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

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***Abstract*— WLANs will become a major portion of the fourth generation (4G) cellular system. The seamless handoff problem in WLANs is a very important design issue to support the new astounding amazing applications in wireless networks. The entire delay time of a handoff is divided into probe, authentication, and reassociation delay times. Because the probe delay occupies most of the handoff delay time, efforts have focused mainly on reducing the probe delay to develop faster handoff schemes. This paper presents a new fast handoff scheme, called the DeuceScan scheme, to further reduce the probe delay for 802.11-based WLANs. A spatiotemporal approach is developed in this work to utilize a spatiotemporal graph to provide spatiotemporal information for making accurate handoff decisions by correctly searching for the next AP (access point). The DeuceScan scheme is a pre-scan approach which efficiently reduces the MAC layer handoff latency. Two factors of stable signal strength and variable of signal strength are both used in our developed DeuceScan scheme. Finally, the simulation results illustrate the performance achievements of the DeuceScan scheme in reducing the handoff delay time and packet loss rate.**

I. Introduction

The IEEE 802.11 standard [1] has enabled low-cost and effective wireless LAN services. It is widely believed that WLANs will become a major portion of the fourth generation cellular system. Real-time applications suffer from the handoff latency when a mobile host (MH) roams between different WLANs. Efforts have been made to develop faster handoff mechanisms in order to reduce the handoff latency. For the IEEE 802.11 MAC operation [1], the handoff function occurs when a MH seamlessly changes its connection from one access point to another. There are many new approaches [8] which have reduced the handoff latency. Mishra *et al.* [2] defined the handoff process as occurring in two distinct logical steps: discovery and reauthentication, and he classified the entire handoff latency into three delays: probe, authentication, and reassociation delays. The probe delay always occupies the largest proportion of the entire handoff latency; and finding ways to reduce the probe delay is the main issue.

In the IEEE 802.11 standard, the discovery phase to help an MH finds potential APs to reassociate with, but the cost of a full scan to probe 11 channels is high. Improving the scan operation can significantly reduce the handoff latency. To improve the handoff latency, many existing handoff schemes [3][4][5][6][7] have been proposed. All existing results can be divided into fast handoff schemes in the discovery phase and in the reauthentication phase. Mishra *et al.* [3] and Shin *et al* [6] use neighbor graphs to capture the mobility topology of an MH; hence, they need a large amount of memory to record the mobility information. To improve the *neighbor graph* scheme, Pack *et al.* [4] proposed a *selective neighbor caching* (SNC) scheme for fast handoff in WLANs. However, cache missing in the cache-based scheme is a fatal problem for the handoff. Shin *et al.* [7] developed a dynamic channel mask in the selective scanning algorithm, scanning a subset of all channels can be used as a generic solution, or called a partial scan. More recently, Ramani *et al.* [5] developed a practical fast handoff, called SyncScan. This scheme is a pre-scan in advance, SyncScan omits the probe delay and slashes the entire handoff delay. Efforts are made in this work to develop a new pre-scan scheme.

This paper presents a new fast handoff scheme, called the DeuceScan scheme, to further reduce the probe delay for WLAN. A spatiotemporal approach is developed in this work which utilizes a spatiotemporal graph to provide spatiotemporal information for making accurate handoff decisions by correctly searching for the next AP. The DeuceScan scheme is a pre-scan approach which efficiently reduces the MAC layer handoff latency. Two factors of signal strength and variation of signal strength are both used in our developed DeuceScan scheme. Finally, the simulation results illustrate the performance achievements of the DeuceScan scheme in reducing the handoff delay time and packet loss rate.

The rest of this article is organized as follow. Section II illustrates the basic ideas of the DeuceScan scheme. Section III presents the DeuceScan protocol. A simulation analysis is presented in Section IV. Section V summarizes the results.

