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Novel framework for proactive handover with seamless multimedia over WLANs

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Abstract: Supporting multimedia applications over 802.11 wireless LANs requires low latency and seamless handover between multiple access points. However, the existing handover process in 802.11 products suffers from very high delay and frequent service disruption, which are not acceptable for streaming multimedia applications. In order to reduce this high delay and service disruption, the authors have designed and implemented a new proactive handover strategy over 802.11. The strategy intelligently issues proactive scan and handover triggers to reduce the effective channel scanning delay. Subsequently, it reserves resources in advance, to reduce the handoff reconnection delay and provide necessary QoS guarantee. Using actual implementation and simulation study, the authors demonstrate that their proposed strategy is capable of achieving magnitudes of latency, jitter and throughput improvements during the 802.11 handover operations, thereby providing seamless multimedia transmission.

1 Introduction

The recent advancements in wireless telecommunication industries have already shown a noticeable migration from traditional, voice-alone domain to an audio-visual world of packet-based technologies. Multimedia streaming over the wireless internet is anticipated to have a significant share in future wireless communications. This increasing demand for wireless data and multimedia services has resulted in extensive deployment of local wireless networks, like IEEE 802.11 [1, 2] WLANs. A series of ratification and amendments of the basic 802.11 [1, 2] standards have also been carried out at par with the commercial deployment. However, one major goal of the emerging wireless entertainment networks lies in supporting seamless roaming from one coverage area to the another, without significant service disruption and quality degradation [3]. Unfortunately, handover operations in present WLANs incur significant latency, typically ranging from hundreds of milliseconds to several seconds, thus making it impossible to support seamless roaming. Service disruption during this prolonged handover latency is quite un-acceptable to delay-sensitive multimedia applications. Thus, to make multimedia over wireless a reality, new, efficient handover solutions need to be designed to significantly reduce this handover latency. The proposal for IEEE 802.11r clearly points out the widespread industry and academic research interests along this direction.

1.1 Our contributions

In this paper we have developed a practical, yet efficient, proactive, fast handover scheme for IEEE 802.11 WLANs. It is a software module residing in 802.11 driver to make fast handover decisions, with suitable QoS guarantee. The complementary problem of finding the best candidate access point (AP) (or AP selection problem), to perform this handover is out of scope of this work. Rather, we focus on improving the handover performance (in terms of delay, jitter and throughput) of an 802.11 station (STA), as it switches from current AP to the target AP. The basic idea is to issue the scan and handover triggers early enough in a proactive manner, so that the handover control messages are exchanged in advance with suitable resource guarantee in the target AP. This helps in reduction of the overall handover latency and service disruption time. We have implemented the framework by developing a suitable 802.11 test-bed, consisting of three WLAN APs and a set of eight WLAN STAs. Through our experimental study, we demonstrate that our strategy significantly outperforms the existing handover schemes of 802.11 systems, by reducing the handover latency and jitter in several magnitudes. More specifically, our contributions in this paper are:

1. Most existing handovers in 802.11 are performed on the basis of noisy received signal strength indicator (RSSI). We are the first to show the advantages of using received signal-to-noise interference (RSNI) and system throughput over the existing RSSI, for issuing scan and handover triggers in a proactive manner. This helps in reduction of the channel scanning delay associated with any handover operation.
2. We design a new set of handover message exchanges to develop a new, proactive handover (PH) framework for 802.11 WLANs. In this framework, the WLAN STAs

requests advanced resource guarantee in the target AP, by using the current AP. This reduces the handover reconnection delay and offers appropriate QoS guarantee to the ongoing multimedia applications.
3. Through our implementation and simulation study, we show that it is possible to achieve magnitudes of handover latency, jitter and throughput improvements over existing 802.11 systems. The framework is efficient enough to make the service disruption time negligible, thereby providing seamless transitions of ongoing wireless multimedia sessions.

It should be noted that the entire work is implemented as a platform independent, software module over the 802.11 drivers. The platform-independent feature allows it to be easily ported over both WLAN STAs (windows as well as Linux based) and APs.

The rest of the paper is organised as follows: Section 2 highlights the existing handover mechanism in 802.11 and major related works on this aspect. Our newly developed RSNI-based, proactive scan and handover triggers are explained in Section 3. Subsequently, the new resource guarantee scheme for QoS guarantee is described in Section 4. The system design and experimental set-up are discussed in Section 5. Experimental and simulation results in Section 6 points out the performance gains achieved by our framework. Finally, Section 7 concludes the paper with pointers to future research works.

2 Problem definition and related works

In this section, we first provide a brief description of the existing handover process in IEEE 802.11. Subsequently, we highlight the major related research works on this topic.

2.1 Existing handover process in 802.11

In 802.11 WLAN, an area is covered by multiple APs, each operating in one of the many channels. A single-radio WLAN STA can only operate in a single channel at a time, and can only associate and maintain connectivity with a single AP. However, on link quality deterioration with its current AP, the WLAN STA attempts to find a new AP with better link quality, and subsequently switches to the best available AP.

Fig. 1 illustrates the existing handover procedure in 802.11 WLANs. The ongoing data traffic is generally interrupted during the entire handover process. The service interruption time mainly consists of two phases: (i) the channel scanning delay and (ii) the reconnection delay, which are explained below:

1. *Scanning delay:* In the first phase of the handoff, the WLAN STA scans all channels to collect information about the neighbouring APs. This channel scanning delay is determined by (i) the number of candidate channels, (ii) the scan time at each channel and (iii) a device-dependent, fixed channel switching overhead. The number of channels depends on the type of network interface card (NIC). In passive scanning, the STA passively waits to hear periodic beacons transmitted by the neighbouring APs in the new channel. In the active scan method, on the other hand, the STA actively broadcasts a Probe Request frame and waits for APs' Probe Response frames. The wait time is either min channel time (if the STA receives no response by the time) or max channel time (otherwise). These two parameters are defined in the 802.11 standard.

