Optimizing the Performance of Handoff Management in Wireless LANs

Li Jun ZHANG and Samuel Pierre

Department of Computer Engineering and Software Engineering, Ecole Polytechnique de Montreal, Montreal, H3C 3A7 Canada

Summary

As the radio range of access point (AP) in a wireless local area network (WLAN) is about 35 meters, mobile nodes (MNs) have to frequently undergo a handoff process when they move beyond the radio coverage area of their associated APs. However, legacy IEEE 802.11-based standards cannot provide sufficient support for mobility management. Besides, as the demands from wireless users for real-time multimedia services increase, quality of service provisioning becomes a challenging issue for mobile users in WLANs. Under the circumstances, this paper proposes a new handoff management scheme to support ongoing real-time applications while MNs change their network attachment points. This MAC-layer-based approach consists of minimizing the total number of scanned channels during handoff, and reducing the probe-waiting time for each examined channel. To analyze the efficiency of the proposal, simulations are conducted with the simulator SimulX for MNs roaming in an environment that integrates the standard mobile IPv6 (MIPv6) with IEEE 802.11b. Simulation results show that our proposed solution delivers better performance than the IEEE 802.11b standard, a variation of this standard in which an MN waits for MinChannelTime on each probed channel, and two other well-documented approaches in the literature: Selective scanning plus AP Caching (Selective + Caching) and Neighbor Graphs.

Keywords:
Mobility management, Handoff management, Scanning, Wireless LAN.

1. Introduction

The rapid advancement of wireless technology enables contemporary Internet service providers to deliver real-time multimedia services, such as audio streaming and video conferencing to mobile/wireless subscribers. Nevertheless, such media streaming applications impose severe quality of service (QoS) requirements on wireless networks. On the other hand, using spread-spectrum technology, wireless local area networks (WLANs) provide stations with free mobility within the radio coverage area of their associated access point (AP), while they are still connected to the network. However, legacy IEEE 802.11-based standards cannot provide enough mobility support, in particular, fast handoff support when mobile nodes (MNs) change their associated APs. Besides, it is well-known that handoff process using traditional standards results in long handover latencies and unacceptable packet loss rates. Hence, new effective and efficient mobility management schemes are required for MNs roaming in WLANs with ongoing real-time applications.

Two operational modes are defined by the IEEE 802.11 standard [1]: *infrastructure* and *ad hoc* mode. With the infrastructure mode, an AP comprises a basic service set (BSS) and provides network connectivity to its associated MNs. One or more APs constitute an extended service set (ESS) that covers a larger service area. With the ad hoc mode, two or more MNs form a peer-to-peer wireless network without deploying any APs. This paper is concerned only with the infrastructure mode.

An ideal WLAN can provide successive radio signal coverage for MNs in its service area. An MN may decide to handoff from one AP to another due to mobility, AP load balancing or signal fading reasons. Generally, handoff process in WLANs takes place at the medium access control (MAC) layer and consists of: *scanning*, *authentication* and *reassociation*.

Scanning attempts to determine the characteristics of available BSSs within the MN’s radio range. Two scanning modes are specified in the baseline standard IEEE 802.11: passive and active scanning [1]. The former allows an MN to listen on each existing channel, and wait for beacon frames periodically sent by neighboring APs, while the latter involves the generation of probe request frames and the subsequent processing of received probe responses from nearby APs.

Upon discover of accessible APs, the MN then selects one AP as its next AP. Such selection usually is based on certain preferences, such as the received signal strength indicator (RSSI), the support data rate, the number of frame retransmission [2], etc. And then the MN launches authentication process with the new AP (NAP). Generally, authentication strives to identify the MN as a member of the specified BSS and to authorize it to communicate with other stations within the same BSS [1]. Two authentication

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methods exist within the standard: *Open System* and *Shared Key Authentication* [1].