II. PRELIMINARY AND BASIC IDEAS

This work aims to develop a new approach to reduce the probe delay. We compare all existing fast handoff schemes [5][6][7] which mainly reduce the probe delay with our DeuceScan scheme. As shown in Fig. 1(a), IEEE 802.11 standard scans channels CH_1, CH_3, CH_6, CH_8, and CH_{11} which have active APs by the full scan operation. Initially, the MH selects and associates with the one of APs (in CH_6) with the maximum receives signal strength (RSS). The MH received the beacon transmitted by the serving AP at a fixed time interval. The neighbor-graph-based scheme [6] only scans all neighbor APs. Compared to the full scan operation used in the IEEE 802.11 standard, this obviously reduces the latency of

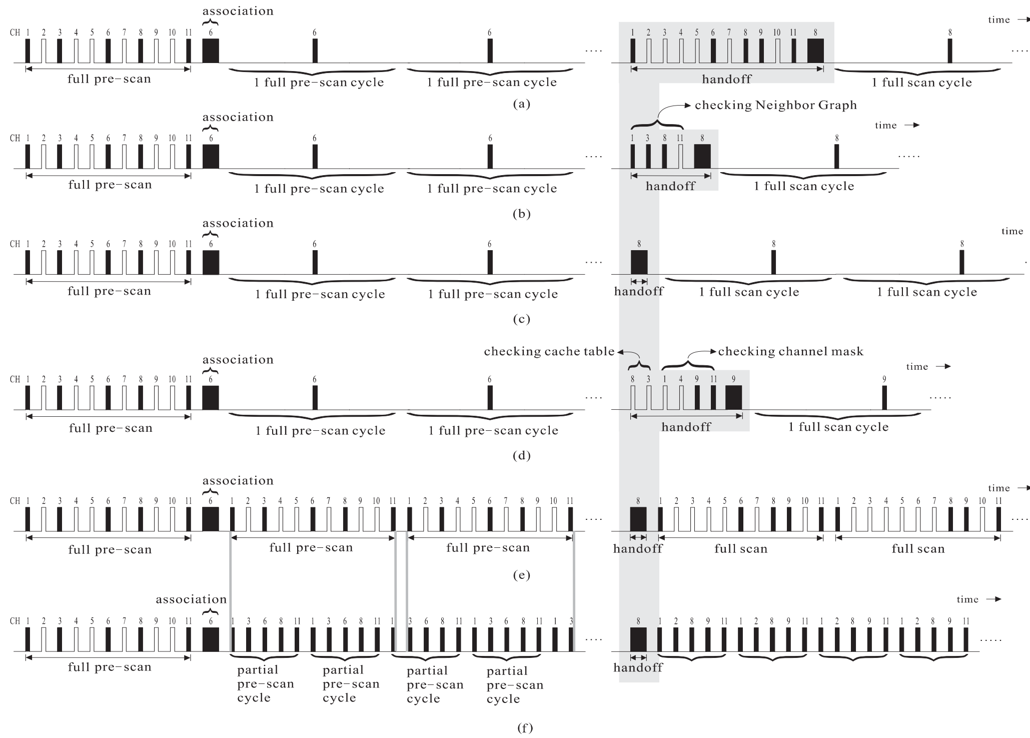

Fig. 1. Probe activities of the (a) IEEE 802.11 standard, (b) neighbor graph, (c) selective scan with cache hit, (d) selective scan with cache miss, (e) SyncScan, and (f) DeuceScan.

channel scanning since a partial scan operation is used. Fig. 1(c) and 1(d) show the selective-scanning-based scheme [7] with cache hit and cache miss. The selective-scanning-based scheme with the cache miss needs a long probe delay because some channels need to be re-scanned. In Fig. 1(e) and (f), the SyncScan scheme [5] and our DeuceScan scheme are pre-scan approaches. This implies that the DeuceScan scheme is a partial pre-scanning operation and the SyncScan scheme is a full pre-scanning operation. Due to the possibility of the handoff sensibility of the DeuceScan scheme is better than the SyncScan scheme, especially when the moving speed, v, of MH is high.

