



# Technical University Berlin

## Telecommunication Networks Group

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### Optimization of Handover Performance by Link Layer Triggers in IP-Based Networks: Parameters, Protocol Extensions and APIs for Implementation

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## **Abstract**

The detection and triggering of handover is an important functionality of handover that has a strong impact on the performance in terms of handover latency and packet loss, in particular in scenarios with frequent handover. It is common to all IP-based mobility solutions that they provide network layer trigger for handover – for example, based on the lifetime field or the network prefix in Mobile IP advertisements. The technical report covers the following aspects of link layer trigger for handover. First, parameters and their combinations for link-layer triggers are identified. Second, the potential performance gain of link layer triggers in comparison of network layer triggers are quantified for Mobile IP and Hierarchical Mobile IP by means of a simulative study. Third, the interaction of the link layer and the network layer are described for Mobile IPv6 and its hierarchical variant as well as for the fast handover extensions of Mobile IPv6. Fourth, the requirements for an application-programming interface (API) are summarized and existing APIs for interaction between link-layer and network layer are evaluated.

## Chapter 1

# Introduction

An IP mobility protocol, such as Mobile IP [10, 12], offers a solution for routing of IP packets to and from mobile nodes. In cellular networks, the mobility of nodes gives rise to phenomena such as *handover*. A handover occurs when a mobile node migrates from one wireless cell to another. A handover includes a number of actions by the mobile node and by the network to ensure the IP routing reachability. When a mobile node executes handover while a communication session is ongoing, the handover may cause disturbances of the communication, or even break off the communication session. Hence, the performance of handover is an important consideration in the design of IP mobility protocols.

Handover detection and triggering are important handover functionalities. They may contribute significantly to the overall service interruption caused by handover, and therefore, can have a strong impact on the handover performance. Regarding the handover as consisting of two subsequent phases (see Fig. 1.1) — namely handover detection and triggering as the first phase, and handover execution as the second phase — optimizing the second phase without considering the first phase might be useless. Reducing the first phase might not result in the expected performance gain if the second phase, handover execution, causes a high latency.

As an example, hierarchical Mobile IP [8] aims at reducing the latency required for handover signaling and therefore at minimizing the overall service interruption.<sup>1</sup> Hierarchical Mobile IP is based on the same mechanisms for handover detection and triggering as the basic Mobile IP scheme: In principle, handover is detected by layer-3 information based on advertisements sent by the network on the wireless link are sent in discrete time intervals. The time interval determines the granularity in which a handover can be detected. In most implementations, the advertisement interval is a parameter that can be adjusted. Decreasing the time interval results in a shorter latency for handover detection and triggering, but increases the signaling overhead. If the advertisements consume a considerable portion of the scarce wireless bandwidth, then the signaling overhead is not acceptable. Consequently, if hierarchical Mobile IP makes use of the standard Mobile IP mechanisms for handover detection and triggering, the performance gain in comparison to basic Mobile IP will be small. This statement is

<sup>1</sup>More precisely, hierarchical Mobile IPv4 distributes the foreign agent functionality among a hierarchy of foreign agents. Foreign agents at the lowest hierarchy are interconnected to foreign agents at a higher hierarchy. The foreign agent at the highest hierarchical level has connectivity to the home agent. When a mobile node migrates from a lowest foreign agent to another, both having a common foreign agent at a higher hierarchical level, then the signaling messages are sent up to the foreign agent at the higher hierarchical level where the rerouting operation is executed. In comparison to basic Mobile IP, the signaling messages traverse less network nodes and the latency for handover execution is reduced.

valid for any mobility scheme: In general, an approach to optimize handover performance should attempt to shorten both phases.

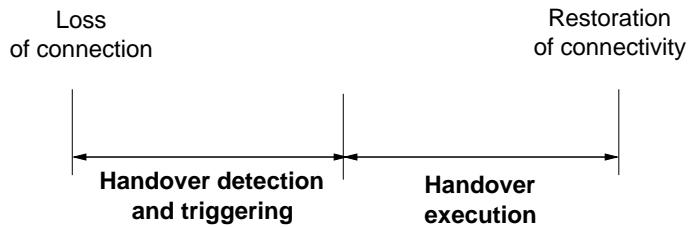


Figure 1.1: Two phases of the handover process

Looking at layer-3 handover triggers in detail, the underlying algorithm offers potential for improvement. Well-known algorithms for handover detection and triggering in Mobile IPv4 – applied in Mobile IPv6 as well – are Lazy Cell Switching (LCS) and Eager Cell Switching (ECS) [12], where ECS can be regarded as an optimization of LCS. The first algorithm, LCS, is based upon the lifetime of the advertisement sent by the network. The mobile node monitors any advertisements, records the lifetime and updates the expiration time when a new advertisement is received from the network. When the advertisement lifetime of the current Mobile IP foreign agent expires, the mobile node assumes that it has lost connectivity and attempts to execute a new registration with another foreign agent. Although the mobile node might already be informed about the availability of a new foreign agent, the mobile agent defers switching until the advertisement lifetime of the old foreign agent is expired. The second algorithm, ECS, makes use of the network identification carried by the advertisement. If the mobile node detects an advertisement with a different network identifier than the current network, the mobile node assumes that a handover has happened and registers with the new foreign agent. The LCS and ECS algorithms are illustrated in Fig. 1.2. In a scenario with overlapping wireless cells, it can be seen that the ECS algorithm switches earlier to the new foreign agent than the LCS algorithm.

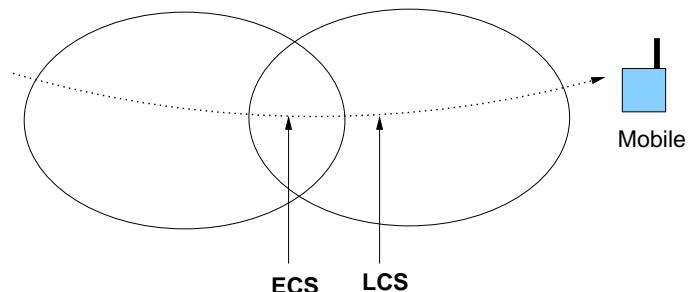


Figure 1.2: Lazy Cell Switching and Eager Cell Switching

The latency for handover detection incurred by the LCS algorithm corresponds directly with the lifetime of the advertisement that is a multiple of the advertisement interval. The advertisement lifetime is typically set to three times of the interval. This takes into account that an advertisement might get lost due to an error-prone wireless channel. Assuming an advertisement interval of 1 second,

that is commonly regarded as a lower bound, the lifetime amounts to 3 seconds. Consequently, the minimum service interruption due to handover is 2 seconds<sup>2</sup> and unacceptable for real-time communication. The ECS algorithm reduces the service interruption, but inherits a disadvantage: The fact that a mobile node receives an advertisement does not necessarily mean that the link to the current foreign agent is broken. Though the current foreign agent is reachable, the mobile node registers with a new one. In these cases, an unnecessary handover is triggered. While with ECS a single handover impairs the communication quality less than with LCS, the overall number of handovers — necessary and unnecessary – is higher. At all, there might be no improvement by the ECS algorithm.