Open system authentication involves the exchange of *authentication request* and *authentication response* frames between the MN. Usually, all stations can be authenticated. While shared key authentication is an optional four-step process using wired equivalent privacy (WEP) key, in which an MN starts authentication by transmitting an *authentication request* to the NAP. Upon receiving this request, the NAP generates a challenge text using a WEP key and sends an *authentication response* with such challenge text as a reply. The MN then encrypts the received challenge text with a shared WEP key and returns an *authentication request* with the encrypted challenge text to the NAP. The NAP subsequently decrypts this request using the shared key and compares the decrypted and the original challenge texts. If they are identical, the NAP transmits an *authentication response* to confirm a successful authentication. Regardless of the authentication method used, the IEEE 802.11 standard requires mutually acceptable responses for a successful authentication [1], and also requires authentication to take place before association (or reassociation). Due to security flaws in open system and shared key authentications, the authentication methods specified in IEEE 802.11 have been replaced by IEEE 802.11i [3]. However, to maintain backward compatibility, IEEE 802.11i allows open system authentication and exchanging authentication messages after reassociation [3] [4], shown in Fig. 1.

Followed by successful authentication, reassociation is launched by the MN. Note that the IEEE 802.11 standard requires each MN to be associated with a single AP at any given time [1]. During reassociation, the MN sends a reassociation request to the NAP. Such frame contains the concerning MAC address of the MN, its previous service set identifier (SSID), the MAC address of the old AP (oAP). Upon receipt of this request, the NAP launches the inter-access point protocol (IAPP) to deliver MN-related security context from the oAP [5]. In doing so, the NAP sends a RADIUS Access-request message to the RADIUS (Remote Authentication Dial-In User Service [6]) server, which then looks up the IP address of the oAP and verifies the SSID, before returning a RADIUS Access-accept message to the NAP. The Access-accept message contains the IP address of the oAP and security block items required to establish a secure communication channel between the involved APs.

After exchanging security elements through Send-Security-Block and ACK-Security-Block packets, both APs own sufficient information to encrypt all further packets. Thereafter, the NAP sends an encrypted MOVE-notify packet to the oAP requesting for the MN's context. Upon verifying the MN's association, the oAP removes the MN from its association table and returns an encrypted MOVE-response packet to the NAP, including the pertaining Context Block. Then, the NAP adds the MN into its association table and broadcasts a Layer 2 Update frame to inform all layer 2 devices, such as bridges and switches, of updating their forwarding table for the MN.

In short, the IAPP allows an AP to communicate with other APs in the same ESS, and minimize the opportunity to transmit MNs' security contexts over the air. However, context transfer using IAPP results in additional delays during handoff. Finally, the NAP sends a reassociation response to the MN [5], [7], [8], thus completes the overall handoff process. Fig. 1 shows the MAC layer handoff process in WLANs.

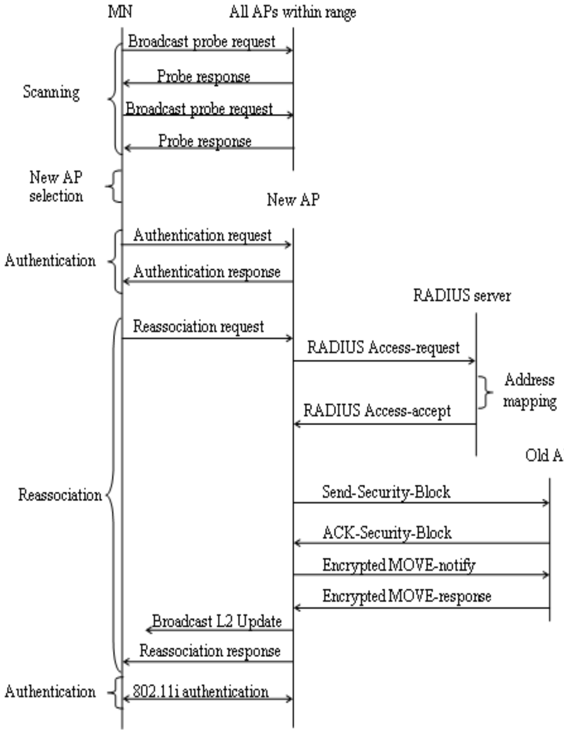

Fig. 1 MAC Layer Handoff Process in WLANs

Probe delays constitute over 90% of the overall L2 handoff latencies [9]. This fact motivates us to develop an effective fast scanning scheme for mobile hosts roaming with ongoing real-time applications. The remainder of this paper is organized as follows. Section 2 provides a brief overview of fast scanning methods in WLANs. Section 3 describes the proposed fast handoff scheme. Basically, this proposal allows an MN with ongoing voice over IP (VoIP) session to launch the authentication process after receiving the first probe response on a scanned channel. Section 4 presents performance evaluations that were conducted through simulations using the simulator SimulX. Simulation results are then analyzed and presented in detail. Finally, Section 5 concludes the paper and outlines future work.