A. Spatiotemporal Graph

Since the DeuceScan scheme is a cache-based scheme, each MH possesses its own individual spatiotemporal graph. The spatiotemporal graph is composed of a series of triangles, where each triangle is established at a different time and location. A triangle is constructed by three APs, AP_{i_1}, AP_{i_2}, and AP_{i_3}, and an MH respectively receives $RSS_{t_i}^{AP_{i_1}}, RSS_{t_i}^{AP_{i_2}}$, and $RSS_{t_i}^{AP_{i_3}}$ from AP_{i_1}, AP_{i_2}, and AP_{i_3} at time t_i, such that there is no $RSS_{t_i}^{AP_{i_j}}$ which exists to satisfy $RSS_{t_i}^{AP_{i_j}} > \min\{RSS_{t_i}^{AP_{i_1}}, RSS_{t_i}^{AP_{i_2}}, RSS_{t_i}^{AP_{i_3}}\}$, where $j \neq \{1,2,3\}$. This implies that the MH receives the largest strength signals from AP_{i_1}, AP_{i_2}, and AP_{i_3}. From the spatiotemporal view point, the MH is located in the area of triangle ∇ at time t_i, which is denoted ∇_{t_i}. The full pre-scanning operation needs to be performed if an MH enters a new location which it has not traversed before. After performing the full pre-scanning operation, the MH can identify ∇_{t_i} at the new location. Assume that the MH enters a different location at time t_{i+1}, then $\nabla_{t_{i+1}}$ must be constructed, where $\nabla_{t_i} \neq \nabla_{t_{i+1}}$. However, it is possible for the condition of $\nabla_{t_i} = \nabla_{t_{i+1}}$ to exist when no handoff has occurred. As mentioned before, an MH keeps a spatiotemporal triangle list $= \{\nabla_{t_1}, \nabla_{t_2}, \cdots, \nabla_{t_i}, \nabla_{t_{i+1}}, \cdots \nabla_{t_j}\}$ at time t_j. A handoff occurs from times t_i to t_{i+1}. In addition, if an MH re-enters an already traversed location whose spatiotemporal triangle is ∇_{t_i},, the MH can extract its spatiotemporal triangle list. The partial pre-scanning operation is performed by only scanning AP_{i_1}, AP_{i_2}, and AP_{i_3}. Our scheme offers a high hit-ratio by utilizing the spatiotemporal property. If a new triangle ∇ does not exist in the spatiotemporal triangle list, this indicates that the MH has not traversed the current location before, therefore a new triangle ∇ is constructed by a full scanning operation. This new triangle ∇ is added the spatiotemporal triangle list.

B. The Deuce Process

The first important property of the deuce process is the partial pre-scanning operation. Given $\alpha+3$ APs, where $\alpha+3 <$ the total channels, AP_{i_1}, AP_{i_2}, $AP_{i_3}, \cdots$, and $AP_{i_{\alpha+3}}$, the main operation of the deuce process is to keep the same result of $RSS_{t_i}^{AP_{i_1}} > RSS_{t_i}^{AP_{i_2}} > RSS_{t_i}^{AP_{i_3}} > \cdots > RSS_{t_i}^{AP_{i_{\alpha+3}}}$ for β consecutive times, and the result is guaranteed accurate and correct. One other advantage of the deuce process is to provide fault-tolerant capability. If a handoff decision is made at time t_i, we can make the correct decision from all accumulated

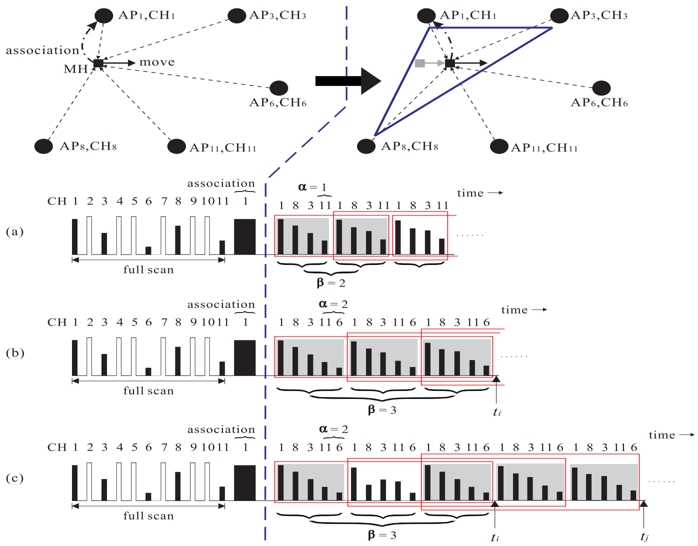

Fig. 2. Examples of (a) $D_s(1,2)$, (b) $D_s(2,3)$, and (c) $D_s(2,3)$.

