LAN services (WLAN). It is widely believed that WLAN will become a major portion of the fourth generation cellular system (4G). Many wireless multimedia and peer-to-peer applications, such as VoIP [1] and mobile video conference, are developed on wireless LANs. The real-time applications suffer the handoff latency when a mobile host roaming between different wireless LANs.

For the IEEE 802.11 MAC operation [3], the ”handoff” function which occurs when a mobile host (MH) moves its association from one access point (AP) to another is a key point to mobile users. There are many analysis results about handoff delay time [4] [5] [20] [6] and many methods [7] [18] proposed to reduce the handoff latency. Mishra et al. [10] divided the complete handoff process into two distinct logical steps: discovery and reauthentication, and classified the entire handoff latency into three delays: probe delay, authentication delay, and reassociation delay. The probe delay occupies very large proportion of the whole handoff latency, hence how to reduce the probe delay is our main object. In the IEEE 802.11 standard, the scan function is used in the discovery phase to help an MH with finding the potential APs to reassociate with, and a full scan of probing eleven channels will be implement when an MH entering the handoff process. To improve the scan operation can significantly facilitate to reduce the handoff latency. In order to decrease the handoff latency, a lot of handoff schemes in connection with different kinds of delays are proposed. Subsequently, the related research results are briefly described with regard to two parts, such as discovery phase including and probe delay and reauthentication phase including authentication delay and reassociation delay.

While reducing the authentication delay and reassociation delay, several methods are stated below. Mishra et al. [11] described the use of a data structure, neighbor graphs, which dynamically captures the mobility topology of a wireless network as a means for pre-positioning the context of a MH ensuring that the MH’s context always remains one hop ahead. The signaling and data overhead may be significant when there are many neighbor APs. Mishra et al. [12] also use the neighbor graphs to reduce the authentication time by proactively distributing necessary key material one hop ahead of the mobile user. Pack et al. [14] proposed a
selective neighbor caching (SNC) scheme, which only propagates an MH’s context to the selected neighbor APs considering handoff frequencies between APs. When the context transfer is needed, neighbor APs with handoff probabilities equal to or higher than a predefined threshold value are selected. Pack et al. [13] proposed a fast handoff scheme based on mobility prediction. An MH performs authentication procedures for multiple APs rather than just the current serving AP in this scheme. These multiple APs are selected by a prediction method called the frequent handoff region (FHR) selection algorithm, which takes into account users’ mobility patterns, service classes, etc. The signaling overhead may be large if there are many selected APs. There are also some people researching in MH’s context transfer at both link and IP layers [8], and the proposed method may reduce the handoff latency in view of multi-layers.

Regarding the probe delay, many approaches are addressed and we describe those following. Table 1 shows the comparisons of several different methods for reducing IEEE 802.11 probe delay, and "pre-scan" means that an MH continuously scan its nearby APs before entering handoff procedure, "probe action" presents how an MH perform scan function during a handoff process, "handoff time" describes the time of completing an entire handoff process, "direction" indicates whether an MH knows the actual direction or not, "located device" shows if an MH equips extra devices for locating, and "used memory" illustrates how many memory spaces a proposed method may use for storing necessary information as running. Li et al. [9] proposed a reliable active scanning (RAS) scheme. It is indicated to efficiently increase the reliability of channel scanning, especially in a noisy environment, by performing the probe request loss detection and retransmission. Although the RAS scheme really decreases the handoff delay time in a IEEE 802.11 WLAN, the handoff latency is still great. This is because the RAS scheme only reduces the retransmission probability when scanning each channel, but not decrease the number of scanned channels. Shin et al. [16] described a method of improving the handoff latency by using neighbor graphs and non-overlap graphs. This method reduces the total number of probed channels (partial scan) as well as the total time spent waiting on each channel. Neighbor graphs capture the mobility topology of a wireless network, hence there needs large memory for recording and there implicitly has direction information. On the other hand, the effectiveness of this method becomes lower when there are many neighbor APs nearby the current AP in the neighbor graph. Shin et al. [17] developed a handoff procedure using a selective scanning algorithm and a caching mechanism. By using a dynamic channel mask in the selective scanning algorithm, scanning a subset of eleven channels can be used as a generic solution (partial scan). However, cache missing and channel mask breaking down may occur within a little AP range overlap environment. Ramani et al. [15] described SyncScan, a low-cost technique for continuously tracking nearby base stations by synchronizing short listening periods at the client with periodic transmissions from each base station. By executing pre-scan in advance, SyncScan omits the probe delay and slashes the entire handoff delay, but it may be out of gear because of its long pre-scan cycle
Table 1.1: Comparisons of different methods for reducing IEEE 802.11 probe delay.