An alternative to layer-3 handover triggers are layer-2 trigger.<sup>3</sup> These layer-2 triggers reduce the time to detect and trigger handover by means of cross-layer information from layer-2 to layer-3. Link layer information such as signal strength may be continuously available and thus can be measured at any frequency, providing valuable information about the present link quality. Link-layer information may therefore allow a mobile node to detect the loss of connectivity more quickly than a layer-3 advertisement-based algorithm. In some cases, link-layer information may be used to detect a decaying wireless link before the link is broken. This facilitates the execution of the handover and the elimination of the time to detect handover. Moreover, link-layer trigger can be employed for other functionality, such as paging as well. An inactive mobile node can be triggered by link-layer information to re-register when it enters a new paging area. The mobile node does not need to monitor the layer-3 advertisements continuously and instead may listen to layer-2 information.

Using link-layer trigger for handover violates a general design paradigm of the Internet protocols: *IP is designed to be independent of the underlying technology*. The success of the Internet technology is largely attributed to such principles. As a consequence of these principles, IP subnets do not carry IP packets with maximum efficiency or minimum costs. With the continuous success of IP protocols, a large portion of the traffic carried by telecommunication networks will be IP traffic and the disjoint optimization of the IP protocols on the one hand and of the underlying technologies and protocols on the other hand, might not be sufficient. In particular in IP networks with wireless links, the usage of standard IP protocols can result in very low performance. The coupling of IP and underlying protocol layers and the usage of link-layer information at the IP layer is an open question and is debated in the IETF community. While it is commonly accepted that the usage of link-layer information can result in a more efficient IP packet transport, it results in a dependence of the IP layer from the underlying technology. Due to the diversity of different technologies, the dependency of the IP from the underlying technology and protocols may result in the development of a multitude of specific protocol stacks. This in turn will aggravate and hamper the application of heterogeneous all-IP wireless networks.

An example for the usage of link-layer information are performance-enhancing proxies (PEPs) in wireless networks [2]. A typical mechanism of transport-level PEPs is to modify the behavior of the TCP connection by generating local acknowledgments to TCP data segments in order to improve the throughput in environments with a large bandwidth-delay product. Though the performance is improved, the end-to-end argument [14] – one of the architectural principles of the Internet – is broken. It is argued that, as a first principle, certain required end-to-end functions can only be correctly performed by the end systems themselves. This is one of the main reasons why PEPs are not recommended for general use. Similar to PEPs, the usage of link-layer trigger for handover breaks with a

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<sup>2</sup>The maximum time to detect and trigger handover is 3 seconds, the mean is 2.5 seconds.

<sup>3</sup>The terms *layer 2* and *link layer* are used synonymously.

certain Internet principle. The implications of such an approach must be carefully considered. One of the challenges for link-layer trigger is to identify the assumptions and mechanisms behind particular schemes in order to design a solution that is independent of the particular implementation of the device driver and can be applied to as many types of link-layers as possible.

In order to reduce the dependency of the IP layer from the underlying technology, a link-layer trigger should be regarded as an abstraction of a notification from layer-2 that a certain event has occurred or is about to occur. Following this definition, a trigger consists of three components: the event that causes the trigger to fire, the entity that receives the trigger, and the parameter that is delivered with the trigger. All of the three components are covered in this document.

The remaining sections of the document are structured as follows: First, different parameters for link-layer triggers are identified and implications from technology discussed. Then, different schemes for the interaction between layer-2 and layer-3 are presented. Finally, the requirements for an application programming interface (API) for link-layer triggers are described and existing APIs reviewed with respect to their utilization for handover purposes.

## Chapter 2

# Performance Gain of Link Layer Trigger for Handover

In order to estimate the performance gain by link layer triggers, a simulation based performance study has been conducted. A subset of the results are described below. Details of the simulation scenario, simulation model and further results, can be found in [17].

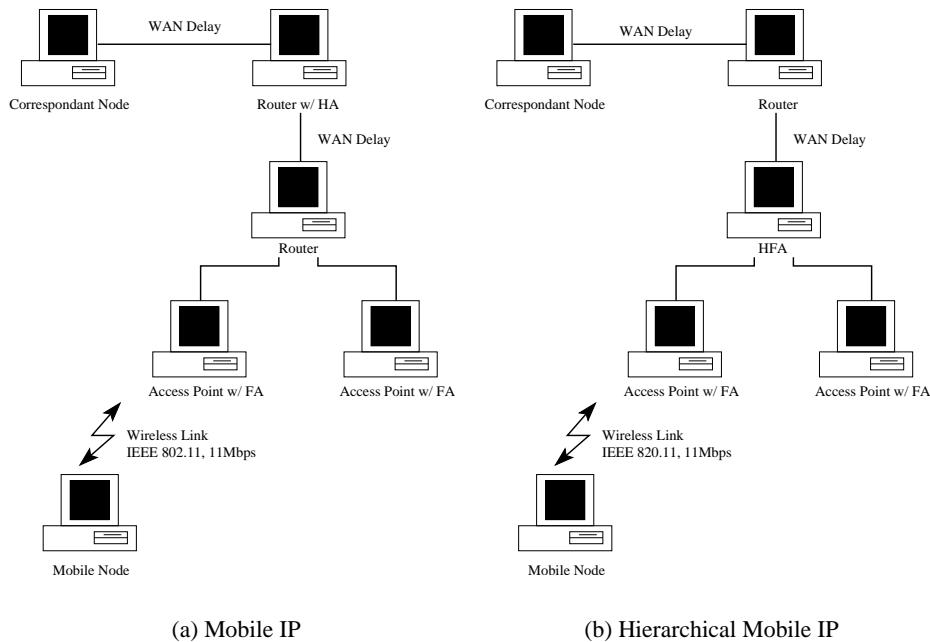


Figure 2.1: Simulation setups

In order to estimate the potential performance gain of link layer trigger in comparison to network layer trigger, the following scenario has been investigated: An IP-based, mobile network consists of an access network and a wide area network representing the Internet. The access network is comprised

of two access points providing IEEE 802.11 wireless links and a gateway that interconnects the access network with the WAN. A mobile node associates with a wireless access point and communicates with a correspondent node by means of Mobile IP. A handover to the neighboring access point (and back) is executed while a communication session is ongoing. The simulation setup is shown in Fig. 2.1 for Mobile IPv4 and hierarchical Mobile IPv4. The access points are located in different IP subnets and execute a Mobile IP foreign agent. In the setup with hierarchical Mobile IPv4 (Fig. 2.1(b)), the gateway executes the Highest Foreign Agent (HFA) as the root node of the foreign agent hierarchy. In both setups, the WAN is realized by a router that executes a Mobile IP home agent, and by links with WAN-typical delays, that can be adjusted as a simulation parameter.

For simulation, the *network simulator* (ns) [7] has been utilized. The implementation of the simulation model is based on the Hierarchical Mobile IP implementation by [4]. Tab. 2.1 summarizes the simulation parameters.