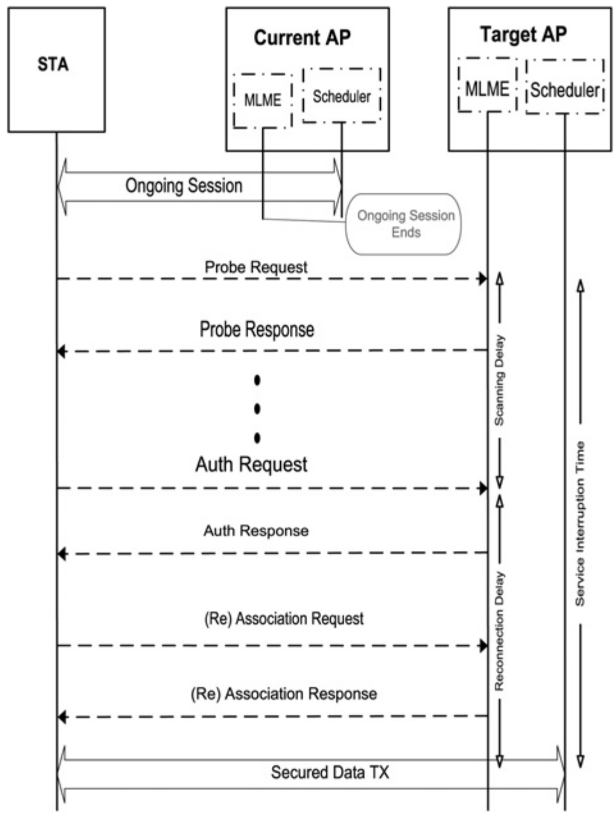

Fig. 1 *Existing handover message exchanges in 802.11 WLAN*

2. *Reconnection delay:* In the second phase of the handoff, the reconnection delay consists of delay components arising from (i) link authentication, (ii) security measurements and (iii) reassociation.

The major shortcomings associated with this legacy handover procedure lie in the following points:

1. With the absence of any defined, efficient handoff triggering mechanism, the channel scanning delay becomes significantly high.
2. The authentication and security establishment mechanisms during connection set-up adds extra latency over the existing delay.
3. Resource unavailability in the AP, to sustain the handover session, often leads to (re)association failure, thereby increasing the handover latency and service disruption time.
4. The absence of any QoS resource negotiation and guarantee makes the handover problem more complex and severe, especially for wireless multimedia applications.

As mentioned before, the significant handover delay in the current 802.11 networks affects the service of any streaming multimedia traffic, which inherently requires some precise QoS guarantee.

2.2 Related works in reducing handoff latency

Most of the existing research works are focused on reducing only the channel scanning delay [4]. In neighbour graph approach [5, 6] STAs rely on pre-obtained neighbouring APs information and scan only the non-empty (with AP nearby) channels. Cisco's CCX [7] uses a similar approach, where STAs communicate with APs to obtain neighbouring APs information. Syncscan [8], on the other hand, reduces

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the passive scan time by having all APs synchronise their beacon broadcast time and having STAs jump to a channel right before that time. This, however, requires a precise synchronisation of all APs and STAs. Researches have also been performed to completely eliminate handoff delay by using multiple radios [9] – one for data communication and another for scanning and handoff. Possible use of sensor overlays [10] to collect neighbouring AP information and assist an STA's handoff procedure has also been studied. However, neither the usage of multiple radios [9], nor sensor overlays [10], is yet supported by any 802.11 vendor. Recent research works [11] have shown the efficiency of advanced scanning in reducing the scanning and handover delays. A close look into the above-mentioned strategies reveals that all these works concentrate only on reducing the scanning delay, with no mention of reconnection delay and QoS guarantee. Moreover, apart from CCX [7] and advanced scanning [11], other approaches such as SyncScan [8], multiple radios [9] and sensor overlays [10] are almost impossible to implement in real 802.11 systems. The proactive scanning method mentioned in [11] decouples the time-consuming channel scanning from the actual handoff, and uses smart triggers, considering both uplink and downlink channel quality to reduce the scanning and handover delay. The major difference between [11] and our proposed PH scheme lies in the fact that our works demonstrate significant improvements in both scanning and reconnection delay and also provides resource guarantee after the handover completion. On the other hand, the work of [11] only focuses on scanning delay reduction and does not mention anything about reconnection delay and resource guarantee. Hence, in comparison with [11], our proposed strategy provides quite more improvement in handover performance.

Apart from WLAN, handover management is also currently being investigated in other OFDM-based wireless systems, such as WiMAX and long term evolution (LTE) [12]. A study of handover management aspects in an integrated 802.11 WLANs and 802.16 WiMAX is shown in [13]. Based on existing optimised handover techniques between mobile WiMAX and 3GPP access networks, an improved IP-based vertical handover technology for mobile WiMAX, legacy GSM systems and 3GPP LTE is presented in [14]. In [15], a handover decision algorithm is presented, which enables a wireless access network to balance the overall load among all attachment points (e.g. base STAs and AP) and maximise the collective battery lifetime of mobile nodes. The proposed cross-layer mechanism in [16] uses channel quality and service quality information from the physical and medium access control (MAC) layers, respectively, to determine the most suitable burst profile, transmission power level and media encoding rate for a connection, or even initialise a handover execution. The efficiency of IEEE 802.21 (the emerging IEEE standard for media-independent handover services) in supporting seamless mobility between IEEE 802.16m and 802.11VHT standards is shown in [17]. In [18], specific changes to the basic SIP messages are proposed for PH and improvement of delay during roaming. Dutta *et al.* [19] illustrate an experimental system that takes advantage of the mobile's relative location with the neighbouring APs to perform proactive handoff. It keeps track of the current location of the mobile and then uses the information from the neighbouring networks to help perform the proactive handoff. In [17], a process of integrating the IEEE 802.21 framework and the media-independent pre-authentication (MPA) technique, to improve handover performance is discussed. Finally, a test-bed implementation and experimental performance results of the combined mobility technique are also depicted. Wu *et al.* [20] provide a comprehensive analysis of handoff performance with standard IPv6 protocols and mobile IPv6, identifies several sources for delay with proposals for improving reactive and proactive handoff performance. In [21], a congestion-aware proactive vertical handoff algorithm is proposed, which uses a data pre-deployment technology to realise soft handoff between cellular interface and *ad hoc* interface.