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<td>pre-scan</td>
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(full scan) when a serving mobile host has high-speed movement. Tseng et al. [19] presented a location-based approach which helps an MH to derive the prospective APs most likely to be visited next by using the current location and the AP topology information acquired from some designated server. Nevertheless, a dedicated server storing the large amount of AP topology information and an MS position measure technique, such as GPS or sensor network, need to be support additionally.

Since the probe delay in IEEE 802.11 handoff procedure is the most influential factor of the entire handoff delay, we present a duece-based spatiotemporal mapping fast handoff scheme, called DueceScan, using spatiotemporal graphs for exactly finding the next AP which a MH will handoff to and reducing the probe delay in IEEE 802.11 WLANs. By combining the usage of pre-scan, deuce process, and spatiotemporal graphs, a MH can precisely judge which access point will be following visited and quickly complete the handoff procedure if necessary. The pre-scan function continuously probes respective received signal strength (RSS) from particularly selected nearby access points. The deuce process provides the fault-tolerant capability to facilitate to select which three access points to be pre-scanned. Spatiotemporal graphs constructed according to the pre-scan and deuce process results can help for determining which access point to be reassociated with next. The proposed method can significantly reduce the layer-2 handoff latency in a IEEE 802.11 WLAN and can be compatible with the existing 802.11 standard. The simulation results also support our discuss and show that our DeuceScan scheme can tolerate high-speed movement of MHs.

The rest of this article is organized as follow. In Section 2 we illustrate the basic idea of our approach in detail. Section 3 clearly describes the DeuceScan algorithm and its advantages. The simulation analysis is presented in Section 4, as well as finally we summarize our results and make some conclusions in Section 5.
Chapter 2

Preliminaries and Basic Ideas

We have known that to reduce the handoff latency is important to MHs in a wireless network, and the probe delay is the most effective factor in an entire handoff procedure. Fig. 2.1 shows probe activities of an MH in several different mechanisms which are designed to reduce the probe delay. In Fig. 2.1(a), an MH observed the IEEE 802.11 standard [3], it initially performed a full scan and found all active APs in channel(CH) 1, 3, 6, 8, 11 respectively, then the MH selected the best AP with the strongest received signal strength (RSS) in $CH_6$ to associate with. The MH received the beacon transmitted by the serving AP at a fixed time interval. When the MH needed to handoff to another AP, it entered the handoff process and executed a full scan, from the scanning results it selected the next AP in $CH_8$ to reassociate with. Fig. 2.1(b) displays that an MH obeyed the scheme using neighbor graphs [16], and the MH only needed to scan the neighbor APs which were recorded in the neighbor graph of the serving AP during a handoff process. In Fig. 2.1(c) and (d), the examples of using the selective scan mechanism [17] with cache hit and cache miss are introduced respectively. When cache hit, the MH had not to probe any other APs during handoff and directly reassociated with the AP listed in the cache table, on the other hand, the MH probed the several channels to find the next AP during handoff according to the channel mask. As shown in Fig. 2.1(e), an MH adopted the SyncScan [15] scheme, and it continuously tracked nearby APs by full scan, hence the MH during handoff could immediately reassociate with the selected AP from the pre-scan results. Fig. 2.1(f) illustrated that our proposed DeuceScan scheme was used, an MH constantly probed selected nearby APs (not full scan), and by the pre-scan it could directly decide which AP to reassociate with. From the above, we clearly know that SyncScan and DeuceScan can effectively significantly reduce the handoff delay time, but there are differences between these two scheme.

Since the pre-scan function is used, both SyncScan and our DeuceScan have to do time synchronize between APs to help MHs with arranging the scanning order of APs that can let MHs exactly receive respective beacons of each AP. We decide to leverage the wide availability of Network Time Protocol (NTP) service over the Internet [2] (same as SyncScan), since it provides a standard out-of-band means for synchronizing APs to absolute time reference. Fig. 2.2 shows the difference between SyncScan and DeuceScan with time slot
Figure 2.1: Probe activities of (a) IEEE 802.11 infrastructure network, (b) neighbor graph, (c) selective scan with cache hit, (d) selective scan with cache miss, (e) SyncScan, and (f) DeuceScan.
sequences. For applying DeuceScan in Fig. 2.2(a), we can see that the MH associated with AP$_1$ in CH$_1$ at time $t_1$, and the MH discovered the RSS ($S_{1,t_1}$) of AP$_1$ at time $t_1$ was lower than a pre-defined threshold for handoff ($S_h$), hence it performed handoff process and reassociated with AP$_3$ in CH$_3$ at time $t_2$. With adopting SyncScan in Fig. 2.2(c), the MH also associated with AP$_1$ in CH$_1$ at time $t_1$, and it found the RSS ($S_{1,t_3}$) of AP$_1$ at time $t_3$ was weaker than the threshold $S_h$, hence it executed handoff process and reassociated with AP$_{11}$ in CH$_{11}$ at time $t_4$. Differing from Fig. 2.2(a), the MH selected AP$_{11}$ to reassociate with during handoff according to its last scan records of $S_{11} > S_3$, and we knew that SyncScan would handoff to the improper AP when an MH in a high speed $v$. As shown in Fig. 2.2(b), the upper half part displays the detailed time slot sequence of Fig. 2.2(a) and the lower half part is for Fig. 2.2(c), that DeuceScan can be aware of oncoming handoff earlier than that of SyncScan is because DeuceScan has the shorter scan cycle.

