

SURVEY OF HANDOFF TECHNIQUES IN IEEE 802.11 WIRELESS NETWORKS

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Abstract

IEEE 802.11 based wireless networks (WLAN) have been witnessing a rapid growth and wide deployment in the last decade. Mobility support in such networks is an essential issue. Hence, assurance of seamless handoff is one of the major problems in mobile networks, especially, for real-time streaming applications like Voice-over IP (VoIP). Handoff or handover¹ is a mechanism that aims to enable a mobile user (MS -Mobile Station) to smoothly move between APs' (Access Points) covering areas. Many handoff techniques have been proposed in the literature. A survey with a brief description of most important handoff proposals is presented in this paper. In addition, these techniques are theoretically evaluated and compared.

1. INTRODUCTION

The last ten years have witnessed the emergence of wireless metropolitan, local and personal area networks (WMAN/WLAN/WPAN) in the home, enterprise, and public access environments. The wide variety of WLAN products currently available in the market is quickly leading to a scenario in which a WMAN/WLAN/WPAN interface will become as ubiquitous as a standard Ethernet [1].

In particular, the IEEE 802.11 protocol, operating in both the 2.4 GHz industrial, scientific, and medical (ISM) and 5.2 GHz unlicensed

¹ Handoff and handover are synonyms so they may be used here interchangeably. „Handoff” is most popular in the American literature, whereas „handover” in the European.

national information infrastructure (UNII) bands, has enjoyed spectacular market success under the Wi-Fi name (WLANs). such networks are being implemented in hot spot areas (e.g. airports, campuses, conference halls, etc.). WLANs can provide high speed data transmission up to 11Mbps as indicated in IEEE 802.11b [2], and 54Mbps as stated in IEEE 802.11a/g [3],[4], and up to 108Mbps, using MIMO (Multiple Input Multiple Output) technique [5], and even more (200, 600Mbps) as predicted in IEEE 802.11n [6]. However, the limited service range of the access points (APs) demands mobile wireless stations (MS) to handoff frequently between different APs in the IEEE 802.11 infrastructure networks. Hence, the *handoff* function is a critical 802.11 MAC operation. This operation must insure a seamless roaming of MSs within its network. Herein, we abandon the seamless roaming between WLANs and WMAN (WiMAX) or 3G cellular networks and Layer-3 handoff, which demands further research and description. So, in this paper we confine just to overview the layer-2 (MAC) handoff techniques within 802.11 WLANs.

2. HANDOFF ISSUES

The handoff process is a structural process, which starts with the detection of need to handoff, initiation, discovery, authentication, re-association with a new AP, and ends with L3 handoff (new IP address resolution).

2.1 When it is needed?

Handoff procedure may be necessary because of the movement of a MS, to balance load between adjacent APs, or because of fading of a link to a stationary mobile.

2.2 Requirements of a good handoff algorithm

The main requirements for a good handoff algorithm are: Low handoff latency, Minimal service interruption (for real-time data), Minimal cell loss and delivering data packets in sequence (data integrity – for non-real-time data), and QoS maintenance [7].

2.3 Handoff initiation

There are several initiation criteria, which depends on RSS (relative Signal Strength), such as the average RSS, RSS with threshold, RSS with hysteresis, RSS with hysteresis and threshold and prediction techniques which take the change in the RSS level to estimate the expected value of the RSS [8,9,10]. There is another technique which depends on the number of retransmissions, so if a frame and its two consecutive retransmission fail the MS assumes that it is not a collision and it initiate a handoff procedure [11].

2.4 Handoff performance metrics

The metrics used to evaluate handoff algorithms [12] are, Call blocking probability, Handoff blocking probability, Handoff probability, Call dropping probability, Probability of an unnecessary handoff, Rate of handoff, Duration time of interruption, handoff. Latency and cell loss.

2.5 Handoff process

The complete handoff, according to [13], [14], is divided into two main steps:

1. Discovery, which involves the handoff initiation phase and the scanning phase, where channels are probed actively or passively scanned.
2. Reauthentication, which involves authentication and reassociation to the new AP as well as transfer of the MS credentials from the old AP to the new AP.

In [15], there is a third step, layer-3 handoff, which involves update of binding information and the care-of address and packet forwarding, while [11] adds as a third step the process of detection, which decides about the moment of handoff initiation.