2. Related Work

Numerous studies have been conducted in order to improve MAC layer handoff performance in terms of handoff delays (time required to complete scanning, authentication and reassociation) and packet loss rates for mobile hosts roaming in IEEE 802.11 networks. Since probe delays consist of the main contributor to the overall MAC layer handoff latency [9], most recently proposed handoff schemes aim to reduce this lengthy delay. This section provides a survey of these schemes, which are further classified into: fast scanning, bypass scanning and cross-layer design approaches.

Fast scanning methods rely on reducing the number of probed channels, the time taken on each channel, scanning-related timers, such as MinChannelTime and MaxChannelTime for active scanning, ChannelTime and beacon interval for passive scanning, etc. Such methods can be further classified into full and selective scanning.

Full scanning means that all available channels are probed while the values of MinChannelTime, MaxChannelTime, probe-waiting time and beacon interval are optimized. Usually, full scanning is based on the assumption that MNs have no preknowledge of existing APs within range when handoff occurs. As a result, all available channels must be searched consecutively. There are several full scanning methods, such as *the tuning technique* [17], which aims to find an optimal value for MinChannelTime and MaxChannelTime to reduce active scanning delays. *Intelligent channel scanning* [22] aims to minimize the probe-waiting time on each channel. *SyncScan* [15] replaces active scanning with passive channel monitoring on nearby APs. Furthermore, a continuous tracking technique is devised by synchronizing short listening periods at MNs with regulated periodic beacon transmission from APs. As a result, MNs can passively scan by switching channels at the exact moment a beacon is about to arrive.

Instead of probing all available channels individually, *selective scanning* reduces the number of channels required to discover APs. Hence, probe delays are significantly minimized compared to full scanning. A number of selective scanning approaches have been proposed in the literature, such as selective scanning plus AP caching methods (also called channel mask schemes [10]) are designed to reduce L2 handoff delay to a level where VoIP communication becomes seamless [11]. Moreover, such schemes focus on reducing the probing time of non-existing channels via selective scanning, as well as the scanning frequency using caching techniques. Another example is called Neighbor Graphs approaches, which aim to reduce the total number of probed channels and the probe-waiting time on each channel [12]-[14].

Bypassing scanning methods aim to remove scanning from handoff. For example, the caching technique [10] or using multiple radio interfaces deployed either at the AP or at the MN to decouple scanning with handoff so that MNs can search proactively for alternate APs while being associated with an AP and interleaving data communication. For example, the *MultiScan* approach exploits multiple radios on the MN side in order to eliminate handoff latency [16].

Cross-layer design approaches: Several handoff schemes have been proposed to improve handoff performance using cross-layer design strategies, such as *Beacon with sufficient IP layer information* [23] [24] allows an enhanced AP to assist and handle fast new address configuration by inserting IP layer information into beacons. This approach drastically decreases overall handoff latencies (both at MAC layer and IP Layer). *IP-IAPP scheme* [25] [26] enhances APs with advanced routing functionalities so that they act as mobility agents for MNs, and are responsible for IP-layer (L3) mobility management. *Link layer (L2) triggers and topology information-aided fast handoff* [27] scheme use pre-handoff triggers to discover agents or address configuration before L3 handoffs. Additionally, post-handoff triggers are applied to eliminate movement detection delays.

3. Proposed Fast Scanning Scheme

Our research objective is to provide fast handoff support for mobile hosts roaming with ongoing real-time applications in WLANs. To more specifically, this research work aims to minimize handoff delays and packet loss rates during handoff. We assume that MNs can completely skip handoff detection using any triggers from the physical layer; this is confirmed by the experimental study conducted in [17].

When the received signal strength is below a pre-defined threshold, the physical layer of an MN sends a physical layer (L1) trigger to the MAC layer. Note that the value of the threshold is based on practical measurements and it is affected by the surrounding interferences. And at the time of receiving the L1 trigger, we assume that the MN moves with ongoing real-time communication with a multimedia server, which is called corresponding node (CN). The MN launches a fast scanning procedure immediately after receiving the L1 trigger. And then it analyzes its currently associated channel. In doing so, a channel analyzer module is defined and designed to store and manage the associated channel information.