We will describe the basic ideas of our DeuceScan such as spatiotemporal graphs, deuce process, and variation of signal strengths in the following paragraphs.

### 2.1 Spatiotemporal Graphs

Spatiotemporal graphs are composed of a lot of spatiotemporal triangles which are established at distinct time and places, as shown in Fig. 2.3, and these triangles are made up of three APs which have the first three strong RSSs receiving from the MH at some time and some place. Each MH will possess its own individual spatiotemporal graph. The more strong RSS an MH receives from an AP, the more close to an AP an MH is, or the higher transmitting power an AP has, and it is known that the link quality of wireless connection is positively related to the signal strength. In our proposed DeuceScan, an MH shall initially perform full scan somewhere and it will select the AP from which the MH receives the strongest RSS. Then the MH records the spatiotemporal triangle composed of the three APs which have the first three strong RSS receiving from the MH. If this triangle is not yet in the MH’s spatiotemporal graph, then add it. The MH will continuously probe this three APs for their RSSs, hence it can judge its move direction (to be close to or to be distant from some AP) by variation of RSSs and determine whether it needs to change to another triangle. When the handoff is
needed, the MH will select the proper one of the other two APs in the current spatiotemporal triangle (besides the serving AP) to reassociate with. This way omits the full scan in the handoff procedure and reduce the handoff latency significantly. Fig. 2.4 describes the properties of spatiotemporal graphs. The current triangle presents the first three closest APs near an MH. MH’s move direction is decided by variation of RSSs. For a selected AP, if the variation of RSSs computed by an MH is incremental, then we know that the MH becomes closer toward the AP gradually, on the other hand, the MH becomes far away the AP. The move direction can help to determine the possible next spatiotemporal triangle and to know which AP is the next new one in the next triangle. A spatiotemporal triangle is a logical triangle, and it presents which are the first three best APs near an MH at some time and some place, but not the actually geographic triangle. An MH may confirm a spatiotemporal at some time and it geographically locates outside the triangle at that time.

2.2 Deuce Procedure with Signal Strength

The deuce procedure is used for confirming whether the RSSs received from an MH at some place are stable by continuously probing nearby APs and judges if it needs to change the current spatiotemporal triangle. The symbol $S_i$ is defined to present the RSS of $AP_i$. We denote a deuce procedure with variables $\alpha$ and $\beta$ as $D_s(\alpha, \beta)$, and the deuce procedure $D_s(\alpha, \beta)$ is describe as follow.

**Step 1:** When the MH turns on, it performs a full scan, and selects a best AP (with the strongest RSS) to associate with.

**Step 2:** From the results of the full scan, the MH selects $\alpha + 3$ APs which have the first $\alpha + 3$ strongest RSSs to form a scan cycle, where $\alpha$ is a pre-defined value. Every successive $\beta$ scan cycles form a deuce window, where $\beta$ is also a pre-defined value.
Figure 2.5: Examples of the Deuce Process with Variables alpha and beta.
To use $\alpha + 3$ APs to form a scan cycle is in order to enhance the fault-tolerant capability. After initial full scan we select the APs which have the fist $\alpha + 3$ strong RSSs receiving from the MH to enter a scan cycle, and this presents that there still $\alpha$ APs for selecting if the full scan has a mistake.

**Step 3:** The MH performs pre-scan function according to the decided scan cycle and judge whether the deuce window is stable.

The symbol $S_i$ is used for presenting the RSS of $AP_i$. We denotes the APs in the scan cycle as $AP_1$, $AP_2$, $AP_3$, ..., $AP_{\alpha+3}$, where $S_{AP_1} > S_{AP_2} > \cdots > S_{AP_{\alpha+3}}$. It is stable means that the RSSs of the scanned APs in successive $\beta$ scan cycles of a deuce window have the same magnitude order (always $S_{AP_1} > S_{AP_2} > \cdots > S_{AP_{\alpha+3}}$).