results before time t_i. Fig. 2(a) shows the case of $D_s(1,2)$ which maintains $RSS_{t_i}^{AP_1} > RSS_{t_i}^{AP_8} > RSS_{t_i}^{AP_3} > RSS_{t_i}^{AP_{11}}$ for two scan cycles. Fig. 2(b) illustrates the case of $D_s(2,3)$ which maintains $RSS_{t_i}^{AP_1} > RSS_{t_i}^{AP_8} > RSS_{t_i}^{AP_3} > RSS_{t_i}^{AP_{11}} > RSS_{t_i}^{AP_6}$ for three scan cycles. Finally, Fig. 2(c) illustrates the case of $D_s(2,3)$ which maintains $RSS_{t_i}^{AP_1} > RSS_{t_i}^{AP_8} > RSS_{t_i}^{AP_3} > RSS_{t_i}^{AP_{11}} > RSS_{t_i}^{AP_6}$ for three consecutive scan cycles. In Fig. 2(c), the second scan cycle has a different result. Therefore, it must wait for the next three consecutive scan cycles with the same result.

III. THE DEUCESCAN SCHEME: DEUCE-BASED FAST HANDOFF SCHEME

A. Deuce Procedures

The DeuceScan scheme by utilizing the spatiotemporal graph to provide a new partial pre-scanning operation. Before describing the DeuceScan scheme, two deuce procedures with stable signal strength and with variable of signal strength are described as follows.

A.1. Deuce Procedure with Stable Signal Strength: The deuce procedure aims to obtain stable and accurate information and help the MH make the correct decision when changing the spatiotemporal triangle from ∇_i to ∇_{i+1}. We present the deuce procedure with stable signal strength, which is denoted $D_s(\alpha,\beta)$, where α is the extra number of scanning APs and β is the number of scan cycles. A scan cycle is the delay time required to scan $\alpha+3$ APs. The use of extra α APs is to provide fault-tolerant capability, and it offers extra scanning chances if the next handoff AP is not in spatiotemporal triangle ∇_i. In addition, β is used to improve the accuracy of the candidate list of potential handoff APs. $D_s(\alpha,\beta)$ is performed as follows.

D1) The MH only pre-scans $\alpha+3$ APs, where $\alpha+3<$ the total channels. The MH received $RSS_{t_i}^{AP_{i_1}}, RSS_{t_i}^{AP_{i_2}}, RSS_{t_i}^{AP_{i_3}}, \cdots, RSS_{t_i}^{AP_{i_{\alpha+3}}}$ from AP_{i_1}, AP_{i_2}, $AP_{i_3}, \cdots$, and $AP_{i_{\alpha+3}}$ at time t_i.

D2) Given a scan cycle, the MH performs the pre-scan function by scanning AP_{i_1}, AP_{i_2}, $AP_{i_3}, \cdots$, and $AP_{i_{\alpha+3}}$ to maintain a stable deuce window.

D3) If the deuce window is stable, the MH confirms that the current spatiotemporal triangle, ∇_i, is composed of AP_{i_1}, AP_{i_2}, and AP_{i_3}. Then it goes to D2 continuously to perform the pre-scan function before executing the actual handoff procedure.

D4) If a handoff decision must be made at time t_i and if the deuce window is unstable, then the current spatiotemporal triangle, ∇_i, is composed of AP_{i_1}, AP_{i_2}, and AP_{i_3} where the results of $RSS_{t_i}^{AP_{i_1}} > RSS_{t_i}^{AP_{i_2}} > RSS_{t_i}^{AP_{i_3}} > \cdots > RSS_{t_i}^{AP_{i_{\alpha+3}}}$ occur most frequently among β scan cycles. Otherwise, go to D2.