Some recent studies are also focused on the improvement of 802.11 authentication algorithms [22]. The concept of multiple, virtual interfaces is formulated in [23] by frequently switching the physical NIC between one *ad hoc* and one infrastructure 802.11 network. However, the concept of both [22, 23] cannot be applied directly to handoff process, since the network information is not known before scanning and how to connect to the AP is not addressed. Although inter access point protocol (IAPP) and lightweight access point protocol (LWAPP) [24] provide mechanisms for configuration and communication between APs, these standards do not mention anything specific for handover improvement. An accurate handoff trigger is essential in the performance of any handoff scheme. Triggers widely used in 802.11 generally include the RSSI [25], the number of retransmission at the STA, the loss of beacons [25] etc. The recent development of radio resource management in 802.11k [26], points out improvement on existing channel measurement techniques and parameters. This motivates us to design and implement a proactive, fast handover scheme, which is capable of reducing both scanning and reconnection delay, to provide seamless multimedia, with some QoS guarantee, over WLANs.

3 Proactive scan and handover triggers

The objective of proactive scanning is to eliminate (or at least reduce) the channel scanning delay. The idea is to make the WLAN STAs actively probe the channels early enough, so that when the handoff trigger is fired it has all the updated information to jump into the reconnection phase. In this section, we first discuss the channel measurement schemes performed using the received channel power indicator (RCPI) and RSNI. Subsequently, we describe the proactive scan and handover triggers issued by our system.

3.1 Need for new channel measurement metrics

Network management of IEEE 802.11 systems needs comparative physical layer (PHY) measurements for efficient handoff decisions. This includes AP signal comparisons (i) on the same channel, the same PHY, in the same STA; (ii) on the same channel, the same PHY, in different STAs; (iii) on different channels, the same PHY, in the same STA; (iv) on different channels, the same PHY, in different STAs; (v) on different PHYs in different STAs; and (vi) on different PHYs in the same STA.

As mentioned in the invention [27], RSSI only addresses categories (i) and (iii) above. The major limitations of the RSSI indicator are: (i) RSSI is a monotonic, relative indicator of power at the antenna connector, which indicates sum of desired signal, noise and interference powers. (ii) In high-interference environments, RSSI is not an adequate indicator of desired signal quality. (iii) RSSI is not fully specified, as there are no unit definitions and no

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performance requirements (accuracy, fidelity and testability). (iv) Since so little about RSSI is specified, it must be assumed that widely variant implementations already exist. (v) It is not possible to compare RSSIs from different products and perhaps not even from different channels/bands within the same product. (vi) Although RSSI has limited use for evaluating AP options within a given PHY, it is not useful in comparing different PHYs. (vii) RSSI must be re-scaled for DSSS and OFDM PHYs. RSSI is clearly not useable by network management for load balancing or load shifting and RSSI from one STA does not relate to RSSI from any other STA. As traditional SINR is estimated using signal strength from RSSI and corresponding noise factors, it also suffers from similar problems. Hence, it is desired to obtain more advanced channel estimation metrics for making intelligent and effective handover decisions.

3.2 Channel measurement using RCPI and RSNI

For a received MAC frame, RCPI is a measure of the total received radio frequency power (signal, noise and interference) in the selected channel. It is a monotonically increasing, logarithmic function (in dBm units) of the received power level. In our system implementation, we have followed the guidelines of radio resource management, mentioned in 802.11k [26]. As shown in Fig. 2, we have modified the beacons and probe resquest/response messages to include the RCPI information. The 802.11 STA monitors the requested channel, measures beacons and probe responses and logs all the necessary information, including the RCPI. It now makes an estimate of average noise power indicator (ANPI). ANPI is a MAC indication of the average noise and interference power, when the channel is idle. Using this RCPI and ANPI, the 802.11 STA computes an estimate of RSNI ratio. IEEE 802.11k standard draft specify RSNI in steps of 0.5 dB. RSNI is computed as the ratio of the RCPI to the ANPI, measured on the channel and antenna connector, using the following expression

$$\text{RSNI} = \left[10 \times \log_{10}\left(\frac{\text{RCPI}_p - \text{ANPI}_p}{\text{ANPI}_p}\right) + 10\right] \times 2 \quad (1)$$

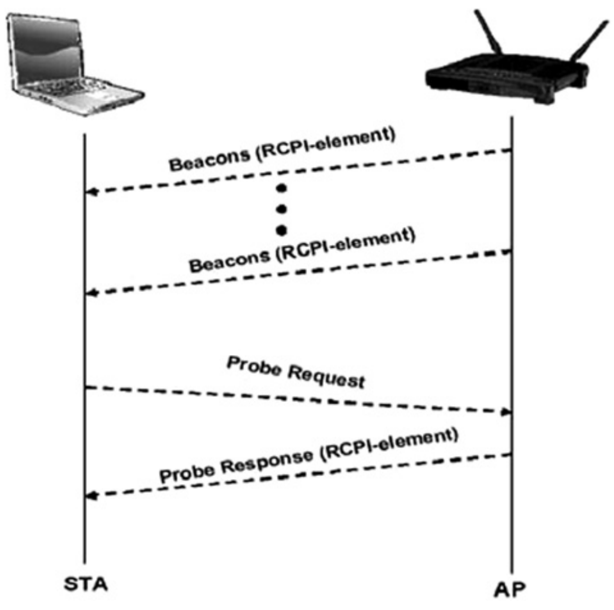

Fig. 2 *Beacons and probe response messages with RCPI*

where RCPI_p and ANPI_p indicates the RCPI and ANPI values in the absolute scale. RSNI in dB is scaled in steps of 0.5 dB to obtain 8-bit RSNI values, which cover the range from 10 to 117 dB. The multiplication factor of 2 and additional factor of 10 in the above expression is needed for this 0.5 dB steps and lower range of -10 dB. It is claimed in 802.11k [26] and proved in [27], that RCPI is a better channel indicator than RSSI. While RSSI often provides noisy channel estimates, RCPI is supposed to be more stable. Later in Section 6, we will show the dynamics of these two metrics (RCPI and RSSI), obtained by means of our experiments.