**Step 4:** If it is stable, the MH confirm that the triangle composed of $AP_1$, $AP_2$, and $AP_3$ is the current spatiotemporal triangle, then jump to Step 3. If it is not stable, jump to Step 3.

Fig. 2.5 shows some examples of the deuce process with different values of $\alpha$ and $\beta$ in a general scenario. In Fig. 2.5(a), a case of $D_s(1,2)$ was presented, an MH first executed full scan to obtain the results of active APs in respective channel, such as $AP_i$ in $CH_i$, where $i=1, 3, 6, 8, 11$. The relation of RSSs of each AP are $S_1 > S_8 > S_3 > S_{11} > S_6$, and the MH selected $AP_1$ to associate with. Subsequently entering the deuce process, $AP_1$, $AP_8$, $AP_3$, and $AP_{11}$ were added into the scan cycle (because of $\alpha = 1$), and every successive two scan cycles formed a deuce window (because of $\beta = 2$). The first two scan cycles had the same magnitude orders of RSSs, such as $S_1 > S_8 > S_3 > S_{11}$, and the MH confirmed that it is in the spatiotemporal triangle composed of $AP_1$, $AP_8$, and $AP_3$. The MH continuously probed APs according to the scan cycle and compared the magnitude orders of RSSs. Fig. 2.5(b) described a case of $D_s(2,3)$, it is similar to the case of $D_s(1,2)$, and the differences are that a scan cycle was composed of five APs and every successive three scan cycles form a deuce window. The MH here confirmed that the current spatiotemporal triangle was made up of $AP_1$, $AP_8$, and $AP_3$. Fig. 2.5(c) also shows a case of $D_s(2,3)$, but the unstable situation occurred. Until three successive scan cycles (in the same deuce window) had the same magnitude orders of RSSs, then an MH confirmed that it is in the spatiotemporal triangle made up of $AP_1$, $AP_8$, and $AP_3$.

### 2.3 Deuce Procedure with Variation of Signal Strength

A single absolute signal strength of an AP can help an MH to determine how far this AP is, but cannot represent MH’s move direction and speed. We consider about the variation of successive two RSSs of an $AP_i$, denoted as $\Delta_{AP_i}$. When the $\Delta_{AP_i}$ increases, the MH can realize that it moves toward $AP_i$. The MH will know that it moves away from $AP_i$ as the $\Delta_{AP_i}$ decreases. In DeuceScan, an MH will continuously probe the three
Figure 2.6: Variable of signal strengths.
APs forming the current spatiotemporal triangle, and the individual variations of each AP can be acquired. These can facilitate to judge the MH’s move direction (to be close to or to be distant from some AP) and determine what is the next AP when handoff. We denote a deuce procedure using variation of received signal strengths with variables $\alpha$ and $\beta$ as $D_v(\alpha, \beta)$, and the deuce procedure $D_v(\alpha, \beta)$ is describe as follow.

**Step 1:** When the MH turns on, it performs a full scan, and selects a best AP (with the strongest RSS) to associate with.

**Step 2:** From the results of the full scan, the MH selects $\alpha + 3$ APs which have the first $\alpha + 3$ strongest RSSs to form a scan cycle, where $\alpha$ is a pre-defined value. Every successive $\beta$ scan cycles form a deuce window, where $\beta$ is also a pre-defined value.

**Step 3:** The MH performs pre-scan function according to the decided scan cycle and judge whether the deuce window is stable.

We denotes the APs in the scan cycle as $AP_{1st}$, $AP_{2nd}$, $AP_{(\alpha+3)th}$, where $\Delta AP_{1st} > \Delta AP_{2nd} > \ldots > \Delta AP_{(\alpha+3)th}$.

It is stable means that the variation of RSSs of the scanned APs in successive $\beta$ scan cycles of a deuce window have the same magnitude order (always $\Delta AP_{1st} > \Delta AP_{2nd} > \ldots > \Delta AP_{(\alpha+3)th}$).

**Step 4:** If it is stable, the MH confirm that the triangle composed of $AP_{1st}$, $AP_{2nd}$, and $AP_{3rd}$ is the current spatiotemporal triangle, then jump to Step 3. If it is not stable, jump to Step 3.