The channel analyzer module forces the MN to switch to the next channel and to achieve wireless medium access control using normal channel access procedure, e.g. carrier sense multiple access with collision avoidance (CSMA/CA). Thereafter, the MN quickly broadcasts a probe request on the examined channel and starts a probe timer. Then, it listens to the examined channel, and waits for probe responses sent by the APs within range. If no response is received before the expiration of MinChannelTime, the MN switches to next channel and continues performing active scanning. Once the first probe response is received, the MN immediately begins authentication with the AP that sent the response. This optimally minimizes the probe-waiting time on the examined channel. Thereafter, successful authentication and reassociation lead to the completion of the L2 handoff.

The advantage of the proposed fast scanning scheme is that probe delays can be reduced significantly, because only a subset of available channels is scanned. Besides, MNs spend the minimal probe-waiting time on each examined channel. As a result, handoff latencies and packet losses are improved for mobile hosts roaming with real-time applications in progress. This proposal is applicable in fast movement cases and in cases where MNs need to handoff as quickly as possible. In addition, it requires neither AP modifications (such as SyncScan [15]), nor pre-knowledge of the wireless network topology (such as the Neighbor Graphs approach [12]-[14] and the selective scanning plus AP caching schemes [11]). Moreover, unlike MultiScan [16], the proposed fast scanning approach does not require the addition of a second radio interface for each MN. Furthermore, simulation results for handoff latencies and packet losses are obtained from the same test bed (unlike the selective scanning plus AP caching schemes [11]), guaranteeing the consistency and credibility of results. However, this proposal also includes certain limitations, such as the possibility for an MN not to select the best AP at the moment of handoff.

4. Performance Evaluation

To evaluate the efficiency of our proposal, simulations were conducted with the simulator SimulX [18], which is a C++ simulator developed at Louis-Pasteur University in France. This simulator is especially designed for IEEE 802.11 networks, and it also provides mobility support in IPv6 networks. The IEEE 802.11b standard [20] with 14 channels, mobile IPv6 protocol [19] and the selective scanning plus AP caching (Selective + Caching) schemes were already implemented. Based on these codes, we implement the IEEE 802.11b standard with 11 channels, The standard IEEE 802.11b with Min (an MN only waits for MinChannelTime on each examined channel), the Neighbor Graphs approaches and the proposed fast scanning scheme. Fig. 2 illustrates the network topology used for simulation scenarios.

The investigated scenario consists of an MN moving inside a building at an average speed of 1 m/s, communicating with a CN that sends UDP packets every 20 ms to emulate 64 kbps pulse code modulated voice stream packetized into 160 bytes. The radio range of each network entity (including MN, CN and AP) is set to 12 meters. The MinChannelTime and the MaxChannelTime is set to 17 ms and 38ms, respectively. These values are corresponding to Cisco devices [9]. AP1 operates on the channel 1, AP2 on channel 6, AP3 on channel 11 and AP4 on channel 6. The default beacon interval for each AP is 100 ms. Five LANs with a 100 Mbps capacity are present, and four WLANs of which the transmission rate ranging from 2 to 11 Mbps.

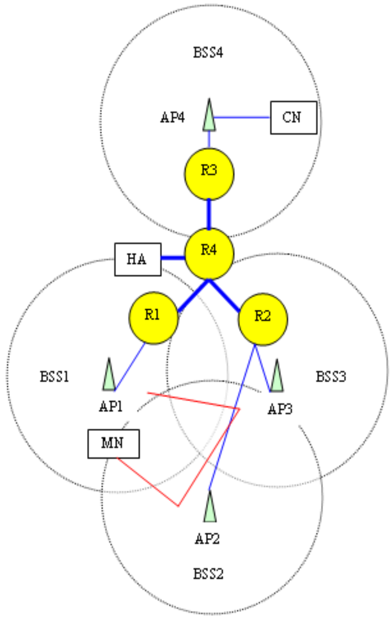

Fig. 2 Network Topology for Simulation

The MN performs three movements: from AP1 to AP2, then to AP3, before returning to AP1. The trajectory of the MN is shown by the line red. However, the following performance analysis is based on the simulation results of the last two movements; this is because the MN performs a full scan for the selective scanning plus AP caching schemes, constructs neighbor graphs and non-overlapping graphs for the Neighbor Graphs approaches during the first movement. Thus, the performance evaluation represents a fair comparison, as the first movement of the MN is excluded from our analysis.