3. HANDOFF TECHNIQUES

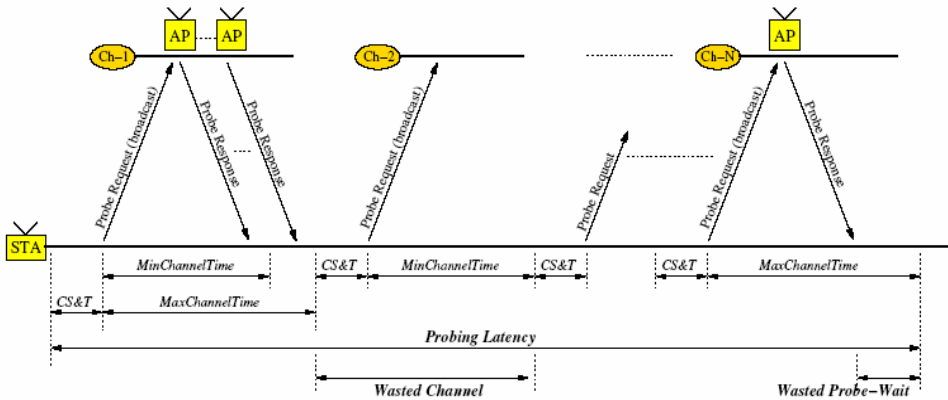
Handoff procedure in 802.11 WLANs must insure as low latency that enables e.g. VoIP applications to proceed without disruption (about 50ms [15]). Hence, the proposed techniques aim to reduce handoff latency in different handoff phases. Below, Firstly, we briefly discuss techniques that reduce the detection and discovery delays. Secondly, schemes

aiming to reduce authentication association delays are presented. At the end we introduce algorithms that reduce L3 handoff delay.

3.1 Handoff techniques based on detection and discovery latency reduction

Existing measurements have shown that the channel scanning phase (discovery) contributes as much as 90% to the entire handoff latency [11], [13]. Hence, most proposals are considering the reduction of handoff discovery phase latency. Proposed handoff techniques can be grouped into graph based, scanning based and multi-radio based.

3.1.1 NG – Pruning



A discovery method using a neighbor graph (NG) algorithm and non-overlap graph (NOG) algorithm was proposed in [15].

Figure 1: A Probing process in the IEEE Standard 802.11. CS&T in the figure means "Channel Switching and Transmission Overhead".

This scheme focuses on reducing both the total number of channels to be probed and the waiting time on each channel. The rationale behind these algorithms is to ascertain whether a channel needs to be probed or not (by the NG algorithm) and whether the MS has to wait more probe response messages on a specific channel before the expiration of *MaxChannelTime* (by the NG-pruning algorithm), Figure 1. The NG abstracts the hand-off relationship between adjacent APs. Using the NG, the set of channels on which neighboring APs are currently operating and

the set of neighbor APs on each channel can be learned. Based on this information, an MS can avoid probing unnecessary channels and spending time waiting for responses from non-existing APs.

Figure 2 illustrates the operation of the NG-pruning scheme. In this example, only three channels (i.e., 1, 6, and 11) are used and the current AP ($AP1$) has five neighboring APs ($AP2$ - $AP6$). The neighbor information can be learned by the construction of the NG. By using this neighbor information, the MH knows that the number of channels it has to probe is just two (i.e., channels 6 and 11). On the other hand, individual NOGs are constructed on each channel, i.e., one NOG on channel 6 and the other NOG on channel 11.

On the other hand, the NOG abstracts the non-overlapping relation among the APs. Two APs are considered to be non-overlapping if and only if the MS cannot communicate with both of them simultaneously with acceptable link quality. When two APs are non-overlapping, a probe response from one of them indicates the unreachability to the other. Thus, during a hand-off, the station can exclude (prune) such unreachable APs from the list of APs to probe, resulting in a faster hand-off.

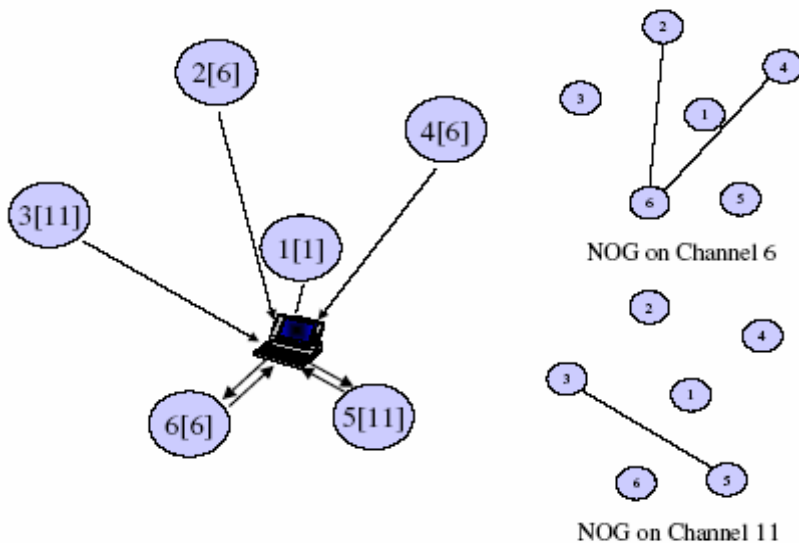
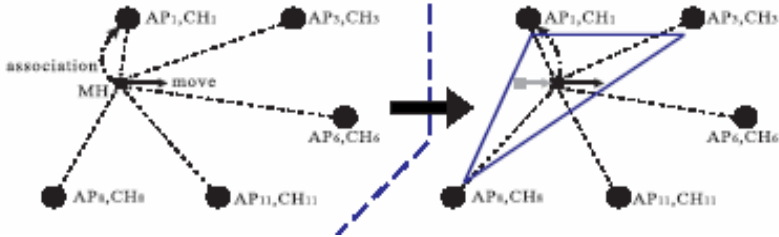