3.3 Issuing scan and handover triggers

Fig. 3 points out the relationship between the achieved throughput and RSNI, for different data rates, in 802.11 network. While higher data rates are achieved by using more efficient modulation and coding schemes (MCS), they also require higher RSNI to decode. As RSNI falls below a certain threshold, the optimal rates as well as the achieved throughput sharply reduces. Thus, a combination of RSNI and achieved throughput seems to be a valid candidate for issuing proactive scan triggers. For handover, we also use throughput and RSNI, but with different thresholds, which ensures proactive scanning is triggered before the handover. Note that, we have already mentioned before in Section 1.1, that the optimal AP selection problem is out of the scope of this paper. Thus, in our approach, as either of the metric falls under the predefined threshold, we select the best neighbouring AP (based collected RSNI) to connect. If $\text{Th}^{(1)}_{\text{scan}}$, $\text{Th}^{(2)}_{\text{scan}}$, $\text{Th}^{(1)}_{\text{ho}}$ and $\text{Th}^{(2)}_{\text{ho}}$, respectively, represent the RSNI and throughput thresholds for scanning and handover, then mathematically we can formulate the condition for scan ($\text{Trigger}_{\text{scan}}$) and handover triggers ($\text{Trigger}_{\text{ho}}$) as

$$\text{Trigger}_{\text{scan}} = (\text{rsni} < \text{Th}^{(1)}_{\text{scan}}) \vee (\sigma < \text{Th}^{(2)}_{\text{scan}}) \quad (2)$$

$$\text{Trigger}_{\text{ho}} = (\text{rsni} < \text{Th}^{(1)}_{\text{ho}}) \vee (\sigma < \text{Th}^{(2)}_{\text{ho}}) \quad (3)$$

where rsni and σ denotes time-varying RSNI and throughput achieved, and $\vee$ represents 'logical OR' operation. Intuitively, we can explain the (2) as: (1) issue the scan trigger when RSNI falls below $\text{Th}^{(1)}_{\text{scan}}$ or when the throughput falls below $\text{Th}^{(2)}_{\text{scan}}$; (2) issue the handover trigger

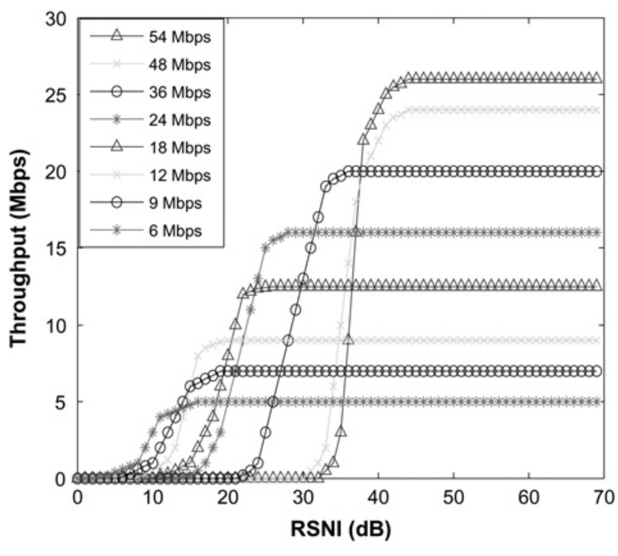

Fig. 3 *Throughput with RSNI*

when RSNI falls below $Th_{ho}^{(1)}$ or when the throughput falls below $Th_{ho}^{(2)}$. Of course, $Th_{scan}^{(1)} > Th_{ho}^{(1)}$ and $Th_{scan}^{(2)} > Th_{ho}^{(2)}$, ensuring the scan triggers always precede the handover triggers. Before switching its radio to other channel for scanning, the 802.11 STA sends 'Sleep Request' to the current AP, so that the AP buffers the packets destined for this STA during its scanning period. Standard active probing (exchange or 'Probe Request' and 'Probe Response') with customised 'Min (Max) Channel Time' is used for scanning process. After the completion of this Min (Max) Channel time the STA switches back to the previous AP (in the previous channel) and send a 'Awake Request' to resume data transmission. While this RSNI-based proactive scan helps in reducing the channel scanning delay, the reconnection delay and QoS guarantee during handover also needs to be solved for supporting seamless multimedia transmission.

4 Advance resource request for QoS guarantee

In this section, we first describe the basic architecture of the resource allocation framework and subsequently discuss the resource guarantee process. In our proposed framework, the WLAN STA communicates with the target AP using its current AP. A set of new MAC frames are introduced for the communication between the STA and the current AP. These frames are termed as PH frames. On the other hand, the communication between the current AP and target AP is performed by using a new encapsulation method. The current AP is responsible for the necessary conversion and reformatting conversion between the two types of messages.

4.1 Architectural overview

Fig. 4 shows the architectural overview of our PH strategy. A new service access point (SAP), termed as Resource Request SAP (RRSAP) is defined to generate and respond to the advance resource guarantee. The RRSAP on the STA is used to generate resource requests and queries. The RRSAP at the current AP receives and processes resource requests from the STAs. A new Resource Request Broker (RRB) is included in the station management entity (SME) on the 802.11 APs. The RRB, in current AP, acts as a termination point for PH Requests issued by the 802.11 STAs, encapsulates PH frames into Resource Request Frames and relays messages between the current AP and the target AP. It re-formats the resource request, issued by the SME of 802.11 STA, for consumption by the RRSAP at the current AP. Similarly, it also re-formats the response from the RRSAP, at target AP, to send it to the SME of 802.11 STA. Any policy dependent processing on the resource request is also performed here. Options are kept for configuring this RRB to block a PH request or limit the number of pending requests from specific 802.11 STA(s).