Fig. 3 shows the probe delays versus AP's capacities. Our proposed scheme outperforms the other four handoff solutions: the IEEE 802.11b standard, the standard with Min, the selective scanning plus AP caching and the neighbor graphs approaches. This is because our proposed scheme enables an MN to quickly terminate the scanning procedure once it finds an available AP to associate with. The average probe delay of the proposed scheme equals 35.70 ms, compared to 210.20 ms for the IEEE 802.11b standard, the performance gain is 83.02%; compared to 189.51 ms for the standard with Min, the gain is 81.16%; compared to 55.51 ms for the Selective scanning plus caching, the MN spends 35.69% less of probe times; compared to 55.51 ms for the Neighbor Graphs, the performance gain is 35.69%.

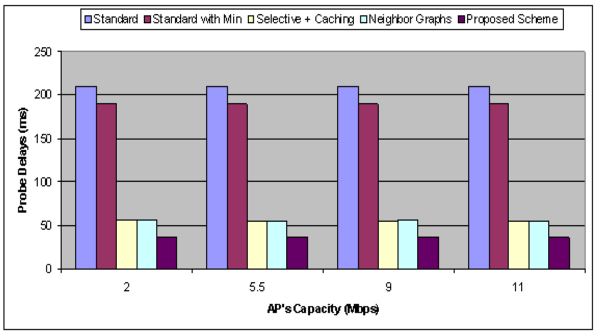

Fig. 3 Probe Delays vs. AP's Capacity

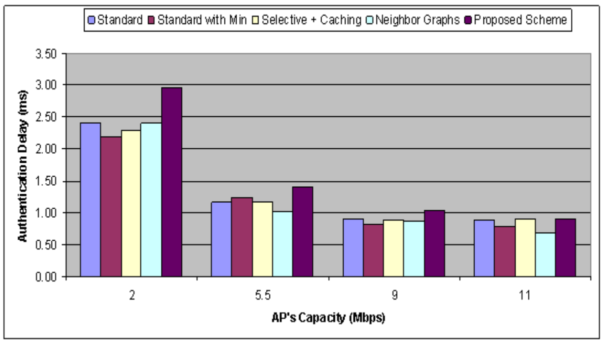

Fig. 4 Authentication Delay vs. AP's Capacity

Fig. 4 shows the relationship between the authentication delays and AP's capacities. Authentication delay decreases rapidly as AP's capacity increases. Neighbor Graphs delivers better performance amongst all solutions. The average authentication delay of the proposed scheme is 1.57 ms, compared to 1.34 ms for the IEEE 802.11b, the decrease is 0.23 ms; compared to 1.26 ms for the standard with Min, the decrease is 0.21 ms; compared to 1.32 ms for the selective scanning plus caching, the decrease is 0.25 ms; compared to 1.24 ms for the neighbor graphs approaches, the decrease is 0.33 ms. All the differences are less than 0.4 ms. Our scheme needs more authentication delays than other solutions. This is because the processing time for executing the proposed scheme (especially the channel analyzer module) is a little bit longer than other approaches as the MN needs to find its current associated channel at the moment of handoff, then it switches to the next channel and starts scanning until it find the first responding AP.

Fig. 5 shows the reassociation delays versus the AP's capacities. From the figure, we observe that reassociation delay decreases rapidly as AP's capacity increases for both standard with Min and the proposed scheme. Selective scanning plus AP Caching schemes yield better performance than other solutions. The average reassociation delay of the proposed scheme is 1.65 ms, compared to 1.80 ms for the standard IEEE 802.11b, the performance gain is 8.29%; compared to 1.65 ms for the standard with Min, the decrease is 0.15%; compared to 1.63 ms for the Selective scanning plus AP caching, the decrease is 0.89%; compared to 1.75 ms for the Neighbor Graphs approaches, the performance gain is 5.61%.