Fig. 2.6 displays different handoff situations when an MH initially associates with $AP_1$ in $CH_1$ and keeps moving. In Fig. 2.6(a), the MH confirmed that the current spatiotemporal triangle was composed of $AP_1$, $AP_5$, and $AP_{11}$, and its move path made the $S_1$ and $\Delta AP_1$ the greatest continuously, and there is no need to handoff. (The deeper gray rectangles on the top of the black ones present incremental $\Delta AP_i$, the white rectangles show decreasing $\Delta AP_i$, and the lighter gray rectangles describe which one is the serving AP.) Fig. 2.6(b) displayed the scenarios of $\Delta AP_1$ decreasing constantly. See the left part, enhanced $S_{11}$ and $\Delta AP_{11}$ were the greatest, hence the MH reassociated to $AP_{11}$ when $S_1$ was weak. The right part depicted that $S_6$ increased and $S_{11}$ decreased, thus the MH reassociated to $AP_6$ as $S_1$ became weak. As shown in Fig. 2.6(c), all the $S_i$, where $i = 1, 6, 11$, decreased progressively, there needed not handoff. We will adopt the variation of RSSs into our DeuceScan for helping with handoff precisely.
Chapter 3

DeuceScan: Deuce-based Fast Handoff Scheme Using Spatiotemporal Graph

The probe delay constitutes the greatest part of the whole handoff latency, for this reason, we concentrate our attention on reducing the probe delay. We proposed a deuce-based fast handoff scheme, called DeuceScan, to address this problem, and the details are illustrated below.

3.1 Construction of Spatiotemporal Graphs

Here we describe the construction procedure of Spatiotemporal Graphs which can help the MH with handoff quickly and precisely. Each MH has its special moving pattern in general, and different moving patterns will lead to different spatiotemporal graphs. An MH can construct its own graphs during moving by applying the deuce procedure. We illustrate the Spatiotemporal Graphs constructing procedure below.

Step 1: When the MH is turned on, it performs a full scan, and selects a best AP (with the strongest RSS) to associate with. The MH enters the deuce procedure with $\alpha$ and $\beta$.

Step 2: If the deuce window is stable, then the MH confirms that the triangle composed of $AP_{1\text{st}}$, $AP_{2\text{nd}}$, and $AP_{3\text{rd}}$ is the current spatiotemporal triangle.

Step 3: Check the existing spatiotemporal graph of the MH, if the current spatiotemporal triangle doesn’t exist, add it into the spatiotemporal graph.

Step 4: Proceed the deuce process and check whether the $S_{AP_{3\text{rd}}} < S_i$ in each scan cycle or the stable status changed. If ”YES” then perform a full scan. Jump to Step 2.

Fig. 3.1 displays the process of construction of spatiotemporal graphs. Fig. 3.1(a) presented that an MH initially performed a full scan, and from the results there are active $AP_1$, $AP_3$, $AP_8$, and $AP_{11}$ in $CH_1$, $CH_3$, $CH_8$, and $CH_{11}$ respectively. Fig. 3.1(b) shown that the MH entered the deuce procedure with $\alpha = 1$ and
Figure 3.1: Construction of spatiotemporal graphs.
\[ \beta = 2, \] it selected \( AP_1, AP_3, AP_8, \) and \( AP_{11} \) into the scan cycle. It is stable because of the successive two same magnitude order of \( S_{AP_1} > S_{AP_{11}} > S_{AP_8} > S_{AP_3}, \) and the \( \Delta_{AP_1AP_3AP_{11}} \) which was the current triangle was added into the spatiotemporal graph of the MH. In Fig. 3.1(c), the first sub-graph described the situation that the stable status changed to \( S_{AP_1} > S_{AP_{11}} > S_{AP_8} > S_{AP_3}, \) then the MH thought it needed to change the triangle and executed a full scan. The second sub-graph shown the situation that it was stable as in Fig. 3.1(b) and the \( S_{AP_8} < S_t, \) then the MH performed a full scan. After the full scan, it was stable of \( S_{AP_1} > S_{AP_{11}} > S_{AP_3} > S_{AP_8}, \) and the \( \Delta_{AP_1AP_3AP_{11}} \) which became the current triangle was added into the spatiotemporal graph of the MH.

**3.2 The DeuceScan scheme**

DeuceScan is a fast handoff scheme designed for reducing the MAC layer handoff latency which utilizes spatiotemporal graphs to provide spatiotemporal information for making better handoff decisions to exactly search for the next AP. The DeuceScan combines the deuce procedure, Spatiotemporal Graphs constructing procedure, and adopts two factors of received signal strength and variation of received signal strength. The following shows the DeuceScan fast handoff scheme.