A.2. Deuce Procedure with Variable of Signal Strength: We provide the deuce procedure, $D_v(\alpha,\beta)$, with signal variation based on the departure and approach rates. We define the variable signal strength as follows. An AP receives $RSS_{t_i}^{AP}$ and $RSS_{t_{i-1}}^{AP}$ at times t_i and t_{i-1}, respectively. The *signal variation* is denoted $\Delta_{t_i}^{AP} = RSS_{t_i}^{AP} - RSS_{t_{i-1}}^{AP}$. If $\Delta_{t_i}^{AP} > 0$, then $\Delta_{t_i}^{AP}$ denotes the approach rate of AP from times t_{i-1} to t_i. If $\Delta_{t_i}^{AP} < 0$, then $\Delta_{t_i}^{AP}$ is the departure rate of AP from times t_{i-1} to t_i. Consider three APs, for which we can estimate $\Delta_{t_i}^{AP_{i_1}}, \Delta_{t_i}^{AP_{i_2}}$, and $\Delta_{t_i}^{AP_{i_3}}$ from times t_{i-1} to t_i. The use of departure and approach rates provides accurate handoff information to make the correct handoff decision.

D1') The MH pre-scans $\alpha+3$ APs, AP_{i_1}, AP_{i_2}, $AP_{i_3}, \cdots$, and $AP_{i_{\alpha+3}}$, where $\alpha+3<$ the total number of channels.

D2') Given a scan cycle, the MH performs the pre-scan function to maintain a stable deuce window. A deuce window is said to be stable if the same order of signal variations for all $\alpha+3$ APs is maintained for β scan cycles. In general, there are three cases as follow.

Case 1: $\Delta_{t_i}^{AP_{i_1}} > \Delta_{t_i}^{AP_{i_2}} > \Delta_{t_i}^{AP_{i_3}} > \cdots > \Delta_{t_i}^{AP_{i_{\alpha+3}}} > 0$. The deuce window is stable if the same result of $\Delta_{t_i}^{AP_{i_1}} > \Delta_{t_i}^{AP_{i_2}} > \Delta_{t_i}^{AP_{i_3}} > \cdots > \Delta_{t_i}^{AP_{i_{\alpha+3}}}$ is maintained for all β scan cycles, where $\Delta_{t_i}^{AP_{i_\kappa}}$ denotes the approach rate of the MH to AP_{i_κ}, $1 \le \kappa \le \alpha+3$.

Case 2: $0 > \Delta_{t_i}^{AP_{i_1}} > \Delta_{t_i}^{AP_{i_2}} > \Delta_{t_i}^{AP_{i_3}} > \cdots > \Delta_{t_i}^{AP_{i_{\alpha+3}}}$. The deuce window is stable if the same result of $\Delta_{t_i}^{AP_{i_1}} > \Delta_{t_i}^{AP_{i_2}} > \Delta_{t_i}^{AP_{i_3}} > \cdots > \Delta_{t_i}^{AP_{i_{\alpha+3}}}$ is maintained for all β scan cycles, where $\Delta_{t_i}^{AP_{i_\kappa}}$ denotes the departure rate of MH to AP_{i_κ}, $1 \le \kappa \le \alpha+3$.

Case 3: $\Delta_{t_i}^{AP_{i_1}} > \Delta_{t_i}^{AP_{i_2}} > \Delta_{t_i}^{AP_{i_3}} > \cdots > \Delta_{t_i}^{AP_{i_\gamma}} > 0$ and $0 > \Delta_{t_i}^{AP_{i_{\gamma+1}}} > \Delta_{t_i}^{AP_{i_{\gamma+2}}} > \cdots > \Delta_{t_i}^{AP_{i_{\alpha+3}}}$. The deuce window is stable if the same results of $\Delta_{t_i}^{AP_{i_1}} > \Delta_{t_i}^{AP_{i_2}} > \Delta_{t_i}^{AP_{i_3}} > \cdots > \Delta_{t_i}^{AP_{i_\gamma}} > 0$ and $0 > \Delta_{t_i}^{AP_{i_{\gamma+1}}} > \Delta_{t_i}^{AP_{i_{\gamma+2}}} > \cdots > \Delta_{t_i}^{AP_{i_{\alpha+3}}}$ is maintained for all β scan cycles, where $1 < \gamma < \alpha+3$.