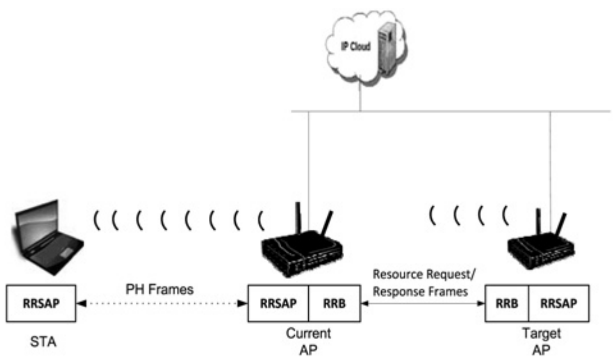

Fig. 4 *Architecture for PH*

4.2 Handover messages with resource guarantee

As shown in Fig. 5, we have defined a set of management frames for supporting our PH process. We now discuss the exchange of these management frames:

1. At first, the 802.11 STA issues 'PH Auth Request' message (where Auth stands for authentication) to trigger a pre-reservation request through its current AP. The necessary key exchanges for suitable security measures and authentication are included with this message. This message also includes special parameters to notify that the STA supports PH mechanism.
2. After performing suitable encapsulation and formatting, the RRB of the current AP issues 'Resource Request' message and transmits it to the target AP.
3. On receiving a 'Resource Response' message from the target AP, the current AP responds to the STA by issuing 'PH Auth Response' message. The response includes a status code, indicating success or failure and a (re)association deadline. Like 'Resource Request', this message also includes parameters to notify that the AP supports the PH mechanism.
4. The STA now transmits a 'PH Auth Confirm' frame to confirm to the receipt of the 'PH Response' frame and to request allocation of QoS resources. This message is also encapsulated by the current AP and sent to the target AP. A set of parameters are included in this message to notify the resources requested by the STA. In our experiments a single parameter is specified by using the corresponding traffic specification.
5. Finally, on reception of the 'Resource Ack' message from the target AP, the current AP issues 'PH Auth Ack' frame as final confirmation of resource availability.
6. The usual (Re)Association Request and Response messages are now exchanged to perform re(association). The

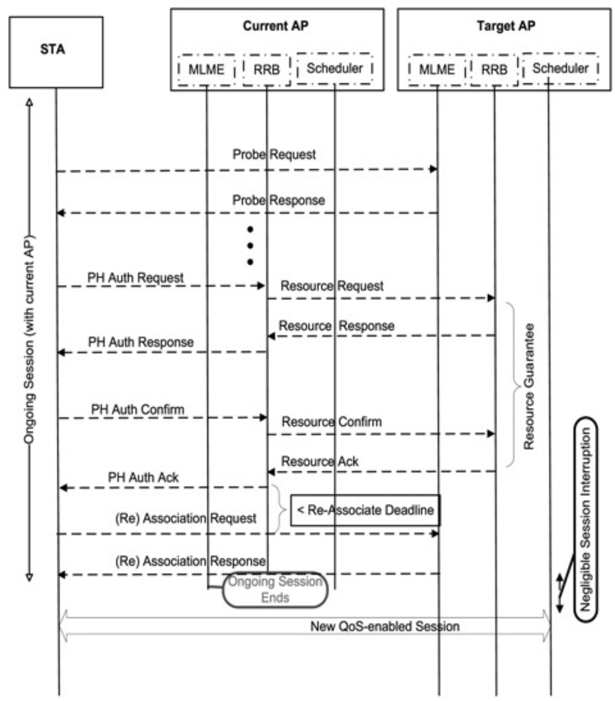

Fig. 5 *Message exchanges for proactive handoff in WLAN*

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time between ‘PH Auth Ack’ and ‘(Re)Association Request’ should be less than the ‘reassociation deadline’.

In this way, using early resource request, in a piggyback manner with the authentication process, the handover reconnection latency can be significantly reduced, while guaranteeing the resource availability for specific QoS.

5 Prototype and testbed set-up

We have developed an implementation prototype of our proposed PH for Atheros ath9k [28] driver working on Atheros AR9281 [28] chips. The prototype of our implementation is illustrated in Fig. 6. The 802.11 miniport driver (ath9k driver in our prototype) [28] is modified to support the new PH mechanism.

In our experimental testbed, we have used three Atheros APs. One desktop connects every AP to the ethernet. A set of eight laptops, labelled as 802.11 STAs, connects one of the three APs using IEEE 802.11 NIC, operating on Atheros Ath9k driver [28]. As mentioned before, the PH framework is made platform independent over Atheros driver and is adapted to AP and 802.11 NIC (STAs). All our experiments are performed in a typical office building, which is shown in Fig. 7. The locations marked with ‘AP A’, ‘AP B’ and ‘AP C’ are placed with three D-Link APs, whereas locations marked with ‘x’ are the places, where we measured the signal strength, RCPI, RSNI, packet latency and throughput of the 802.11 STAs. The solid boxes in the figure denote the pillars in the building.

Different software libraries are developed to extract useful information, like, RSSI, RSNI, RCPI and transmission rates from the device driver on a packet-level granularity. Iperf [29] is used to generate network traffic and measure the packet latency and system throughput. Using Iperf, a streaming video (over UDP) traffic, according to ITU-H.264 specifications [30] is generated at 25 Mbps rate. A single run of the entire handover experiment is performed for about ∼5 min and the results of an average of ten runs are collected and reported. Table 1 show the values of major parameters (e.g. scan and handover thresholds, min channel time and probe response time) used in our experiments. These values are obtained and tuned by running the experiments multiple times. In the next section we discuss the experimental and simulation results to show the improvement achieved by our PH strategy.