Figure 2: NG-Pruning Algorithm

3.1.2 DeuceScan

A spatiotemporal approach is developed in [16]. It 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. Both factors, signal strength and variation of signal strength, are used in DeuceScan scheme. 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 which RSS is the best for the MS, Fig 3. This implies that the MS receives the largest strength signals from these three APs. The full pre-scanning operation needs to be performed if an MS enters a new location which it has not traversed before. After performing the full pre-scanning operation, the MS can identify the triangle at the new location. MS keeps a spatiotemporal triangle list, so if it re-enters an already traversed location whose spatiotemporal triangle is in list, the MS can extract its spatiotemporal triangle list. If a new triangle does not exist in the spatiotemporal triangle list, this indicates that the MS has not traversed the



current location before, therefore a new triangle is constructed by a full scanning operation.

Figure 3: DeuceScan method

3.1.3 Selective Scanning

This technique was proposed in [14]. It aims to reduce the probe delay by improving the scanning procedure, using a selective scanning algorithm and to minimize the number of times the previous scanning procedure was needed with the use of a caching mechanism. Among the 14 possible channels that can be used according to the IEEE 802.11b standard, only 11 are used in USA and, among these 11 channels, only three do not overlap. These channels are 1, 6 and 11 as shown in figure 4.

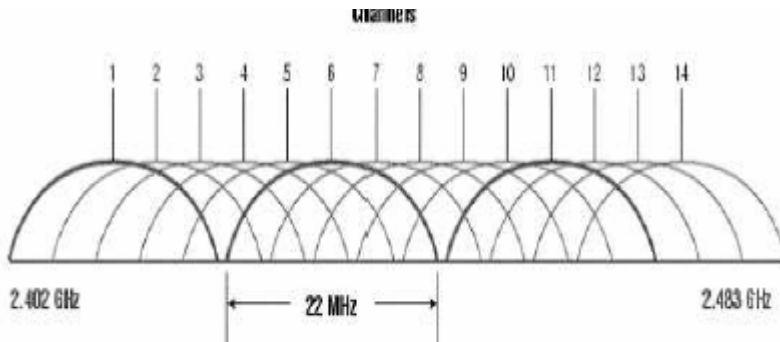


Figure 4 : Channel frequency distribution in IEEE 802.11b

The selective scanning algorithm is based on this idea. In the selective scanning, when a MS scans APs, a channel mask is built. In the next handoff, during the scanning process, this channel mask will be used. In doing so, only a well-selected subset of channels will be scanned, reducing the probe delay, the procedure is depicted in the flowchart of fig 5. This approach reduces the handoff latency by 30-60% of the latency with the original handoff. Further reduction is achieved by using AP cache. The AP cache consists of a table which uses the MAC address of the current AP as the key. Corresponding to each key entry in the cache is a list of MAC addresses of APs adjacent to current one which were discovered during scanning. This list is automatically created while roaming. Thus, When a handoff is needed, we first check the entries in cache corresponding to the current key. Every time we have a cache hit, no scanning is required. Scanning is required only if a cache miss occurs.