Parameter	Values
<b>Traffic Model Parameters</b>	
Traffic type	UDP
Packet size [Bytes]	1024
Inter-burst time [ms]	10
<b>Mobility Model Parameters</b>	
Handover model	Exponentially distributed cell-dwell time
Mean value for pdf [s]	10
<b>Mobile IP parameters</b>	
Tunnel lifetime [2]	600
Tunneling type	Reverse
Foreign agent packet encapsulation	Enabled (no co-located CoA)
Advertisement period [s]	1
Advertisement lifetime [s]	3
Type of handover trigger	Advertisement-based, Link layer trigger
<b>Network setup parameters</b>	
Wireless Link	IEEE 802.11 11Mbps
Wired links (except WAN links) [ms]	10Mbps, 2ms
WAN links [ms]	0, 50, 100, 200
Simulation time [s]	3600

Table 2.1: Simulation parameters

Fig. 2.2(a) and 2.2(b) compare the mean handover latency for Mobile IP and hierarchical Mobile IP. If the handover is triggered by the expiration of the advertisement lifetime (layer 3 trigger), the mean handover latency in Mobile IP is about 2.6s for a round trip time RTT between the mobile node and correspondent node of 20ms (10ms RTT between the mobile node and the home agent). This value increases linearly with the growing RTT. Using a link layer trigger, the value can be decreased to about 600ms for a RTT of 20ms.

Considering hierarchical Mobile IP, the handover latency is independent of the RTT between mobile node and correspondent node/home agent. However, the time to detect the handover contributes

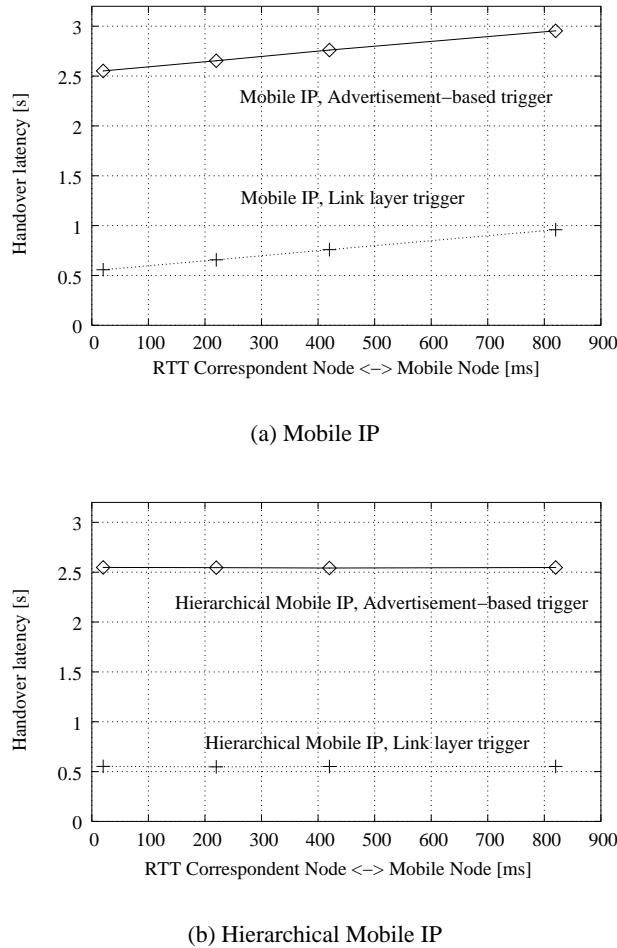


Figure 2.2: Comparison between advertisement-based and link layer trigger

significantly to the overall service interruption. Hence, also in hierarchical Mobile IP, a link layer trigger decreases the handover latency to about 600ms.

The described simulation results for link layer trigger assume that a mobile node waits for new Mobile IP advertisement when it has received a link layer trigger for handover. Clearly, this waiting time again contributes to the service interruption. In the above scenario the mean waiting time amounts to about 500ms. However, in Sec. 5, protocol extensions for Mobile IP and hierarchical Mobile IP will be described that shorten the time for handover detection to a minimum.

## Chapter 3

# Parameters for Link-layer Trigger

In this section, the possible parameters to be utilized for handover trigger are described and discussed. In particular, the assumptions behind the parameter are highlighted.

### 3.1 Signal Strength

The signal strength is a measure for how strong the signal at the location of the receiver is. Often, the parameter is also named *Received Signal Strength Indicator (RSSI)*. Typically the signal strength is measured in mW or dBm. The latter unit represents the received signal strength in decibel relative to 1mW. The received signal strength expresses the impairment of the transmitted signal by the communication channel. The impairment is caused by physical phenomena, i.e. attenuation, reflection, refraction, scattering and diffraction. The attenuation in free space can be described by the *free space loss*, a well-known law in radio communications. In addition to the free-space loss, the signal is attenuated due to the terrestrial propagation of the signal, i.e. by the topography of the surface along the propagation path. In indoor and urban outdoor environments, walls and obstacles contribute to so called *propagation losses*. The reflection of signals cause multi-path propagation and results in *fading*. Small changes in the topography give raise to *long-term fading*. Scattering at fixed and mobile obstacles causes *short-term-fading*. As a result, the received signal strength fluctuates significantly.

Considering the usage of the signal strength for handover trigger, the following must be taken into account:

- The use of the signal strength as handover trigger requires the definition of a threshold. If the signal strength is higher than this threshold, the link is considered as good. If the signal strength is lower than this threshold, the link is considered as bad and a handover will be triggered. However, the signal strength threshold is a system-specific parameter (for example, about -65dBm for IEEE 802.11a at a data rate of 54Mbps and -70dBm for IEEE802.11b at a data rate of 2Mbps) and often depends of the modulation type and the selected data rate. Moreover, the threshold might be even specific for devices from different vendors.
- The measurement of the signal strength usually includes interference. Consequently, in environments with high interference, the channel might be is bad although the measured signal strength indicate a good channel.

- The measurement of the signal strength requires that the mobile node receives at least a signal from a transmitter, e.g. by the access point. In some systems (e.g. W-CDMA, [11]), the access point transmits a pilot signal continuously.<sup>1</sup> Other system do not enjoy this feature. For example in IEEE 802.11 wireless LANs, the access point transmits a link layer beacon that can be used for signal strength measurements. However, the beacon is sent at discrete time intervals of typically 100ms. In such systems, this time interval determines the minimum duration between two samples of signal strength.
- The received signal strength may change rapidly. A typical, well-known example for such a scenario is the *corner effect*. When a mobile turns a corner in a Manhattan-like environment, the signal from the old access point is blocked and the signal strength drops suddenly.
- In order to include the signals of other mobiles in the same (or adjacent) cell, the wireless network card must be forced to work in promiscuous mode. In this mode, the mobile node consumes more energy.
- The fluctuation of the received signal strength due to short-term and long-term fading may result in short and sharp declines of the signal. If the signal strength is sampled at an fade-out, then a handover can be triggered without being necessary. Therefore, the signal is averaged with a time window of a certain size. The size of the window is a technology-specific parameter and may also depend on the environment. For example, for GSM the last 32 samples are stored and averaged (GSM 05.08, Annex A).
- In order to limit the interference in a mobile network, some systems (e.g. IS-95 and W-CDMA) provide power control. If a mobile node moves near the cell border, then the power control increases the transmitting power in order to increase the received signal strength. The maximum transmission power is limited, and therefore, a handover will be executed. To avoid ping-pong handover, a hysteresis is used addition to the threshold. However, in systems with power control, the signal strength should be coupled with layer-2 handover trigger, otherwise the interference increases to high. In fact, systems like IS-95 and W-CDMA apply soft handover where the mobile node can be connected to more than one access point. This *soft handover state* is controlled by the power control function.
- The employed antenna system at the receiver as well as at the transmitter impacts the signal strength. With a high-gain antenna the received signal strength is higher than with a low-gain antenna. Applying the same threshold for both cases might result in unnecessary handover in a scenario with high gain antennas. However, when a mobile node moves through the coverage of a network, it usually does not know the gain of an access point. This fact makes the dynamic adaption of the signal strength threshold in the mobile more difficult.