**Step 1:** When the MH turns on, it performs a full scan, and selects a best AP (with the strongest RSS) to associate with, denoted as \( AP_{cur} \) and \( S_{AP_{cur}}. \) Then the MH enters deuce procedure with \( \alpha \) and \( \beta. \)

**Step 2:** Set integer \( i = 1. \) The MH probes \( AP_{cur} \) to get \( S_{AP_{cur}} \) in a scan cycle \( C_i, \) and judges whether \( S_{AP_{cur}} < S_h, \) where \( S_h \) is a pre-defined threshold for handoff. If “NO” then jump to Step 2, and if “YES” then jump to Step 3.

**Step 3:** Let \( i = i+1. \) The MH probes \( AP_{cur} \) to get \( S_{AP_{cur}} \) in a scan cycle \( C_i, \) and determines whether \( S_{AP_{cur}} < S_h. \) If “NO” then jump to Step 2, else jump to Step 4.

**Step 4:** If \( i = \beta, \) the MH decides to handoff and jump to Step 5, else jump to Step 3.

**Step 5:** Here denotes the two best APs with the first two strongest RSS in a scan cycle \( C_i \) as \( AP_{1st} \) and \( AP_{2nd}, \) and their RSSs are \( S_{AP_{1st}} \geq S_{AP_{2nd}}. \) Besides, the symbol \( S_{\Delta} \) is a pre-defined small constant used for computing the variation of two RSSs. If \( S_{AP_{1st}} > S_{AP_{2nd}} < S_{\Delta} \) then jump to Step 7, else jump to Step 6.

**Step 6:** The MH reassociates to \( AP_{1st}. \) Jump to Step 2.

**Step 7:** If \( \Delta_{AP_{1st}} \) and \( \Delta_{AP_{2nd}} \) both increase, the MH reassociates with \( AP_{1st}. \) If \( \Delta_{AP_{1st}} \) and \( \Delta_{AP_{2nd}} \) both decrease, the MH reassociates with the \( AP_{2nd}. \) If \( \Delta_{AP_{1st}} \) increase and \( \Delta_{AP_{2nd}} \) decrease, the MH reassociates with the \( AP_{1st}. \) If \( \Delta_{AP_{1st}} \) decrease and \( \Delta_{AP_{2nd}} \) increase, the MH reassociates with the \( AP_{2nd}. \) Jump to Step 2.
3.3 Adding a Centralized Server

The above handoff procedure will be executed continuously by the MH until the wireless connection broken. Fig. 8 shows an example of applying DeuceScan (case 1). In Fig. 3.2(a), the MH owned his spatiotemporal graph composed of spatiotemporal triangles \( \triangle AP_1 AP_3 AP_8 \), \( \triangle AP_1 AP_3 AP_{11} \), and \( \triangle AP_1 AP_3 AP_{12} \). \( \triangle AP_1 AP_3 AP_8 \) is the current spatiotemporal triangle of the MH, and it associated with \( AP_1 \). It is stable of \( S_{AP_1} > S_{AP_3} > S_{AP_{11}} > S_{AP_8} \). Fig. 3.2(b) displayed that there could be an unstable status occurred when the MH moved, and the MH was still stable of \( S_{AP_1} > S_{AP_3} > S_{AP_{11}} > S_{AP_8} \) finally. Fig. 3.2(c) shown that the stable status changed to \( S_{AP_1} > S_{AP_{11}} > S_{AP_3} > S_{AP_8} \), and the \( \triangle AP_1 AP_3 AP_{11} \) became the current triangle of the MH. The MH needed not to perform a full scan when changing the stable status because that the \( \triangle AP_1 AP_3 AP_8 \) had been in its own spatiotemporal graph. In Fig. 3.2(d), the MH was in the stable status of \( S_{AP_1} > S_{AP_{11}} > S_{AP_3} > S_{AP_8} \), and it still associated to \( AP_1 \). That \( S_{AP_1} < S_h \) appeared in the successive two scan cycles, hence the MH decided to handoff. \( S_{AP_1} \) and \( S_{AP_{11}} \) were almost the same (\( |S_{AP_1} - S_{AP_{11}}| < S_{\Delta} \)), the \( \Delta_{AP_3} \) was positive (\( S_{AP_3} \) was incremental) and the \( \Delta_{AP_{11}} \) was negative (\( S_{AP_{11}} \) was decreasing), hence the MH selected \( AP_3 \) to reassociate with.