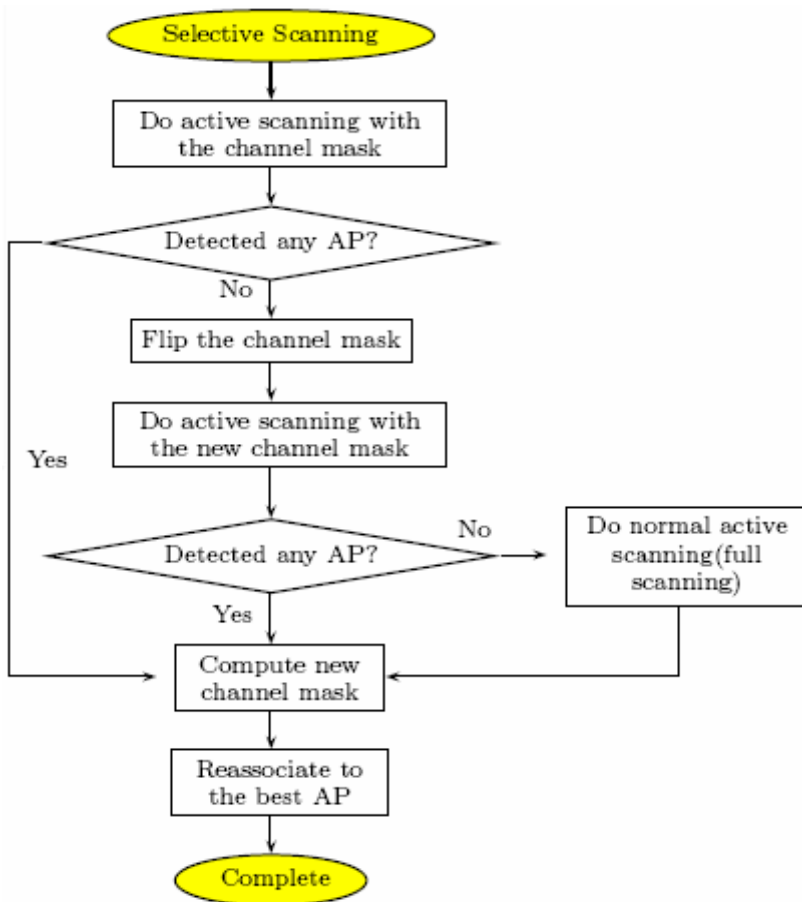


Figure 5: selective scanning procedure

3.1.4 Tuning Scheme

In this scheme authors conclude that detection and search (discovery) phases are the main contributors to the handoff time [11]. So, they try to reduce the delay of these two phases. They use the frame losses to determine the optimal handoff trigger timing to a new AP. If a frame and its next two consecutive retransmissions fail, the MS concludes that the frame failure is caused by the MS's movement (not by collision) and therefore search phase start and hence, no probe needed to detect the need for handoff. This way the detection phase delay is reduced. In addition, in order to reduce the probe delay, they leveraged the active scan mode and derived new values for *MinChannelTime* (the time to wait for the first response in an idle channel) and *MaxChannelTime* (indicates the time to wait in order to collect all responses in a used channel, see

figure 1) from their measurement results and analytical models. Specifically, they used smaller values of 1 msec and 10.24 msec for *MinChannelTime* and *MaxChannelTime*, respectively.

3.1.5 SyncScan

SyncScan scheme was proposed in [17], in order to reduce the probe delay. It allows an MS to monitor the proximity of nearby APs continuously. The MS regularly switches to each channel and records the signal strengths of the channels (passive scan), example process in figure 6. By doing so, the MS can keep track of information on all neighbor APs. Moreover, through continuous monitoring the signaling quality of multiple APs, a better handoff decision can be made and the authentication/reassociation delay can be also reduced. To minimize the packet loss during the periodical switching, the power saving mode (PSM) in the IEEE 802.11 specification is utilized. Synchronization with APs is a critical issue in *SyncScan*, so the network time protocol (NTP) can be leveraged. The process of monitoring is as follows: if d was a stagger parameter that determines the beacon broadcasting timing and if APs operating on channel 1 broadcast beacon frames at time T , then APs on channel 2 will do the same at time $T + d$, APs on channel 3 will send beacon frames at time $T + 2d$, and so on. By this schedule, the MS switches from the current channel c to the channel $c + 1$ and receives beacon frames from APs on the channel $c+1$. Repeating this operation, the MS learns information on neighbor APs. Consequently, *SyncScan* enables an MS to determine the time when a handoff should be triggered, what reduces the handoff delay.

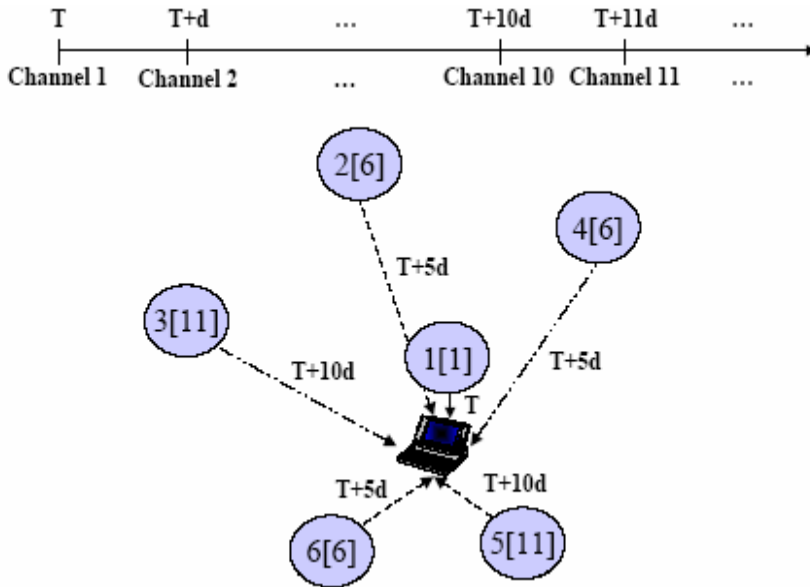


Figure 6: The SyncScan algorithm process

3.1.6 Smooth handoff

A smooth MAC layer handoff scheme and a greedy smooth MAC layer handoff scheme were proposed in [18]. In the *smooth handoff*, the scan channel phase is splitted into multiple subphases. In each subphase a group of the operating channels is probed. The wireless station can use the interval between two consecutive subphases to send and receive data frames. After all channels are scanned, the wireless mobile station knows all APs working on 11 channels, then it can choose the AP with the best signal quality, the operation of this scheme is shown in figure 7. Obviously, this can reduce packet delay and jitter during the channel scanning phase, which is important for time critical applications as VoIP. If the wireless station's available queue buffer size is small, our scheme can efficiently reduce packet loss as well. Further extension of the smooth handoff into a greedy smooth handoff scheme was also proposed. The later scheme not only scans channel smoothly but also reduces the number of channels being scanned by adopting selective scan in the smooth handoff.