## 3.2 Signal-to-Interference Ratio (SIR)

The signal-to-interference ratio is a measure for how clear a signal is compared to the interference. Interference can be caused by background noise, e.g. by microwaves or machines in industrial en-

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<sup>1</sup>In W-CDMA the mobile node continuously searches for the pilot signal. This pilot signal is sent by an access point with a period of 26.667ms using a designated (short) code (CDMA PN sequence). The code is the same for all access point, but has a certain phase to distinguish between access points.[11]

vironments. Another source of interference are other communication devices (mobile nodes, access points) working on the same (co-channel interference) and on neighboring frequency channels (adjacent channel interference). The SIR is measured in decibel (dB). The SIR requires two samples of the signal: First, the received power is determined before a certain signal is received (interference). The second sample is taken, when the reception of the signal starts. Then, both values can be used to calculate the SIR.

Similar to the signal strength, the SIR is also time-variant since the contributing terms of the SIR fluctuate: The received signal as well as the co- and adjacent channel interference changes. Therefore, an average of the SIR value must be calculated. Moreover, the SIR is affected by similar factors as the signal strength: This includes threshold and hysteresis, to compensate short-term fluctuations of the measure. A specific factor is the application of directed antennas. These antennas direct a beam towards a certain receiver and increase the received signal strength. Simultaneously, interference signals and noise from other directions are reduced or even suppressed.

In comparison with the received signal strength, the SIR includes the interference. This fact is of particular importance since the signal might be lost in noise even when the received signal strength is sufficient. Therefore, the SIR gives a more precise measure of the link quality than the received signal strength.

### 3.3 Bit Error Rate (BER)

The bit error rate (BER) is the percentage of bits that have errors relative to the total number of bits received in a transmission. The BER is usually expressed as ten to a negative power.

In most wireless systems an error control is used to detect and correct bit errors. The bit error rate may be assessed excluding or including the error control. Clearly, the resulting measure will be different. If the signal-to-interference ratio is bad, the error control might compensate the erroneous wireless channel.

In some systems, for example in GSM [13], the BER is expressed as *signal quality*: The BER is assessed before channel decoding, a particular value of BER is assigned a integer number on a scale from 0 to 7 expressing the signal quality.

Similar to the parameters before, the calculation of the BER requires that data are received by that node.

### 3.4 Frame Error Rate (FER)

The frame error rate (FER) is the percentage of frames that have errors relative to the total number of frames. The FER is usually expressed as ten to a negative power.

In some wireless systems, the mobile nodes are able to detect erroneous or lost frames. For example, IEEE802.11 uses a *send&wait* scheme with immediate acknowledgement. Hence, a frame loss (more precisely MPDU loss) can be easily detected. Other systems employ similar ARQ protocols that use retransmissions. Typically, implementations of systems with ARQ provide the information about the number of retransmission that can be used to calculate the frame error rate.

The assessment of the frame error rate requires an observation over a relatively high number of frames. Although it can be expected that the frame error rate is correlated with the signal-to-interference ratio and the bit-error rate, the frame error rate reacts with a certain delay to a decaying

wireless link. If the wireless link decays rapidly, a number of packets must get lost in order to increase the FER. Hence, the main problem with the usage of the FER parameter for handover trigger is the fact that packets, that are sent but not received, do not count for the FER. Consequently, the FER starves at the previous value although the link is already broken.

### 3.5 Summary

A link layer trigger for handover is an abstraction of a notification from the link layer to the network layer that a certain event has occurred or is about to occur. The components of a link layer trigger are the event that causes a trigger to fire, the entity that receives the trigger and the parameter that is delivered with the trigger.

As potential parameters have been identified: signal strength, signal-to-interference ratio (SIR), bit error rate and frame error rate. While the signal strength is an indicator for how strong the signal is, it requires an averaging to compensate short-term fluctuations. However, the signal strength is typically regarded as the received signal power *including* interference. Hence, the SIR is the better measure since it considers signal power and interference power separately. Nevertheless, also the SIR parameter requires that a signal is transmitted for SIR estimation. Not all wireless systems provide a pilot signal as in IS-95 or W-CDMA. In systems without a continuous signal for channel estimation (e.g. IEEE 802.11 or Bluetooth), other mechanisms are utilized, such as periodically sent beacons. These beacons provide samples of the signal quality at equidistant points of time. In such systems, the granularity of a link layer trigger based on SIR is limited by the interval of the beacons. In comparison to the FER parameter, the SIR reacts more rapidly to fast changing link conditions.

In addition to the SIR, the signal strength parameter in combination with the BER is a reasonable parameter for handover trigger. By combining both parameters, the disadvantage of the signal strength parameter – excluding the interference – is leveraged.

Finally, all of these parameters are specific to the technology. A method to overcome this obstacle is the parameterization parameters. This means that the measured values need to be weighted with technology specific factors. This parameterization makes the assessed values comparable and enables to trigger handover between different technologies based on layer-2 information.

Tab. 3.1 gives an overview about the availability of different parameters for link layer trigger in IEEE 802.11b [9], Bluetooth [5], [13], IS95 and W-CDMA [11] and HiPERLAN-2 [3].

All of the discussed parameters and parameter combinations can be used to detect a decaying wireless link and therefore provide an indication that a handover is about to occur. As it will be described in Sec. 5, the detection of a handover in advance can be utilized to execute an *anticipated* handover. However, this kind of handover requires protocol modifications of the existing Mobile IP protocols. For a non-anticipated handover, it is usually sufficient to indicate a *link up/link down* message to the network layer.

LL Trigger	IEEE 802.11b	Bluetooth	GSM	IS95	W-CDMA	HIPERLAN/2
Signal strength downlink	Yes (Beacon)	Yes (Beacon)	Yes (Control channel)	Yes (Pilot channel)	Yes (Pilot channel)	Yes (Beacon)
Signal strength uplink	No	NA	Yes (Control channel)	No	Yes (Pilot channel)	Yes (Via Resource Request)
SIR downlink	Yes (Indirect)	Yes (Indirect)	No	No	Yes	Yes (Indirect)
SIR uplink	No	NA	No	Yes	Yes	Yes
BER downlink	No	No	Yes (Dedicated mode)	No	No	No
BER uplink	No	NA	Yes (Dedicated mode)	No	No	No
FER downlink	Yes	Yes	NA	No	Yes	Yes
FER uplink	No	NA	NA	No	Yes	Yes

Table 3.1: Availability of parameters for link layer trigger in popular link layer technologies

## Chapter 4

# Interaction Between Link Layer and Network Layer

While potential parameters to trigger handover have been identified in the last section, different schemes for the interaction between the link layer and the network layer are presented in this section.