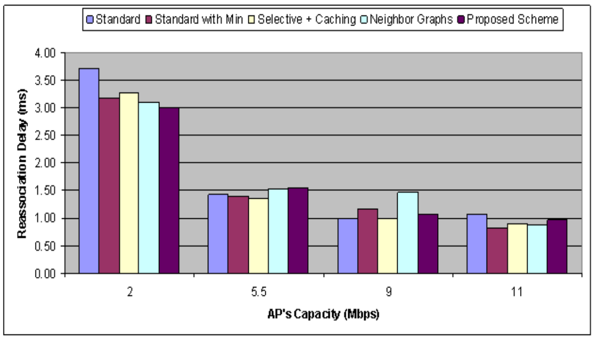

Fig. 5 Reassociation Delay vs. AP's Capacity

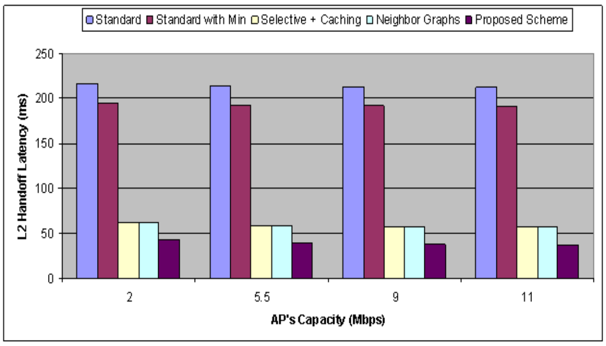

Fig. 6 L2 Handoff Latency vs. AP's Capacity

Fig. 6 shows the L2 handoff latencies versus the AP's capacities. The increasing of AP's capacity leads to shorter L2 handover latencies. This is because the time taken for exchanging frames between the MN and the involved APs becomes shorter due to higher transmission rate of the AP. Our proposed scheme delivers better performance than the other schemes. The average L2 handover delay of our proposal equals 38.92 ms, compared to 213.34 ms for the IEEE 802.11b standard, the performance gain is 81.76%; compared to 192.41 ms for the standard with Min, the gain is 79.77%; compared to 58.46 ms for the Selective scanning plus AP caching, the performance gain is

33.42%; compared to 58.38 ms for the Neighbor Graphs approaches, the optimization is 33.33%.

Fig. 7 illustrates the relationship between L3 handoff latency and AP's capacity for MIPv6 with route optimization (RO) Mode. The increasing of AP's capacity leads to shorter L3 handover latencies. We explain this by the fact that L2 handoff delays are an important component of L3 handoff latency. As a result, the lower the L2 handoff delays, the shorter L3 handoff latencies. Our proposed scheme delivers better performance among all solutions. The average L3 handover delay is 69.91ms, compared to 273.33ms for the IEEE 802.11b standard, the performance gain is 74.42%; compared to 254.53ms for the standard with Min, the gain is 72.53%; compared to 125.27ms for the Neighbor Graphs approaches, the optimization is 44.19% compared to 123.45ms for the Selective scanning plus AP caching schemes, the performance gain is 43.37%.

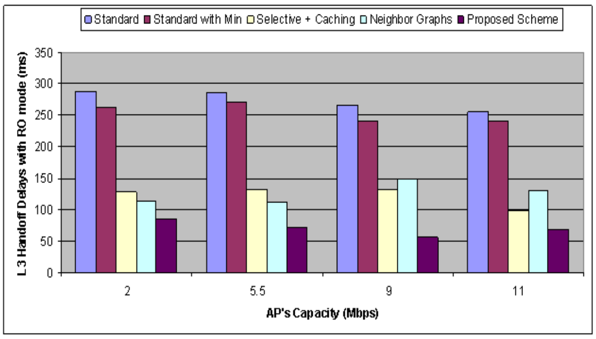

Fig. 7 L3 Handoff Delay vs. AP's Capacity for RO Mode

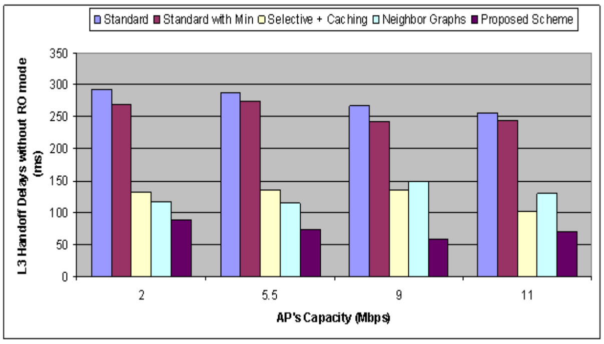

Fig. 8 L3 Handoff Delay without RO vs. AP's Capacity

Fig. 8 illustrates the relationship between L3 handoff latency and AP's capacity for MIPv6 without RO Mode. The increasing of AP's capacity leads to shorter L3 handover latencies. We obtain the same observation as Fig. 7. In addition, our proposed scheme delivers better performance than other solutions. The average L3 handover delay is 72.42ms, compared to 276.02ms for the IEEE 802.11b standard, the performance gain is 73.76%; compared to 257.18ms for the standard with Min, the gain is 71.84%; compared to 127.90ms for the Neighbor Graphs approaches, the optimization is 43.38% compared to 126.33ms for the Selective scanning plus AP caching schemes, the gain is 42.68%. Another observation is that L3 handoff delay without RO mode is longer than that with RO mode. This is obvious because the signaling messages traverse a triangular route via the home agent of the MN in case of handoff without RO.