Figure 7: Operation of smooth MAC layer handoff

3.1.7 MultiScan

This handoff scheme, proposed in [19], utilizes multiple (here two) radio interfaces. The primary interface is associated with the current AP and used for data transmission. At the same time, the secondary interface opportunistically scan and pre-associate with alternate APs and eventually seamlessly handoff ongoing connections, figure 8. After the completion of a new association by the secondary interface, interface switch from the secondary interface to the primary one is triggered. As a result, the formerly secondary interface becomes primary for data transmission and the formerly primary interface is used for channel scanning. Consequently, MultiScan achieves a *make-before-break* (Soft) handoff by using multiple radio interfaces. MultiScan is similar to SyncScan but it requires neither changing the Access Points (APs), nor having knowledge of wireless network topology.

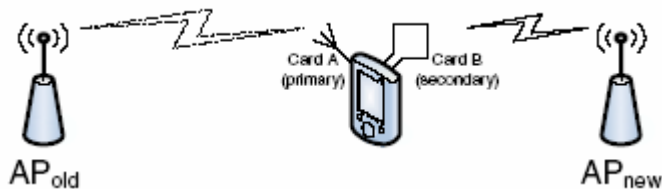


Figure 8: Multi-radio handoff scenario in MultiScan.

3.1.8 Make Before Brake

Three handoff algorithms which implement *make-before-break* mechanisms at the MAC layer were proposed in [20]. First algorithm uses a single radio card on the client (as is done traditionally), but optimizes MAC layer handoff by periodically probing in the background for APs on other channels even when it is already associated with an AP and actively sending and receiving data. It is similar to SyncScan except that it does not require the APs to send beacons at fixed time periods. When the card is actively associated with an AP, it switch and perform *active* probing on all other channels periodically. This ensures pro-active maintenance of up-to-date information about the neighboring APs but it

also suffers from packet loss and increased jitter when probing is performed.

The other two algorithms that use two radio cards on the client so that when one card is involved in communicating data, the other card can probe for neighboring APs. Of these multiple radio algorithms, the first one uses one dedicated card for data transmission and control card exclusively to gather information about nearby APs thereby implementing a *soft* version of make-before-break. When the channel quality of the link to the current AP starts degrading, the stored information is consulted to determine which is the best AP. Based on this information, the data card *switches channels, authenticates* and *associates* with that AP, thus the probing delay can be completely eliminated, but the channel switching, authentication and association delays still remain. The second algorithm uses two cards which can both perform control and data forwarding functions thereby implementing a *strict* version of make-before-break. Here, any one of the two cards can probe channels, switch them, authenticate and associate with a new AP while the other card is sending and receiving data from the old AP thus, the probing, channel switching, authentication and association delays have all been eliminated, similarly to Multiscan, this dynamic process is shown in figure 9.

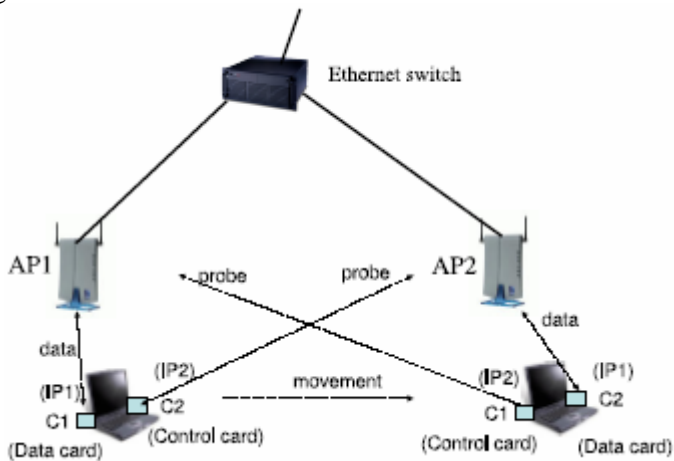
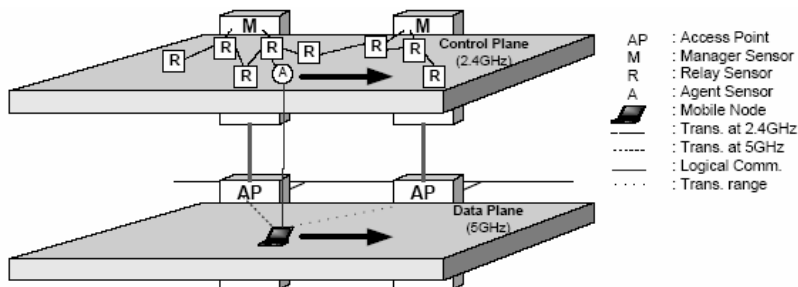


Figure 9: Two-card dynamic algorithm

3.1.9 Selective Active Scanning using Sensor networks

This scheme was proposed in [21]. It proposes a new architecture that augments the existing IEEE 802.11 access protocol (data plane at

54Mb/s) with an overlay sensor network (control plane at 2Mb/s). As the



two planes use different access frequencies (5GHz and 2.4GHz), communications can occur in parallel within each respective plane, see figure 10.