The MH entered the stable status of \( S_{AP_1} > S_{AP_{11}} > S_{AP_3} > S_{AP_8} \) subsequently. Fig. 9 presents another example of applying DeuceScan (case 2). Fig. 3.3(a) and (b) are similar as those in Fig. 3.2, there are differences in the MH’s moving direction and its spatiotemporal graph composed of spatiotemporal triangles \( \triangle AP_1 AP_3 AP_8 \) and \( \triangle AP_1 AP_3 AP_{11} \) only. In Fig. 3.3(c), the stable status changed to \( S_{AP_1} > S_{AP_3} > S_{AP_{11}} > S_{AP_8} \), and the \( \triangle AP_1 AP_3 AP_{11} \) was considered to be the current triangle of the MH. The MH performed a full scan and entered the stable status of \( S_{AP_1} > S_{AP_3} > S_{AP_{11}} > S_{AP_8} \), then the \( \triangle AP_1 AP_3 AP_{11} \) was added into its spatiotemporal graph. In Fig. 3.3(d), the MH was in the stable status of \( S_{AP_{11}} > S_{AP_3} > S_{AP_1} > S_{AP_8} \), and it still associated to \( AP_1 \). That \( S_{AP_1} < S_h \) appeared in the successive two scan cycles, hence the MH decided to handoff to \( AP_{11} \) which had the best signal strength. The MH entered the stable status of \( S_{AP_{11}} > S_{AP_3} > S_{AP_1} > S_{AP_8} \) subsequently.

### 3.3 Adding a Centralized Server

In the DeuceScan fast handoff scheme, each MH needs to record its own spatiotemporal graph information, and there will occupy much memory space. We can establish a centralized server (it can be co-located within an authentication server) to store complete spatiotemporal graphs of the entire area, and an MH can get the required information from the server. An MH only needs to download little part of spatiotemporal graphs related to the serving AP from the server and temporarily stores these data for a period of time until handoff to another AP. An MH will download the related part of graphs when reassociates to a new AP. With a centralized server added, the complete data can be offered, and MHs can save their memory space. Fig. 3.4 shows the concept of a centralized server which stores complete spatiotemporal graphs of the entire area.
Figure 3.2: Applying the DeuceScan scheme (csae 1).
Figure 3.3: Applying the DeuceScan scheme (case 2).

Figure 3.4: Adding a centralized server.
Chapter 4

Simulation Results

We write a C++ program to simulate our DeuceScan and other existing fast handoff schemes. In the following simulation, we use "STD", "NG", and "SSC" to represent IEEE 802.11 Standard, the approach using neighbor graphs, and selective scan with caching mechanism respectively. The system parameter are given in Table 2. The performance metrics of the simulation are described below.

- **Handoff latency**: a period of time between an MH moving its association from one AP to another.

- **Packet loss**: the number of all lost packets during handoff of an MH.

- **Link quality**: the average received signal strength of an MH during a period of time.

An effective fast handoff scheme should achieve low handoff latency, low packet loss, and high link quality.

4.1 Variables alpha and beta

With different $\alpha$ and $\beta$, there will result in different outcomes. Fig. 4.1 shows the results derived from different $D(\alpha,\beta)$, separately in handoff latency, packet loss, and link quality when an MH’s speed increases.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of MHs</td>
<td>500</td>
</tr>
<tr>
<td>Number of APs</td>
<td>100~200</td>
</tr>
<tr>
<td>Network region</td>
<td>1000 ×1000 m</td>
</tr>
<tr>
<td>Radio propagation range</td>
<td>100 m</td>
</tr>
<tr>
<td>Mobility</td>
<td>5~30 m/s</td>
</tr>
</tbody>
</table>
In fig. 4.1(a), we can see that the handoff latency raises as the speed increases for all different D(α,β), and the handoff latency of D(1,2) < that of D(2,2) < that of D(1,3) < that of D(3,2) < that of D(2,3). This is because a deuce window size of D(1,2) < that of D(2,2) < that of D(1,3) < that of D(3,2) < that of D(2,3). A deuce window size is equal to ((α + 3)*β), where (α + 3) APs forming a scan cycle and β successive scan cycles composing a deuce window. The smaller a deuce window size is, the lower the handoff latency will be. Fig. 4.1(b) displays the relation between packet loss and an MH’s speed. As an MH’s speed increases, the handoff latency will increases, so that the packet loss will correspondingly increases. Fig. 4.1(c) performs the results of link quality for different D(α,β) when an MH’s speed raises. With a smaller deuce window size, an MH can early find and confirm that the signal strength from the current AP is low (< \( S_h \)), and it can early execute handoff procedure so that the average link quality will be better. Here we can see the link quality of D(1,2) > that of D(2,2) > that of D(1,3) > that of D(3,2) > that of D(2,3) when an MH’s speed increases. From Fig. 4.1, the value of We select the D(1,2) as the DeuceScan procedure in the following.