D3') If the deuce window is stable, the MH confirms that the current spatiotemporal triangle, ∇_i, is composed of AP_{i_1}, AP_{i_2}, and AP_{i_3}, then goes to D2' to continuously perform the pre-scan function if the actual handoff procedure has not occurred.

D4') If a handoff decision must be made at time t_i and if the deuce window is unstable, then the current spatiotemporal triangle, ∇_i, is composed of AP_{i_1}, AP_{i_2}, and AP_{i_3} where the results of AP_{i_1}, AP_{i_2}, and AP_{i_3} occur most frequently among β

scan cycles. Otherwise, go to D2.

B. The DeuceScan Scheme

B.1. Constructing the Spatiotemporal Graph: Before effectively performing the $D_s(\alpha,\beta)$ and $D_v(\alpha,\beta)$, a spatiotemporal graph, which is a spatiotemporal triangle list should be constructed.

S1) If an MH is turned on, it initially performs a full pre-scan operation for all channels in order to associate with a AP with the strongest RSS. The MH executes the $D_s(\alpha,\beta)$, where α = the total number of channels $-$ 3. ∇_{t_1} is estimated at time t_1, and the spatiotemporal triangle list = $\{\nabla_{t_1}\}$.

S2) If an MH enters a new location at time t_i, $i > 1$, then the $D_s(\alpha,\beta)$ is performed, where α = the total channels $-$ 3. A spatiotemporal triangle, ∇_{t_i}, is estimated and spatiotemporal triangle list = spatiotemporal triangle list $\cup$ ∇_{t_i}.

S3) If an MH enters a location at time t_i, $i > 1$, and MH is located in ∇_{t_μ} if a spatiotemporal triangle, ∇_{t_μ}, already existes in the current spatiotemporal triangle list. Then the $D_s(\alpha,\beta)$ is performed to prepare accurate information of candidate handoff APs, where $\alpha <$ the total channels $-$ 3. Go to step S2.

B.2. Handoff with the DeuceScan Process: Let AP_{cur} denote the currently associated AP and MH receives $RSS_{t_i}^{AP_{cur}}$ from AP_{cur}. Let $RSS_{threshold}$ denote the threshold value of RSS. If $RSS_{t_i}^{AP_{cur}} < RSS_{threshold}$ and $RSS_{t_i}^{AP_{next}} > RSS_{threshold}$ is received, then the handoff procedure is executed to hand over to AP_{next}.

S1) When an MH enters a new location at time t_i, the MH performs the partial pre-scanning procedures $D_s(\alpha,\beta)$ and $D_v(\alpha,\beta)$ when $RSS_{t_i}^{AP_{cur}} > RSS_{threshold}$ to estimate the current spatiotemporal triangle, ∇_{t_i}, where AP_{i_1}, AP_{i_2}, AP_{i_3} and the $AP_{i_1} = AP$, and candidate handoff APs are AP_{i_2} and AP_{i_3}.

S2) From the result of performing $D_s(\alpha,\beta)$, the best candidate handoff AP is AP_{i_2} and the second-best one is AP_{i_3}. If the same result is obtained when $D_v(\alpha,\beta)$ is executed, then the final best and second-best handoff APs are AP_{i_2} and AP_{i_3}.

IV. SIMULATION RESULTS

A simulator was written using the C++ program to simulate the performance of our DeuceScan scheme with all existing fast layer-2 handoff schemes [1][5][6][7]. The performance metrics of the simulator are defined as follows. (1)*Packet loss*: The total number of packets lost during the handoff procedure for an MH. (2)*Handoff latency*: The time period between an MH changing its association from the current associated AP to another one. (3)*Link quality*: The average received signal strength of an MH for a period of time. In simulation parameters, there are 500 mobile hosts and 100-200 APs in wireless environment. The network region is 1000m * 1000m, and radio propagation range is 100 m. The speed of mobile hosts are 5-30 m/s.