Figure 10: Overlay sensor network architecture for handoff management

The sensor network is in charge of maintaining a knowledge base on the network status. Improvements can be achieved by distributing the information concerning the surrounding access points (channel used, supported rate, etc.) to external agents. By consulting these agents, the MSs can limit the number of scanned channels and take informed decision about the most appropriate AP to be associated with. The MS broadcasts an AP List Request on the control plane. The neighboring relay nodes reply with an AP List Response if they satisfy some criteria. The mobile node processes all the received messages, builds a list of the neighbor access points and initiates a scanning process solely based on this list.

3.1.10 Adaptive Fast Handoff

A hybrid handoff solution is proposed in [22]. In this approach, the handoff related parameters (e.g., the number of channels to be probed, Min/MaxChannelTime, the number of APs to be authenticated in advance, and so on) are dynamically determined depending on the applications' requirements, figure 11. The set of channels to be probed can be constructed by considering the typical channel assignment policy and/or by utilizing other schemes such as NG-pruning and SyncScan. As a result of the probe procedure, the MS obtains a set of neighbor APs. Then, the MS authenticates and reassociates to the AP with the highest SNR. In this step, proactive authentication based on mobility estimation

is performed. In other words, if the estimated mobility is high, the context regarding authentication/reassociation is propagated to more neighbor APs; otherwise, only less neighbor APs receive the context. This procedure can be accomplished by employing the SNC scheme. The adaptive fast handoff scheme reduces both the number of channels to be probed and the channel waiting time depending on the application requirement. In terms of authentication/reassociation delay reducing, the context propagation procedure is performed in a distributed manner. However, with the help of the central system, cost-effective context transfer considering the mobility and network topology can be accomplished.

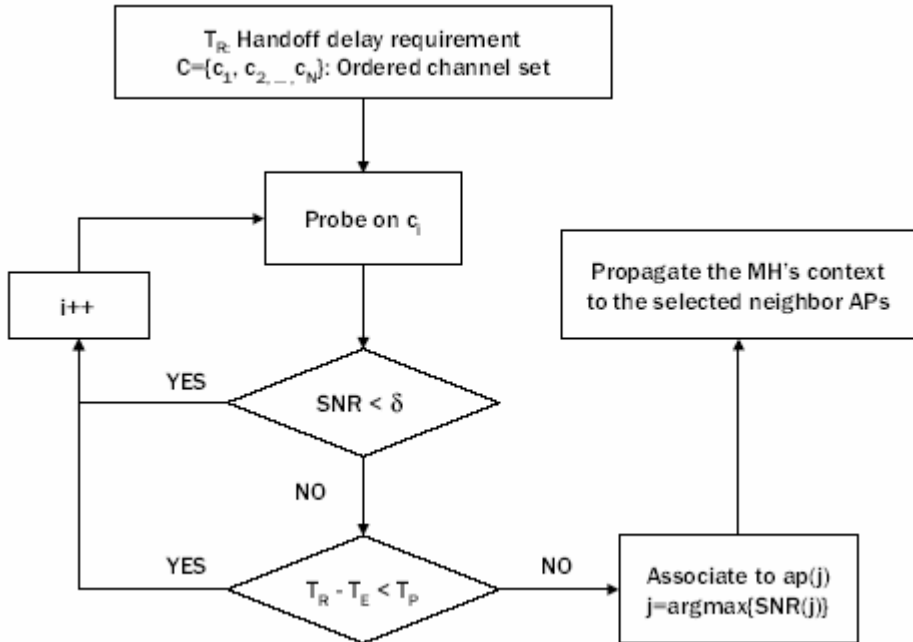


Figure 11: An adaptive handoff framework in IEEE 802.11 networks.

3.2 Handoff schemes based on re-authentication delay reduction

Because mobile hosts should be authenticated during and after handoff, the used authentication mechanism need to be responsive to the handoff time-scale required in micro-mobility environments. However, since AAA (Authentication, Authorizing, and Accounting) servers are located at locations far away from the AP, current handoff schemes cannot meet all requirements of the real-time multimedia applications

[23]. Thus, some techniques were proposed to reduce re-authentication delay, mostly using preauthentication.

3.2.1 Pre-authentication scheme

In this scheme [24], stations can authenticate with several APs during the scanning process so that when association is required, the station is already authenticated. As a result of preauthentication, stations can reassociate with APs immediately upon moving into their coverage area, rather than having to wait for the authentication exchange. Preauthentication makes roaming a smoother operation because authentication can take place before it is needed to support an association. However, since this scheme doesn't predict where the MS moves in the future, the preauthentication may be useless in some cases and cause unnecessary authentication procedures in the wireless link.