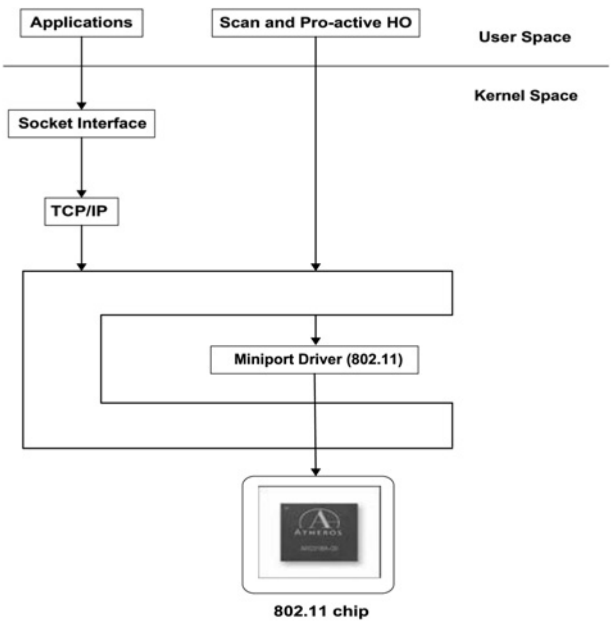

Fig. 6 *Implementation prototype*

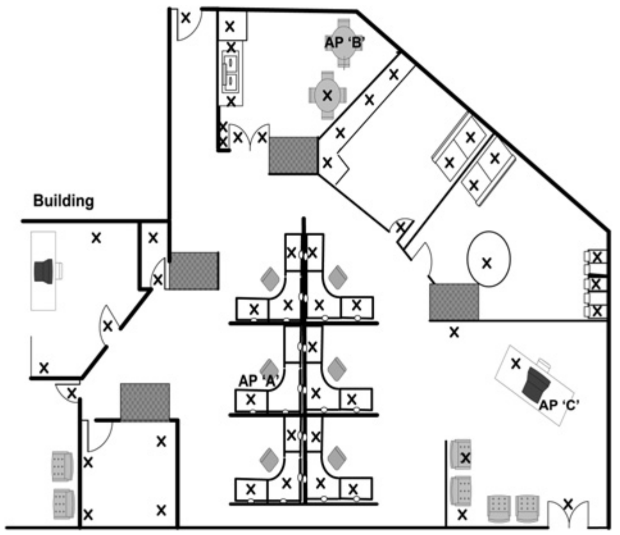

Fig. 7 *Office space for running experiments*

Table 1 Parameters used in experiments

Parameter	Value
$\text{Th}^{(1)}_{\text{scan}}$	20 dBm
$\text{Th}^{(2)}_{\text{scan}}$	5 Mbps
$\text{Th}^{(1)}_{\text{ho}}$	12 dBm
$\text{Th}^{(2)}_{\text{ho}}$	1 Mbps
min channel time	5 ms
avrg. probe response time	1.05 ms

6 Performance results and comparison

We broadly divide our performance results into two categories: (i) experimental results obtained from actual 802.11 test-bed in Atheros Ath9k driver working over AR9281 [28] chips and (ii) simulation results for comparing with other major existing research works.

6.1 Experimental results

Fig. 8 shows the schematic diagram of our experiment, involving eight 802.11 STAs, where a set of four STAs (Station Set-1) are equipped with our PH strategy and the rest four (Station Set-2) obey existing 802.11 handover process implemented in Atheros Ath9k driver (over AR9281 chips) [28]. All the eight STAs follow the same trajectory, starting from the coverage area of AP ‘A’ and going under the coverage areas of AP ‘B’, AP ‘C’ and finally returning back to AP ‘A’.

Figs. 9 and 10, respectively, demonstrate the variation of average RSSI and RCPI achieved with the distance from the AP. When the 802.11 STA is very close (within 10 m) to the AP, both the RSSI and RCPI are pretty high (∼−30). However, as shown in Fig. 9, with the mobility of the 802.11 STA, the RSSI fluctuates sharply with huge variation. It clearly points out that, even for a distance of ∼50 m, along both the axes from AP, the RSSI occasionally toggles between very low (<−70) and reasonably moderate

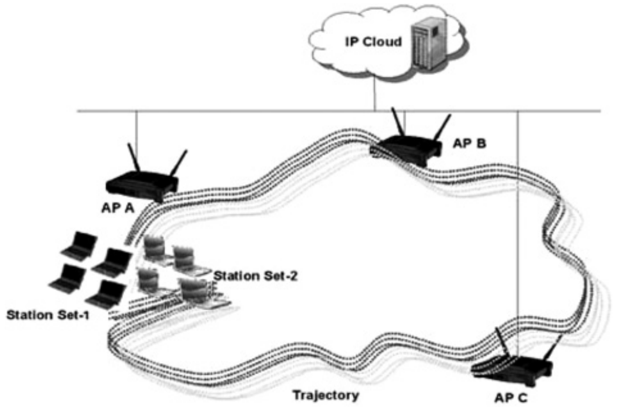

Fig. 8 *Handover scenario with multiple 802.11 STA*

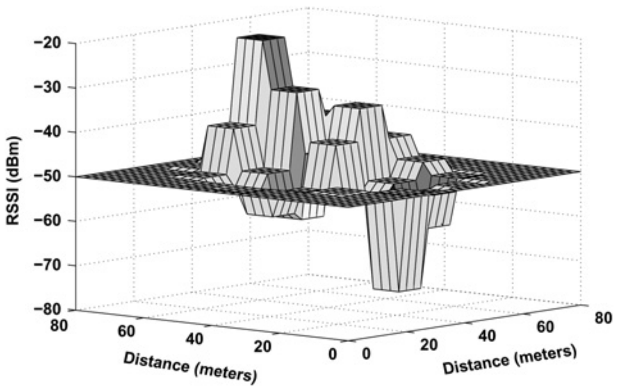

Fig. 9 *RSSI dynamics with distance*

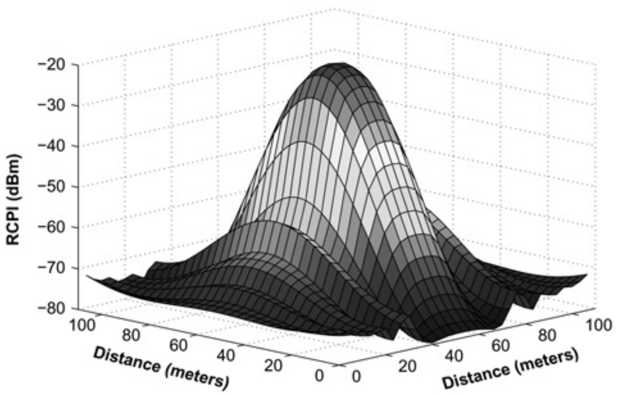

Fig. 10 *Dynamics of RCPI with distance*

(∼−45) values. This makes RSSI not suitable to indicate the issuance of scan and handover triggers. On the contrary, as shown in Fig. 10, RCPI decreases with pretty less variation and reduces sharply to a very low value when the distance from the AP increases to 80 m on both X and Y axes – indicating a possibility of handover. This makes RCPI and RSNI (derived from RCPI) a more effective choice to issue handover triggers.