### 4.2 Handoff latency

We first investigated how the speed of an MH affect the handoff latency. Fig. 4.2 shows the relation of handoff latency and an MH’s speed. As shown in Fig. 4.2(a), the higher the speed of an MH has, the more the handoff latency will be. The handoff latency of IEEE 802.11 Standard > that of the approach using neighbor graph > that of selective scan with caching mechanism > that of DeuceScan. This is because STD, NG, and SSC (when cache miss) have to scan channels during handoff (STD: full scan, NG and SSC: partial scan), and DeuceScan (using pre-scan) needs not. In Fig. 4.2(b), the handoff latency of SyncScan is larger than that of DeuceScan. Although SyncScan and DeuceScan both adopt pre-scan, the time of a scan cycle of the SyncScan is longer than that of DeuceScan, and this leads the handoff latency of SyncScan increases faster than that of DeuceScan with speed of an MH increasing.

We studied how handoff latency can be affected by number of neighbor APs of a serving AP which the MH associates with. Fig. 4.2 shows the relation of handoff latency and number of neighbor APs. Fig. 4.3 shows that the more the number of neighbor APs is, the higher handoff latency will be. The handoff latency of IEEE 802.11 Standard > that of the approach using neighbor graph > that of selective scan with caching mechanism > that of DeuceScan, as shown in Fig. 4.3(a). STD always performs a full scan during handoff, hence the handoff latency of STD increases steadily with number of neighbor APs increasing (The waiting time for the responses of APs in each channel increases, but number of channels is always 11.). Since NG needs partial scan during handoff, the handoff latency will increase larger when the number of neighbor APs is small than 11 (our simulation set that an AP in a channel as number of APs is smaller than 11). When SSC
(a) Handoff latency vs. speed.

(b) Packet loss vs. speed.

(c) Link quality vs. speed.

Figure 4.1: Different D(alpha,beta).
Figure 4.2: Handoff latency vs. speed.

Figure 4.3: Handoff latency vs. number of neighbor APs.
occurs cache miss, the average handoff latency will significantly increase. Our DeuceScan selects fixed $\alpha + 3$ APs, the handoff latency of DeuceScan doesn’t be affected by the number of neighbor APs. In Fig. 4.3(b), the handoff latency of SyncScan is larger than that of DeuceScan. This is because that the scan cycle in pre-scan function of SyncScan is a full scan, and that of DeuceScan is composed of fixed $\alpha + 3 (< 11)$ APs.

### 4.3 Packet loss

It is trivial that the higher the handoff latency is, the more the packets are lost. Fig. 4.4(a) displays the relation of packet loss and speed of an MH. The results are similar to that of Fig. 4.2(a), the packet loss of all schemes increase with the speed of an MH increasing. Fig. 4.4(b) shows the relation of packet loss and number of neighbor APs of a serving AP. We know that the more the number of neighbor APs is, the more the packets are lost.

### 4.4 Link quality

We use average RSS value to present the link quality. An MH has the better link quality will be good for communication over a wireless environment. When $S_{AP_{cur}}$ is low, the MH will execute handoff procedure in order to reassociate with another AP which has the best signal strength. If the handoff latency is low, an MH can handoff to a new AP more quickly, and the duration of an MH staying in low signal strength will be short. Fig. 4.5(a) illustrates the link quality of an MH will quickly decrease with speed increasing no matter applying which scheme. SyncScan and DeuceScan have better link quality because they do not perform scan.
operation during handoff leading to low handoff latency. DeuceScan has the better link quality than that of SyncScan because of shorter scan cycle within the pre-scan operation. In Fig. 4.5(b), we simulated the situation described in Fig. 2.2, and there showed the differences in link quality of DeuceScan and SyncScan respectively. When an MH’s speed is fast, it will handoff to different APs by applying different schemes (AP$_3$ in DeuceScan, AP$_{11}$ in SyncScan). We can see that the MH applying DeuceScan has better link quality, and the better link quality can lead to lower packet loss.
Chapter 5

Conclusions

This paper presents a new fast handoff, called DeuceScan, scheme to reduce the probe delay for 802.11-based WLANs. A spatiotemporal approach is developed in DeuceScan scheme to utilize spatiotemporal graph to provide the spatiotemporal information for making better handoff decisions to exactly search for the next AP. It efficiently reduces the MAC layer handoff latency. Our DeuceScan scheme is a pre-scan approach by continuously probing respective received signal strength (RSS) from particularly selected nearby access points. Two factors of signal strength and variation of signal strength are both considered in our DeuceScan scheme. The simulation results illustrate our approach have better performance in handoff delay time, packet loss and link quality compared to existing fast handoff schemes.
Bibliography


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