3.2.2 FHR-based fast handoff

This scheme was proposed in order to reduce the handoff latency caused by authentication procedures [23]. In this scheme, a mobile station (MS) entering the area covered by an access point (AP) performs authentication procedures for multiple (neighboring) APs, rather than just the current AP. These multiple APs are selected by a prediction method called the frequent handoff region (FHR) selection algorithm, which utilizes traffic patterns and user characteristics, which are collected and managed by a centralized system. FHR is constructed based on the handoff frequency and users' priority. Since a mobile host is registered and authenticated for an FHR in advance, handoff latency resulting from re-authentication can be significantly reduced.

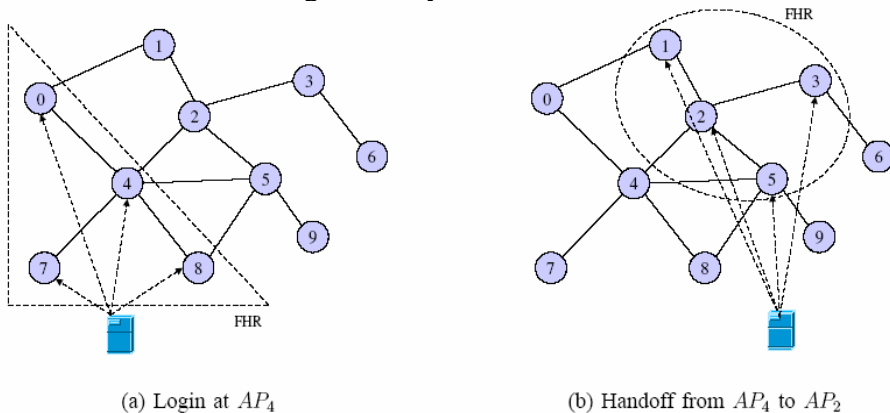


Figure 12: FHR scheme

3.2.3 PNC Handoff

Proactive neighbor caching (PNC) scheme was proposed in [25]. The PNC scheme uses a neighbor graph, which dynamically captures the mobility topology of a wireless network for pre-positioning a MS' context (MS' session , QoS, and security information). The PNC scheme ensures that the MS' context is always dispatched one hop ahead and thereby the handoff latency is reduced. If a MS associates to an AP, the AP propagates MS' context to all neighbor APs. If a cached context does not exist in the new AP, the new AP requests the context from the old AP. After receiving the context the new AP propagates the context to its all neighbors. After transferring context, the old AP and its neighbors removes the MS' context, the PNC operation is shown in figure 13. Experimental results show that the PNC scheme reduces the reassociation latency by an order of magnitude from 15.37 ms to 1.69 ms.

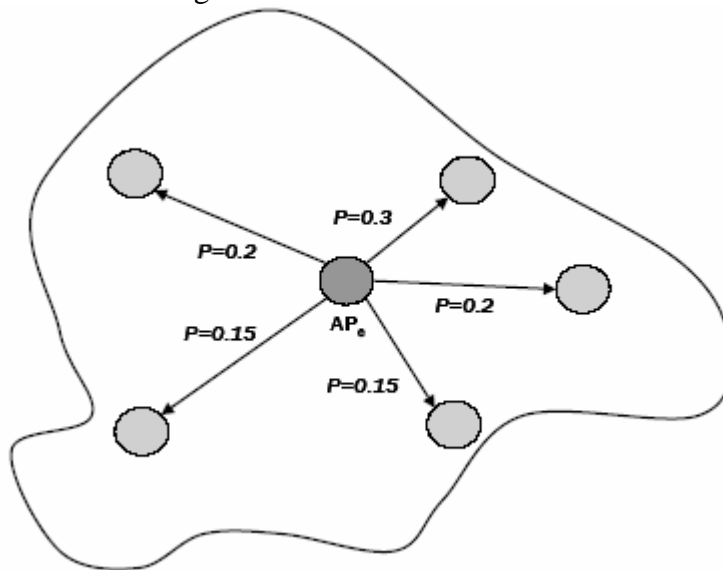


Figure 13: The PNC operation

3.2.4 SNC Handoff

SNC (Selective Neighbor Caching) scheme [26], is similar to the PNC scheme. An AP in the SNC scheme proactively propagates the MS' context to neighbor APs. However, the AP sends the MS' context to its neighbor APs whose handoff probabilities (neighbor weight) are equal to or higher than a pre-defined threshold value. The neighbor graph and its weights are calculated by measuring handoff patterns among APs as

illustrated in fig 14. If the MS moves to an AP not receiving the MS's context, the cache miss occurs and results in a longer handoff latency. Overall, by adjusting the threshold value, the SNC scheme can balance the tradeoff between the signaling traffic and the handoff latency. The performances of the SNC and PNC schemes are expected to be highly dependent on the cache size and cache replacement policy.