The average packet latency of all STAs, is reported in Fig. 11. When the 802.11 STA is close to its current AP, with favourable channel conditions (e.g. RSNI > -45) the transmit MAC-queue is almost empty, thereby resulting pretty less packet latency (∼3 ms). However, as the STA moves away from the AP, the RSNI starts degrading, resulting in packet retransmissions and increasing number of packets in the MAC queue. Finally, after performing the necessary scanning and reconnection, the STA begins communicating with the target AP. This results in significant increase in packet latency. It is quite clear from Fig. 11, with the existing 802.11 handover strategy (implemented in Ath9k driver) [28], the packet latency during handover increases almost exponentially to ∼7– ∼8 s. However, our PH scheme provides a reasonable average packet latency (during handover) of only ∼20 ms. The same trend is repeated when the handover occurs from AP ‘A’ to AP ‘B’, AP ‘B’ to AP ‘C’ and AP ‘C’ to AP ‘A’. The lower packet latency offered by our strategy is attributed to its fast, proactive scanning and resource guarantee during the handover process. Fig. 12 demonstrates the comparative average delay jitter between existing 802.11 handover process [28] and our PH strategy. It clearly points out that, while existing 802.11 handover schemes (implemented in Ath9k driver) [28] often results in pretty high delay jitter (∼30 ms), our PH scheme can significantly reduce the delay jitter to only a few milliseconds or some hundreds of microseconds. The issuance of advance scanning and handover triggers, coupled with proactive resource request is responsible for this improvement. We believe that for a streaming video application (like HDTV), such a difference in packet latency and jitter is very significant, and our strategy provides a major step towards this handover latency improvement.

The comparative throughput, between our PH scheme and existing 802.11 handovers [28], is shown in Fig. 13. As shown in the figure, initially, when the WLAN STAs are close to the corresponding AP, the channel condition is pretty good and both the strategies achieve pretty high (∼20 Mbps) throughput. However, as the 802.11 STA moves away, the

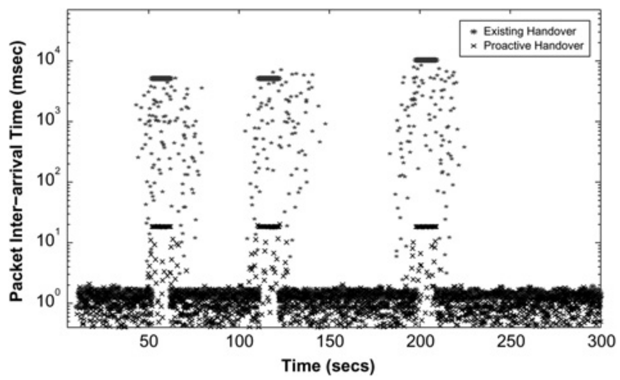

Fig. 11 *Average packet delay dynamics (Atheros driver)*

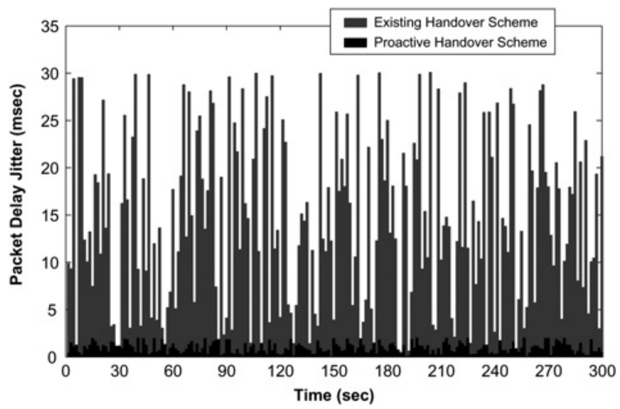

Fig. 12 *Average delay jitter (Atheros driver)*

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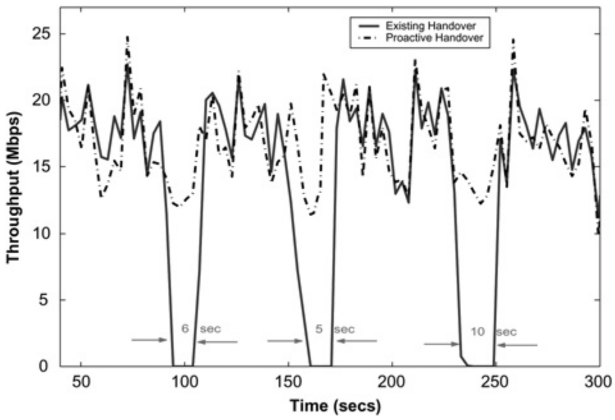

Fig. 13 *Average throughput (Atheros driver)*

RSNI (channel condition) starts deteriorating, and finally the handover occurs. It is clearly visible from Fig. 13, that during this handover scheme there is a significant service disruption for ∼6–10 s in existing 802.11 handovers of the Atheros driver [28], and the multimedia stream gets halted with almost negligible throughput. On the other hand, our proposed PH scheme still provides more than 12 Mbps throughput during the handover process, with almost no service disruption. This results in the continuation of the multimedia streaming application in almost seamless fashion, with somewhat less throughput. The reason is again attributed to the fast and PH strategy with QoS guarantee.

In order to capture the relative merits of proactive triggers and advanced resource guarantee, we have captured the handover delay, jitter and throughput results with only proactive scan (no resource guarantee) and only resource guarantee (no proactive scan). Table 2 shows that while both proactive triggers and advanced resource guarantee improves the handover delay, jitter, throughput and service break time, the improvement is more induced by the advanced resource guarantee. Of course, the combined effects of both proactive triggers and advanced resource guarantee is much more than the individual improvement.