A. Packet Loss

In general, the higher the moving speed of an MH is, the higher the packet loss is. Fig. 3(a) shows that the packet loss of $D(1,2)$ < that of $D(2,2)$ < that of $D(1,3)$ < that of $D(3,2)$

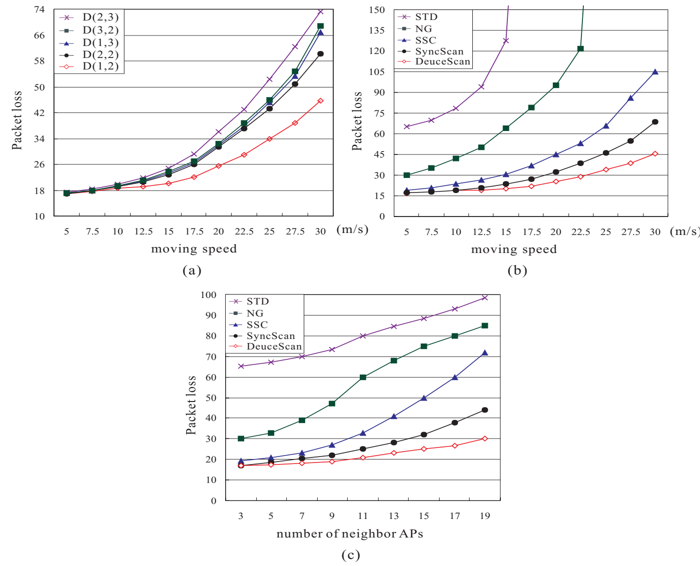

Fig. 3. Performance of packet loss.

< that of $D(2,3)$. It is verified that the higher the handoff latency is, the greater the packet loss is. Fig. 3(b) shows that the packet loss of STD > that of NG > that of SSC > that of SyncScan > that of DeuceScan vs. the moving speed. Fig. 3(c) shows that the greater the number of neighbor APs is, the greater the packet loss is.

B. Link Quality

The performance effect of link quality vs. moving speed under different values of α and β is illustrated in Fig. 4(a). Generally, the higher the moving speed of an MH is, the lower the link quality is. Fig. 4(a) illustrates that the link quality of $D(1,2)$ > that of $D(2,2)$ > that of $D(1,3)$ > that of

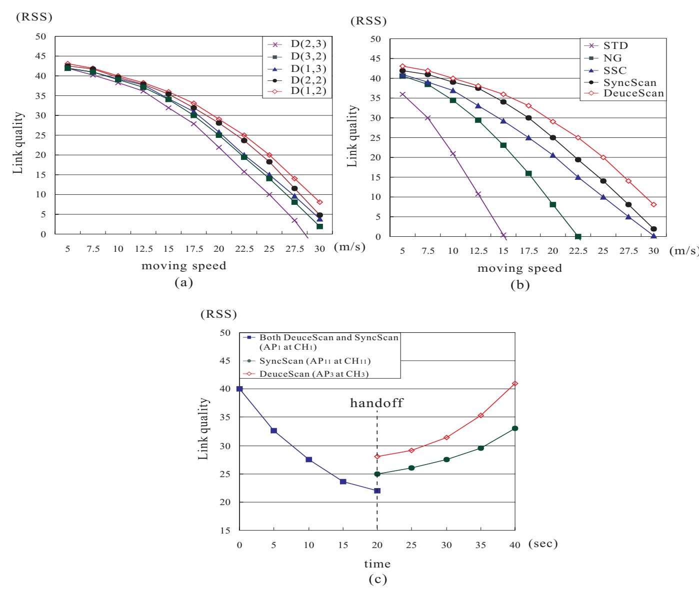

Fig. 4. Performance of link quality.