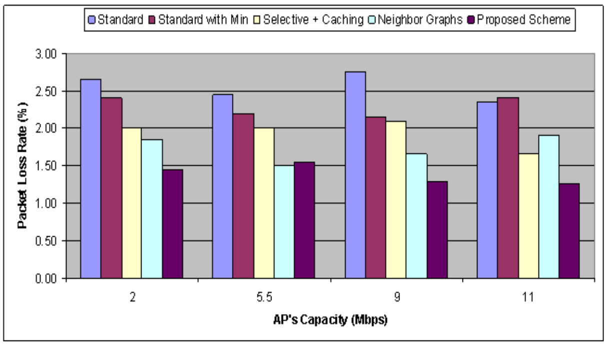

Fig. 9 Packet Loss Rate vs. AP's Capacity

Fig. 9 shows the relationship between packet loss rates and AP's capacities. Packet loss rate is defined as a ratio of the number of lost packets over the total number of transmitted packets at the application layer. Again, our proposed solution yields better performance than other schemes. The average packet loss rate for the proposed scheme equals 1.39%, compared to 2.55% for the IEEE 802.11b standard, the performance gain is 45.49%; compared to 2.29% for the standard with Min, the optimization is 39.30%; compared to 1.94% for the Selective scanning plus AP caching schemes, the gain is 28.35%; compared to 1.72% for the Neighbor Graphs approaches, the performance gain is 19.19%. To maintain VoIP quality, the packet loss rate should be at or below 3% [21], thus our proposed fast scanning solution can meet this requirement.

4. Conclusion

This paper proposes a fast scanning scheme to enhance the handoff performance for MNs roaming in WLANs with ongoing real-time applications. Our proposal allows mobiles to actively scan only a subset of all accessible channels without pre-knowledge of the wireless environment and it also decreases the probe-waiting time to an optimal minimum on each examined channel. As a result, handoff latency is reduced significantly, making the support of real-time ongoing services in WLANs possible.

Simulations results show that our proposal delivers better performance than the IEEE 802.11b standard, the standard with MinChannelTime, the Selective scanning plus AP caching schemes and the Neighbor Graphs approaches. As the average L2 handoff latency of the proposed fast scanning scheme is about 39 ms, the support of multimedia applications such as VoIP for mobile hosts roaming in WLANs seems promising.

In the near future, large-scale simulations will be conducted for performance analyses and novel effective mobility management schemes will be proposed in which cross-layer design will be taken into account.

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Li Jun ZHANG received the M.Sc degree in Computer Engineering (2007) from Ecole Polytechnique de Montreal, Montreal, Canada and the B.Sc in Mathematics (1993) from Jilin University, Changchun, China. She is now pursuing the Ph.D. in Computer Engineering and Software Engineering Department at Ecole Polytechnique de Montreal. Her current research interests include mobile and wireless networking architectures, mobility management and wireless network security for next-generation heterogeneous networks. She has applied three IP-layer seamless handoff related patents in USA, one book chapter, and has published several peer-reviewed conference papers. She is a student member of ACM and IEEE.

Samuel Pierre received the B.Eng. degree in Civil Engineering in 1981 from the Ecole Polytechnique de Montreal, Quebec, Canada, the B.Sc. and M.Sc. degrees in Mathematics and Computer Science in 1984 and 1985, respectively, from the UQAM, Montreal, and the M.Sc. degree in Economics in 1987 from the University of Montreal, and the Ph.D. degree in Electrical Engineering in 1991 from the Ecole Polytechnique de Montreal. He is currently a Professor of Computer Engineering at the Ecole Polytechnique de Montreal, where he is the Director of the Mobile Computing and Networking Research Laboratory (LARIM) and the Chairholder of the NSERC/Ericsson Chair in Next-Generation and Mobile Networking Systems. His research interests include wireline and wireless networks, mobile computing, artificial intelligence, and telelearning.