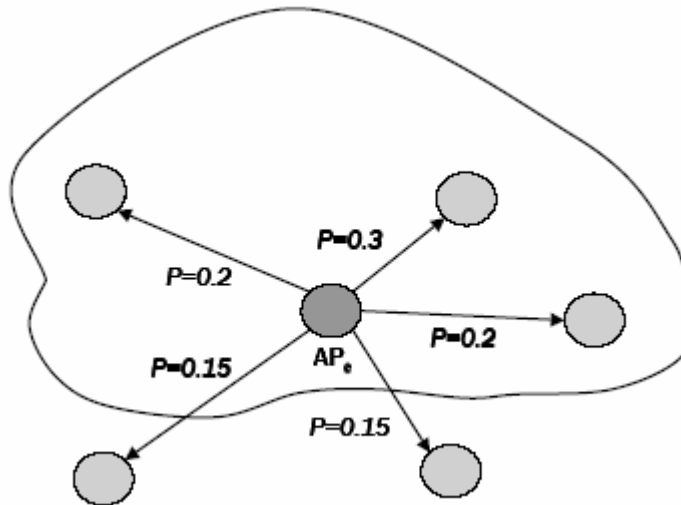


Figure 14: The SNC scheme operation

3.3 Evaluation and Comparison

The aim of, presented above, handoff techniques were to reduce the handoff latency. The first set tried to do that by reducing the delay in the detection and discovery phase. The tuning scheme used the number of frame retransmissions to determine when the handoff is needed and initiate the handoff, minimizing the detection process delay to 3ms (300 times shorter than the fastest detection phase) [17]. It suggests to reduce the probe delay by minimizing the waiting time (*MaxChannelTime* and *MinChannelTime*).

NG-pruning and DeuceScan used neighbor and spatiotemporal graphs to reduce the probe delay from 350 ms in full scan option to 59 ms in NG-pruning and about 20 ms in DeuceScan [15],[16], however these two approaches are very complex since graphs have to be constructed. The selective scanning, selective active scan and the adaptive fast handoff used selective scanning (i.e. probing just a selected number of the available and used channel). They reduce handoff delay to

100ms in selective scanning and with caching to 4 ms [14], while in selective active scan to 40ms [21]. SyncScan and smooth handoff used synchronized and splitted scanning in order to reduce the probe delay. These methods reduce handoff delay to 27 and 33ms respectively, but they suffer from signaling overhead and synchronization necessity in SyncScan [17],[18]. Finally, multiple radios were used in the MultiScan and make-before-brake handoff schemes. These two approaches give the best results (0 ms delay), so they seamlessly perform (soft) handoff [19],[20]. A comparison based on measurements and simulations in references of proposed techniques are collected in table 3.1.

Table 3.1: Discovery delay reduction based handoff techniques comparison

HO_Scheme	Tuning	NG prunning	Deue Scan	Sync Scan	Smooth	Mluti Scan	Mk_bfr_break	Slctv Scan	Activ Scan
HO_Latency [ms]	90	59	20	27	33	0	0	4.5	40
Devices change necessity	MS	MS/AP	MS/AP	MS/AP	MS	MS	MS	MS	MS/ AP
Compatibility with 802.11	Yes	Partially	partially	partially	yes	partially	partially	Yes	partially
Complexity	Low	high	high	high	moderate	high	High	moderate	High
Signaling overhead	Low	high	high	high	moderate	moderate	high	moderate	high
Packet losses	N/A	30	16	20	3	N/A	21-3-0	16	N/A

Regarding the second set (i.e. the techniques based on reauthentication delay reduction), we have four proposals. The preauthentication scheme minimizes handoff association delay to 7 ms similarly FHR reduces it to 6 ms. However, PNC scheme outperforms other techniques giving 1.69 ms delay in case of cache hit.in means of complexity the preauthentication and FHR are the most simple ones while PNC and SNC are moderately complex because of neighbour graphs construction. The two first schemes better utilize bandwidth since they need less signalling overhead to perform handoff. In the same

context SNC generates less signalling than PNC. Table 3.2 compares these schemes.

Table 3.2: reauthentication delay reduction based handoff schemes comparison

HO_Scheme	Pre-Authent.	FHR	PNC	SNC
HO_Assoc_Latency [ms]	7	6	1.69	N/A
Devices change necessity	AP	AP	AP	AP
Compatibility with 802.11	N/A	No	Yes	partially
Complexity	Low	low	moderate	moderate
Signaling overhead	Low	low	High	moderate
Cache hit probability	N/A	N/A	80%	60%

4. CONCLUSIONS

A brief survey and description of MAC handoff techniques in WLANs (802.11) have been introduced in this paper. Techniques were grouped into two main classes. The first one includes schemes that concentrate on reducing detection and discovery delay, which constitute more than 90% of the total handoff time. Schemes that uses the make-before-break mechanism are the best in the means of handoff latency elimination. It is clear that they give good results regarding handoff latency but the challenge is the increasing energy consumption. This type of techniques (make-before-break) will reduce all phases' delays (i.e. discovery, authentication and association).

The second group of handoff schemes is based on reauthentication/reassociation delay reduction. There are four techniques, which varies in the level of handoff delay reduction. Clearly, SNC and PNC are the best in this regard, but they are more complicated. SNC outperforms PNC in minimizing the level of signalling overhead needed.

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