We have also captured the results in power save mode, which the clients enter during scanning.In the beginning the 802.11 clients request the serving AP for entering into the power save mode. At this point the current AP begins buffering all the DL packets for respective clients, until the client wakes up. The corresponding communication disruption is pretty much dependent on the duration of the scanning. The service disruption time is significantly negligible (∼50–60 ms).

Table 2 Relative merits of proactive triggers and resource guarantee

Type	Avrg. delay, s	Avrg. jitter, ms	Avrg. throughput, Mbps	Service break time, s
without proactive triggers and resource guarantee	8	30	0.05	6
with proactive triggers and advanced resource guarantee	0.02	0.7	12	0
only proactive triggers	1	10	2	2
only advanced resource guarantee	0.10	4	4	0.4

6.2 Simulation results

In order to further evaluate the performance of our PH scheme, we have simulated and compared our strategy with existing SNC [6], Sync Scan [8] and proactive scan [11] using NS-2 [31]. This is performed by enhancing the existing 802.11 NS-2 module to support the RSNI-based triggers and PH operations. The parameters of the simulation are kept same as the actual prototype implementation. Fig. 14 demonstrates that our strategy constantly achieves almost ∼17% less packet latency over existing smart triggers [25] and proactive scan-based [11] handover strategies. Fig. 15 demonstrates the comparative average throughput, obtained across all the 802.11 STA, between our strategy, and existing existing SNC [6], Sync Scan [8] and proactive scan-based [11] handover strategies. Note that, before the beginning of any handover operation, all the strategies achieve similar throughput (∼19 Mbps). As the scanning and first handover (from AP ‘A’ to AP ‘B’) begins at around (95–100 s), the throughput starts degrading. However, it is clearly visible that our proposed PH strategy outperforms the other two handover schemes by achieving ∼20% improvement in average

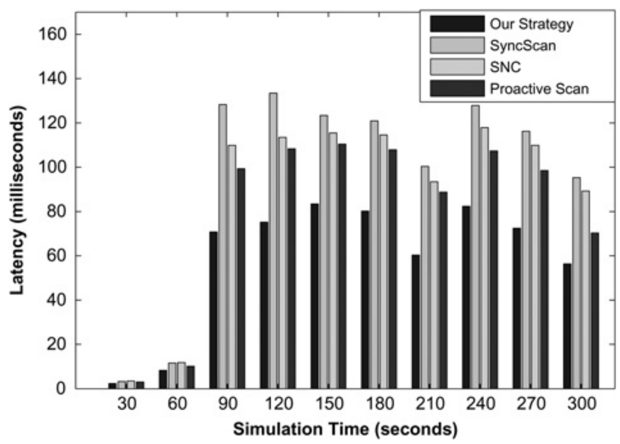

Fig. 14 *Comparative average delay (simulated)*

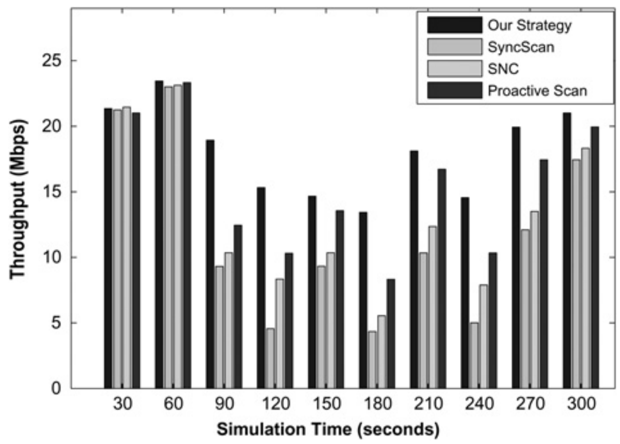

Fig. 15 *Comparative average throughput (simulated)*

throughput. The reason is attributed to a combination of proactive triggers (scan and handover) and early resource request and guarantee used in our handover strategy. The same incidence is repeated again during the second (from AP 'B' to AP 'C') and the third handovers (from AP 'C' to AP 'A') at around 160–170 s and 240–250 s, respectively. After these three handovers, slowly all the strategies get back to their original throughput (~19 Mbps).

Note that, the improvement in delay, jitter and throughput comes at the cost of extra messaging overhead involving PH and Resource reservation message overheads. Thus, we make an estimate of this extra overhead involved in our proposed hand over strategy. The management frames involved in the process are small frames of size Probe Request/Response: 64 Bytes, PH Auth. Request/Response/Confirm/Ack: 128 Bytes and Association Request/Response: 128 Bytes. With a most conservative (i.e. lowest) MCS of BPSK-1/2 in OFDMA-based 802.11 g systems, the one-way message transmissions require only 22 (for Probe Request/Response) and 44 (other messages) OFDMA data carriers. As the duration of an OFDMA data carrier is only 40 μs, the one-way management frames account for only 0.088 and 0.176% of total OFDMA resources available per second, which is quite negligible. Using this estimation, with our proposed message exchange sequences, mentioned in Fig. 5, a total of only 299 OFDMA data carriers are involved to complete an entire handover process. This is quite close to existing handover methods, as the existing methods also use similar management message exchanges with little difference in management message sizes.

7 Conclusion

In this paper, we propose a fast and practical handover solution with QoS guarantee in IEEE 802.11 wireless LANs. It is a software module residing in 802.11 drivers, which explores RSNI-based proactive scan and handoff triggers and issues advanced resource request to the target AP. Implementation on typical 802.11 test bed demonstrate that, comparing to existing 802.11 drivers, our framework is capable of achieving more than 50 times improvement in packet latency, jitter and throughput. Simulation results also show that, while comparing to other recent research works on PH, our proposed framework provides almost 20% improvements in packet latency, jitter and throughput. We believe that this would lead significant step to support seamless transmission of indoor wireless multimedia applications. In future, we would like to investigate into the effects of our handover strategy over other major OFDMA systems, such as Mobile WiMAX (802.16e).

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