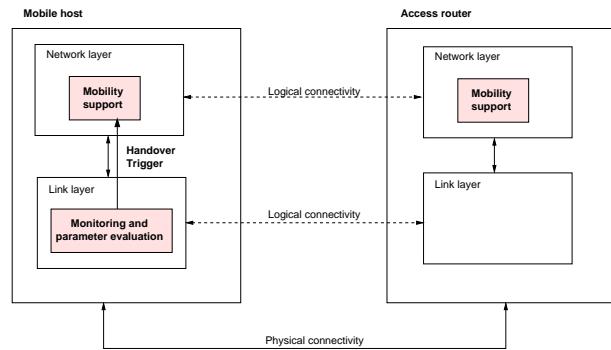
Principally, three general schemes with respect to the entity that delivers and receives the handover can be distinguished. These schemes are illustrated in Fig. 4.1.

**Mobile triggered and initiated handover.** The handover trigger is generated by the link layer in the mobile node and received by the mobile node's network layer (vertical triggering) (see Fig. 4.1(a)).

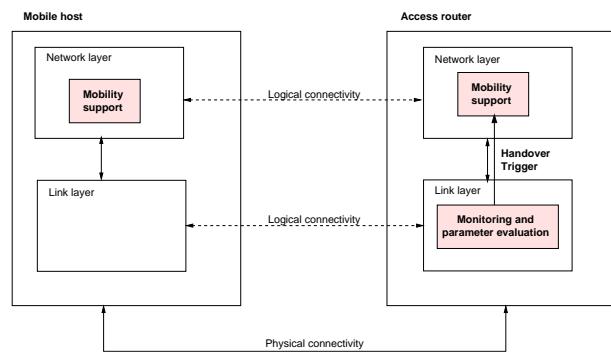
**Network triggered and initiated handover.** The handover trigger is also transferred vertically, similar to the mobile triggered and initiated handover scheme, but the trigger is generated and received in the network node (e.g. access router) (see Fig. 4.1(b)).

**Mobile triggered and network initiated handover.** The handover trigger is generated by the mobile node and transferred to the network (e.g. access router). The network initiates the handover signaling procedure when it receives the handover trigger (see Fig. 4.1).

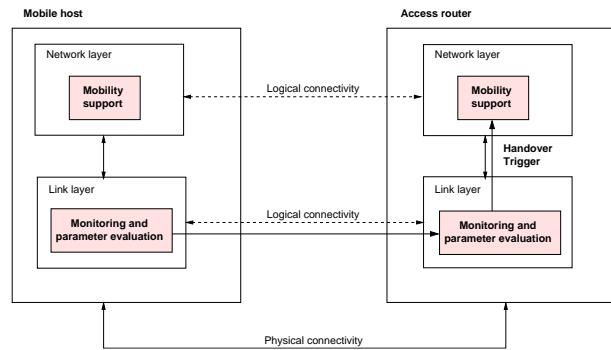
A theoretical case that completes the above three cases is the scheme where the network triggers a handover, transfers the trigger to the mobile node, and the mobile node initiates the handover procedure. However, this case assumes that the mobiles transmit signals to the network frequently in short time intervals in order to enable the network to monitor the signal quality. Since this is an unrealistic assumption, this scheme has not practical relevance and is not considered.



(a) Mobile triggered and initiated



(b) Network triggered and initiated



(c) Mobile triggered and network initiated

Figure 4.1: General schemes for handover triggering

In order to illustrate the schemes, an IEEE 802.11 network with the signal strength as the parameter for handover trigger is considered as a typical example. In the *mobile triggered and initiated handover* scheme, the device driver for the IEEE 802.11 wireless network card in the mobile node monitors the channel of the current access point and traces the channel quality in terms of the received signal strength. This is accomplished by monitoring the link layer beacons sent by the access points at time intervals of about 100ms where the access points can be differentiated by their MAC address. When the signal strength of the current access point drops below a predefined threshold, the link layer informs the network layer that the current link to the access network is broken. When the connectivity to a new access point could be re-established, the availability of the new link to the access network is notified to the network layer and the mobile node initiates the handover procedure. In the second scheme, *network triggered and initiated handover*, the network (e.g. the access router) monitors the signal strength of the data received by a mobile. When the mobile is about to move to the new access point, the signal strength decays and the mobile node can be forced to execute a handover. In the third scheme, *mobile triggered and network initiated handover*, the mobile node monitors the channel of the current access point. If the signal strength received by the mobile node falls below the threshold, the mobile node sends a link layer message including the channel status to the access point at link layer. The link layer at the access point triggers the network layer that the mobile node is about to handoff.

## Chapter 5

# Protocol Extensions for Link Layer Triggered Handover

The general schemes described in Chapt. 4 can be used to enhance existing protocols for mobility support. In the next sections, the sequence of messages and timing for link layer triggered handover for

- Mobile IPv6 [10]
- Hierarchical Mobile IPv6 [15]
- Extensions of Mobile IPv6 for fast handover [6]

are described. The protocol extensions include the *mobile triggered and initiated handover* and the *network triggered and initiated handover*.

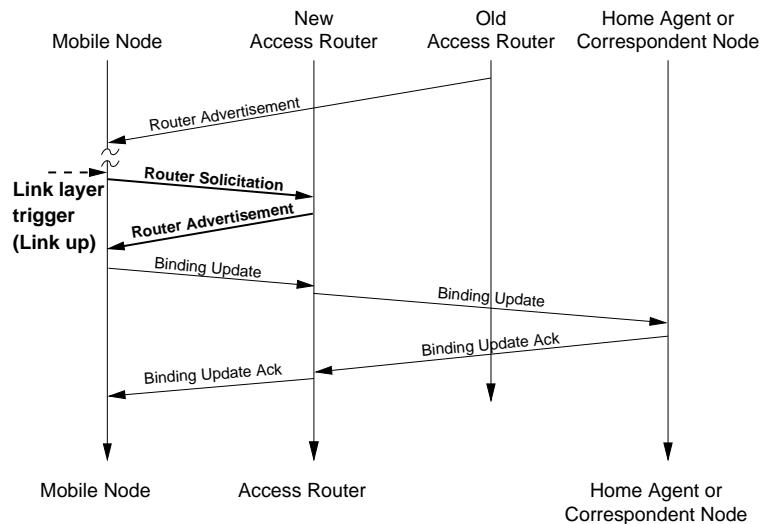
### 5.1 Protocol Extensions for Mobile IPv6

Mobile IPv6 can be easily enhanced by link layer trigger for handover without introducing additional types of messages. The protocol messages used to initiate a link layer triggered handover are set in bold lines and text.

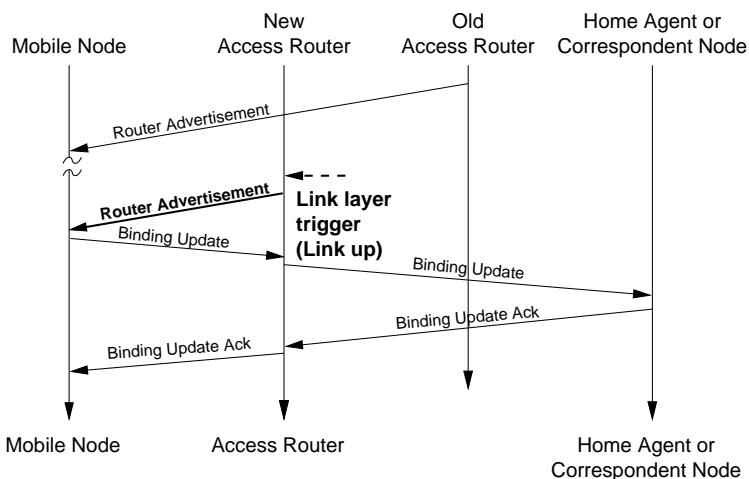
In Fig. 5.2(a) a timeline for a handover triggered by link layer information in the mobile node is shown. When the network layer of a mobile node receives a link layer trigger, it sends a *Router Solicitation* message. The access router receiving the solicitation message replies with a *Router Advertisement* message. The handover is completed by exchanging a *Binding Update* and *Binding Update Ack* message between the mobile node and the home agent/respondent nodes.