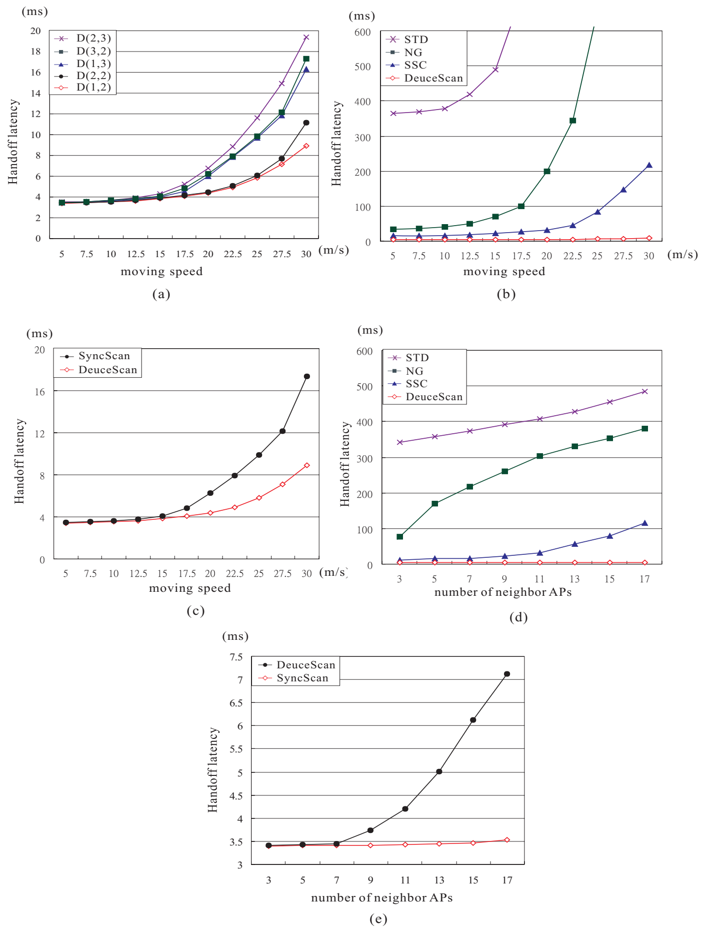

Fig. 5. Performance of handoff latency.

$D(3,2)$ > that of $D(2,3)$. An MH with better link quality implies that good communication quality is maintained over a wireless environment. When $RSS_{t_i}^{AP_{cur}} < RSS_{threshold}$, the MH executes a handoff procedure to reassociate with the next AP with the best and most stable signal strengths. In Fig. 4(b), the SyncScan and DeuceScan schemes maintain high link quality because the pre-scanning operation is adopted. DeuceScan has better link quality than that of SyncScan because of the partial pre-scanning operation. Fig. 4(c) simulated a handoff situation described the differences in link quality between the DeuceScan and SyncScan schemes. After a handoff occurred in time $t = 20s$, if MH's moving speed is high, the MH using the DeuceScan scheme has better link quality.

C. Handoff Latency

Fig. 5(a) shows that the larger deuce window size has the higher the handoff latency. The increased number of extra scanning APs increases the handoff latency. But, the increased number of extra scanning APs and large deuce window size can effectively acquire accurate handoff information with fault-tolerant capability. Fig. 5(b) illustrates that the handoff latency: STD >NG >SSC >DeuceScan. Fig. 5(c) shows that the handoff latency of SyncScan was larger than that of DeuceScan, because of the partial pre-scanning property. Fig. 5(d) shows that the handoff latency: STD >NG >SSC >DeuceScan, under a fixed moving speed. The STD always performs the full scanning operation during the handoff, hence the handoff latency of STD steadily increases as the number of neighbor APs increases. But, the NG performs a partial scanning operation during the handoff, and the handoff latency greatly increases as the number of neighbor APs approaches 17. When the SSC experiences a cache miss, the average handoff latency significantly increases. Fig. 5(e) shows that our DeuceScan scheme was not affected by the number of neighbor APs, but the SyncScan scheme was affected by the number of neighbor APs, since a full pre-scanning operation is performed.

V. CONCLUSIONS

This paper presents a new fast handoff scheme, called the DeuceScan scheme, to further reduce the probe delay for WLANs. A spatiotemporal approach is developed in this work to utilize spatiotemporal graph to provide spatiotemporal information for making accurate handoff decisions to correctly search for the next access point. The DeuceScan scheme, using a pre-scan approach, efficiently reduces the MAC layer handoff latency. Two factors of stable signal strength and variable signal strength are both used in our developed DeuceScan scheme. Finally, the simulation results illustrated the performance achievements of the DeuceScan scheme in reducing the handoff delay time and packet loss rate, compared to existing fast handoff schemes.

VI. ACKNOWLEDGMENT

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