For the *network triggered and initiated handover* (Fig. 5.1(b)) a solicitation message is not needed. When the new access router receives a link layer trigger for handover, it sends a *Router Advertisement* message in order to initiate the handover procedure.

In both schemes the link layer informs the network layer that the new link is available (*Link up*). In the network triggered case, this means that the mobile node has already executed a link layer registration. In the mobile node initiated case, the link layer trigger must also include the MAC address of the new access point.



(a) Mobile triggered and initiated



(b) Network triggered and initiated

Figure 5.1: Timeline for link layer triggered handover in Mobile IPv6

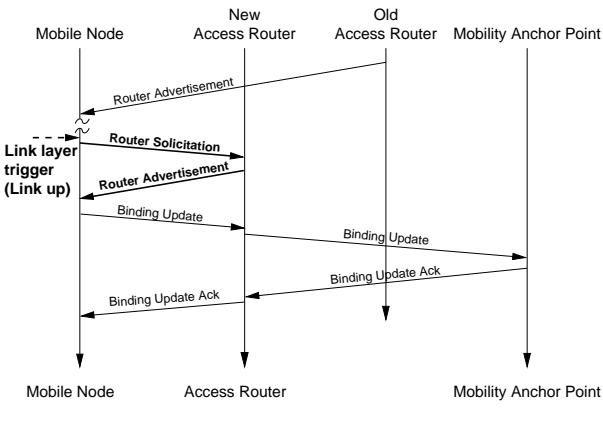
## 5.2 Protocol Extensions for Hierarchical Mobile IPv6

The protocol extensions for link layer triggered handover in Hierarchical Mobile IPv6 are very similar to Mobile IPv6: The extensions are easy and do not require new message types.

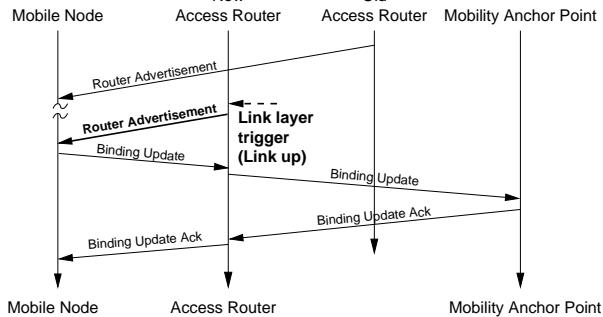
For *mobile triggered and initiated handover* (Fig. 5.2(a)), the mobile node sends a *Router Solicitation* message to the access router when it receives a link layer trigger for handover. The new access router replies with a *Router Advertisement* message. This procedure is followed by the exchange of a *Binding Update* message and *Binding Update Ack* message to complete the handover.

For the *network triggered and initiated handover* there is no need for a *Router Solicitation* message. When the access router receives the link layer trigger, it sends a *Router Advertisement* message to the mobile node and the mobile node completes the handover procedure by sending a *Binding Update* message to the Mobility Anchor Point (MAP) and receiving *Binding Update Ack* message.

In contents of the link layer information is the same as in the non-hierarchical case.



(a) Mobile triggered and initiated



(b) Network triggered and initiated

Figure 5.2: Timeline for link layer triggered handover in hierarchical Mobile IPv6

### 5.3 Protocol Extensions for Fast Handover in Mobile IPv6

In order to minimize the handover latency, in [6] protocol enhancements for Mobile IPv6 have been proposed. This Internet draft presents two schemes, namely

- Anticipated handover,
- Tunnel-based handover.

Both schemes explicitly utilize the link layer trigger for handover to gain predictive information about the new access router. They combine link layer trigger at access routers and mobile node to harmonize handover at link layer and network layer. Unlike the schemes described in Sec. 5.1 and 5.2, for the fast handover extensions new message types are introduced. Moreover, both schemes add new functionality since they establish a bi-directional tunnel between the old and the new access router. The following two sections describe how to employ link layer trigger for handover in both schemes.

#### 5.3.1 Fast Handover in Mobile IPv6: Anticipated Handover

In general, in the *anticipated handover* scheme, a network layer handover to the new access router is executed while the mobile node has still link layer connectivity to the old access router.

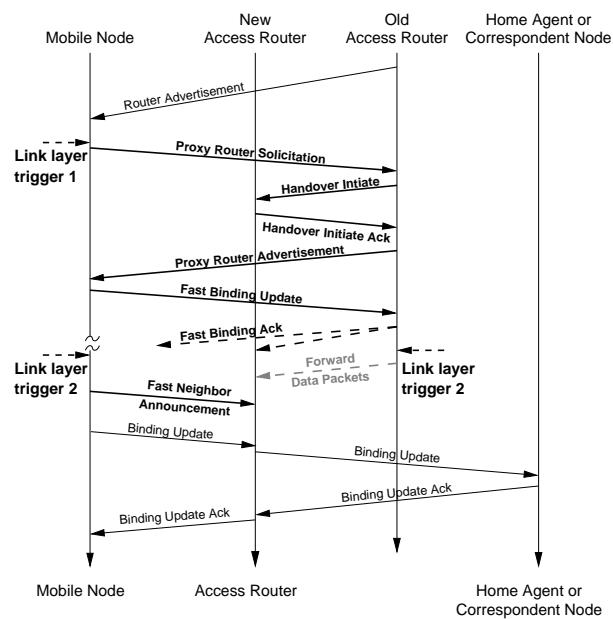
In the *mobile triggered and initiated handover* scheme (Fig. 5.1(a)), the mobile node has predictive information about the new access router to which it will move while it has still connectivity to the old access router. When the mobile node receives a link layer trigger it initiates signaling to the old access router by sending a *Proxy Router Solicitation* message. The old access router exchanges messages with the new access router in order to obtain<sup>1</sup> a new care-of address: The old access router sends a *Handover Initiate* message to the new access router that replies with a *Handover Ack* message containing the new care-of-address. Then, the new access router sends a *Proxy Router Advertisement* message. As soon as the mobile node receives the advertisement indicating the new care-of-address, the mobile node sends a *Fast Binding Update* message to the old access router using its new care-of-address and executes a link layer handover. On reception of the *Fast Binding Update* message, the old access router creates a temporary bi-directional tunnel and starts forwarding packets towards the new care-of-address of the mobile node via the tunnel. Finally, the old access router sends a *Fast Binding Ack* message to via the new and optionally the old link of the mobile node. In order to complete the handover, the mobile node sends a *Fast Neighbor Advertisement* to the new access router and announces its arrival. To complete the process of establishing the new care-of-address on the new access router, the mobile node sends a *Binding Update* message to its home agent or correspondent nodes.

In the *network triggered and initiated handover* scheme (Fig. 5.3(b)), the old access router receives a link layer trigger that the mobile node is about to move to the new access router. Unlike the *mobile triggered and initiated handover* scheme, there is no need to send a *Proxy Router Solicitation* message. Instead, the old access router sends a *Proxy Router Advertisement* message after it has received the link layer triggered and exchanges information with the new access router about the new care-of-address of the mobile node.

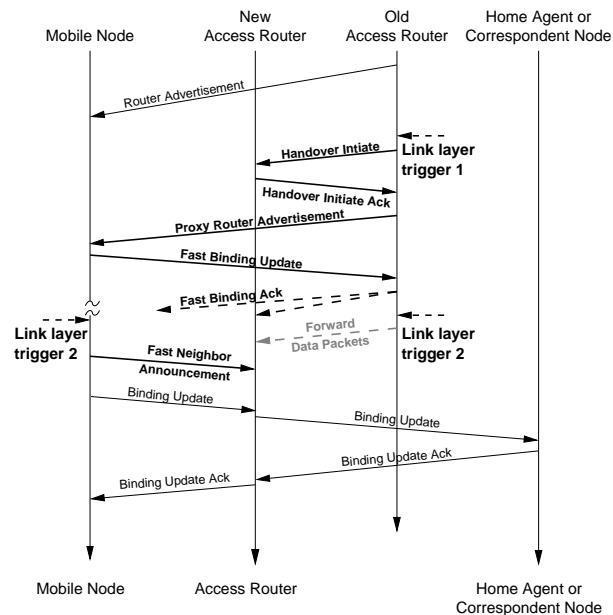
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<sup>1</sup>or validate

Both schemes require two types of link layer trigger. The first trigger, either at the mobile node or at the old access router, indicates that the mobile node is about to move. This trigger must occur enough in advance so that it is possible for the old access router to exchange a *Handover Initiate* and *Handover Initiate Ack* message, and to send a *Proxy Router Advertisement* message. The second type of link layer trigger informs the network layer of the particular node that the new link is up. In both cases, the link layer trigger includes also the IP address of the new access router.



(a) Mobile triggered and initiated



(b) Network triggered and initiated

Figure 5.3: Timeline for anticipated, link layer triggered handover in Mobile IPv6

### 5.3.2 Fast Handover in Mobile IPv6: Tunnel-Based Handover

In the *tunnel-based handover* scheme, the mobile node defers the network layer handover process until it is on the new access router, or possibly later. The old access router tunnels data packets to the mobile node by using its old care-of-address until the mobile node executes a regular handover at the network layer. If the mobile node executes an additional handover prior having completed the handover at the network layer, the tunnel is moved by the old and the new access router to accommodate the mobile node's movement.

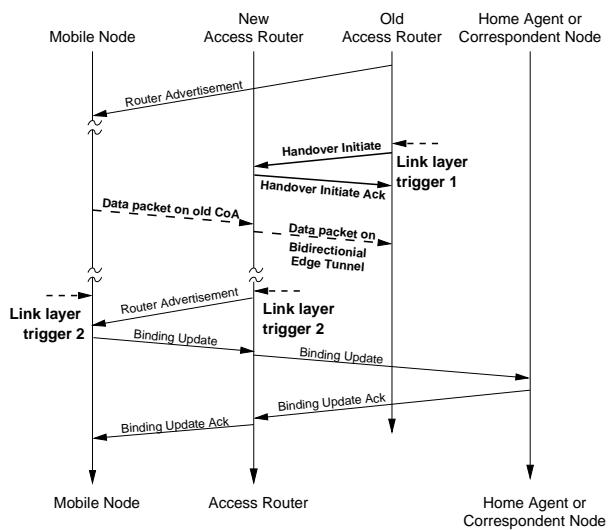
In the tunnel-based handover scheme, a link layer trigger is used to set up a bi-directional tunnel between the old and the new access router. The tunnel enables the mobile node to send and receive packets using the old care-of-address though the address might be topologically incorrect on the new sub-network. For the tunnel-based handover scheme, two case can be distinguished: Either the handover is triggered by the old access router (Fig. 5.4(a)) or by the new access router (Fig. 5.4(b)). A mobile node trigger and initiation is not considered.

In the first case (Fig. 5.4(a)), the old access router receives a link layer trigger that the mobile node is about to move (*Link layer trigger 1*). The link layer trigger contains the mobile node's link layer address and an IP address for the new access router. The old access router sends a *Handover Initiate* message to the new access router. The new access router replies a *Handover Initiate Ack* message and a bi-directional tunnel between both routers is set up. Then, the mobile node starts the link layer handover. The start of the link layer handover is indicated as a link layer trigger at the mobile node itself as well as at the old access router that the link is broken (*Link layer trigger 2*). Then the old access router starts forwarding packets destined for the mobile node via the bi-directional tunnel to the new access router. The completion of a link layer handover is indicated at the mobile node and the new access router as a link layer trigger that the new link is available (*Link layer trigger 3*). On reception of this trigger, the new access router starts delivering packets to the mobile node and forwards outbound packets from the mobile node to the old access router. The mobile node can decide to initiate a handover at network layer by exchanging a *Binding Update* message and *Binding Update Ack* message with the home agent. This means that the mobile node receives a new care-of-address that is topologically correct and the bi-directional tunnel between the old and the new access router is torn down.

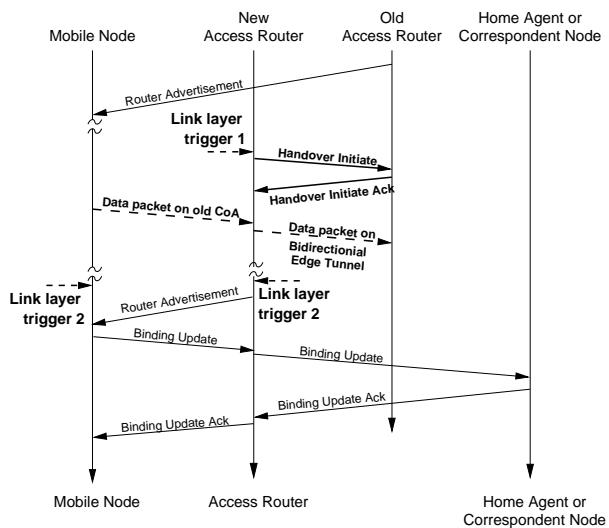
In the second case (Fig. 5.4(b)), the new access router receives a link layer trigger containing the mobile node's link layer address and the IP address of the old access router (*Link layer trigger 1*). The start of a link layer handover is indicated by a link layer trigger at the mobile node and the old access router (*Link layer trigger 2*). Similar to the first case (Fig. 5.4(a)), a bi-directional tunnel is established between the old and new access router. The completion of the link layer handover is indicated again by a link layer trigger at the mobile node and the new access router that the link is available (*link layer trigger 3*). The new access router starts forwarding packets to the mobile node tunneled from the old access router and starts tunneling packets from the mobile node to the old access router. The bi-directional tunnel is torn down, when the mobile node executes a handover at the network layer by exchanging a *Binding Update* message and *Binding Update Ack* message with the home agent via the new access router.

In both schemes, the link layer triggers are different. For a handover initiated by the old access router, the first link layer trigger indicates that the link decays. When the handover is initiated by the new access router, the link layer trigger indicates that the new link is up. However, it is common in both cases that the link layer trigger includes the MAC address of the mobile node and the IP address

of the old or new access router.



(a) Triggered and initiated by old AR



(b) Triggered and initiated by new AR

Figure 5.4: Timeline for fast link layer triggered handover in Mobile IPv6 with tunnel-based handover

## Chapter 6

# Application Programming Interface (API) for Link Layer Triggered Handover

An API is a set of functions and definitions, such as a set of *primitives*, that can be mapped to various software and hardware implementations. An API for link-layer triggered handover can be considered as a virtual interface between device driver and network protocol stack. An API hides implementation details from higher layer functionality. In what follows, the requirements for such an API are described and existing APIs with respect to their utilization for link layer triggered handover are evaluated.

### 6.1 Requirements

In addition to the general requirements, such as packet transport, asynchronous behavior, plug- and play support, support of multiple instances of drivers, and power-management support, the use of link layer information for wireless interfaces have specific requirements. In particular, these requirements are:

- General requirements of link layer trigger for handover
  - Specific issues for device configuration (e.g. channel selection, to force a link layer handover to a certain access point)
  - Switching between non-promiscuous and promiscuous mode,
  - Fast information about link status and MAC addresses
- Specific wireless information
  - Link up/down
  - Signal strength/BER
  - SIR

## 6.2 Evaluation of Existing APIs

The following existing APIs have been selected:

- Rooftop
- Network Device Interface Specification (NDIS)
- Linux Wireless Tools

### 6.2.1 Rooftop API

The Rooftop<sup>1</sup> API [1] is a framework for wireless communication in IP-based networks. The framework includes a *Link API*, *Radio Device API*, *Support for Time-Synchronized Radios*, *Smart Antenna API*, *Physical Radio Interface Specification*. It is intended to

- Offer a platform-independent language and methodology that defines an interface between *upper* and *lower* modules in a system,
- Provide standard methods for permitting module-specific extensions,
- Facilitate porting of various modules among multiple platforms.

The Rooftop *Link API* offers a number of wireless statistics, such as percentage of successful packets, the time to deliver a packet, the perceived link capacity, and the interference factor for this link.

The Rooftop API is implemented in several devices, such as Nokia wireless routers<sup>2</sup> and wireless Internet gateway (WNR)<sup>3</sup>.

### 6.2.2 Network Device Interface Specification (NDIS)

NDIS stands for Network Driver Interface Standard. Originally, NDIS was a joint effort by 3Com and Microsoft, while continued the development of the NDIS to an industry de-facto standard. Since then, NDIS is an integral part of all *Windows* operating systems and all Windows compliant network adapters are shipped with NDIS compatible drivers. In fact, a NDIS *specification* does not exist and is basically a description of the NDIS functions and API in Microsoft's Device Driver Kits (DDK) for a specific operating system. However, the implementation of NDIS varies, depending of the Windows system and version.

The actual NDIS version (Microsoft Windows 2000 and later versions) differentiate between four types of kernel-mode drivers: A *miniport driver* directly manages a network interface card and provide an interface to higher layer drivers. An *intermediate driver* interfaces between upper level *protocol drivers*, and a miniport driver. A *protocol driver* implements transport functionality, or an application-specific interface. Finally, *filter hook drivers* are used to filter packets.

The NDIS specification is widely deployed, and drivers for many different types of devices exist. However, wireless-specific extensions of NDIS drivers for wireless network cards do not yet exist

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<sup>1</sup>Now Nokia Wireless Routers

<sup>2</sup><http://www.nwr.nokia.com/solution/index.html>

<sup>3</sup>[http://bobcat.spawar.navy.mil/hdrlos/draft\\_refdocs/AWTOct98Review.pdf](http://bobcat.spawar.navy.mil/hdrlos/draft_refdocs/AWTOct98Review.pdf)

nor wireless extensions are envisaged for the near future. Moreover, due to the modularization of the driver the access to low-level functionality is more difficult, since the parameters must be mapped in each driver module.

### 6.2.3 Linux Wireless Tools

In principal, the *Linux Wireless Tools* [16] implement a wireless API for the Linux operating system. The toolkit provides a set of parameters for wireless interfaces, the methods to access the parameters (pre-defined kernel system calls *ioctrl*) as well as user interfaces (*iwconfig* for the configuration of the interface and *iwspy* to get wireless statistics).

The *Linux Wireless Tools* are open software under the *GNU Public License*. They are implemented for Linux kernel 2.0.x and later, and are included in many Linux distributions. Several Linux-based Mobile IP implementations make use of the *Linux Wireless Tools*, e.g. the Dynamics Mobile IPv4 implementation by HUT<sup>4</sup>. The *Linux Wireless Tools* provide support for a number of wireless devices, mostly wireless LAN type devices. The device driver offers the following information for a wireless device:

- Status
- Quality - link (general quality of reception)
- Quality level (signal strength at the receiver)
- Quality - noise (signal strength without reception of a packet)
- Discarded - nwid (number of discarded packets due to an invalid network identifier)
- Discarded - crypt (number of packet unable to decrypt)

### 6.2.4 Comparison

In table 6.1 the selected APIs are compared with respect to their use for link layer trigger.

	<b>Rooftop</b>	<b>NDIS</b>	<b>Wireless Tools</b>
Wireless extensions	Yes	No	Yes
Type of wireless interfaces	Wireless interfaces	General network interfaces	Wireless LAN type interfaces
OS dependent	No	Yes (Microsoft OS)	Yes (Linux)
Evolves with new wireless interfaces and technologies	Easy	Difficult	Easy
Distribution	Small	Large	Small

Table 6.1: Comparison of APIs

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<sup>4</sup><http://www.cs.hut.fi/Research/Dynamics/>

## Chapter 7

# Summary and Conclusions

The technical report examines handover trigger from the link layer to the network layer. These link layer trigger augment existing network layer trigger, for example based on the lifetime of network layer advertisements. Link layer trigger shorten the time for handover detection and therefore decrease the overall service interruption caused by handover. First, potential parameters for service interruption has been discussed and it turned out that the signal-to-interference ratio and the combination of signal strength and bit-error-rate offer an appropriate information about link layer status for a wide range of network interfaces. While it is sufficient to provide the basic Mobile IPv6 and Hierarchical Mobile IPv6 with information about *link up* and *link down*, the protocol extensions for fast handover in Mobile IPv6 require a link layer trigger in advance of a handover in order to execute an anticipated handover based on the SIR or combined signal strength/BER. For such handover schemes, a link layer trigger can rapidly inform the network layer of a decaying wireless link. However, the variety of wireless technologies and wireless interface card makes a parameterization of thresholds necessary. Due to parameterization of the assessed values, a comparison is possible and a handover trigger even between different technologies is possible.

Considering existing application programming interfaces for interaction between link layer and network layer, it can be summarized that the widely deployed *NDIS specification* for network drivers in Microsoft operating systems offers an abstract interface, but does not include wireless-specific extensions yet. Moreover, the modularized structure of the drivers makes an extension difficult. However, the *Rooftop API* and the *Linux Wireless Tools* are examples for wireless-specific driver extensions that can be utilized for handover trigger from link layer.

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