Influence of Velocity on the Handover Delay associated with a Radio-Signal-Measurement-based Handover Decision

Marc Emmelmann
Technical University Berlin
Telecommunication Networks Group TKN
Berlin, Germany
Email: emmelmann@ieee.org

(Extended Version)

Abstract

Velocity has a non-neglectable influence on the handover delay experienced by a user if the handover is triggered on a radio-signal-measurement (RSM) based handover scheme. Assuming currently used RSM schemes employing signal averaging (low-pass filtering) and a hysteresis margin, the analytical description of the delay is derived as a function of the velocity. The latter is used to determine the minimal overlapping of two adjacent radio cells required for a seamless, i.e. interrupt-free handover. Results show that the required overlapping for a zero-delay handoff does not scale with the handover frequency. Especially for small radio cell sizes, the overlapping may easily exceed 60% of the cell's diameter. The improvement gained by dynamically adapting RSM-scheme's parameter, i.e. the hysteresis margin, to the current velocity is neglectably small. Hence, a RSM-based handover decision is not suitable for high handover frequency scenarios and should be supported by other handover trigger mechanisms.

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I. INTRODUCTION

Upcoming wireless local area networks (WLANs) will provide throughput rates of several 100 Mbit/s [2] or even push this limit even beyond 1 Gbit/s. [1] As these future networks cannot infinitely increase the emitted radiation power, the coverage area of each WLAN radio cell will most likely shrink especially if higher frequency bands (e.g. the 30, 40, or 60 GHz) are employed in order to provide these high data rates in the future. [1]

Along with the fact of extremely reduced cell sizes comes another challenge: to support user's mobility possibly at high velocities. In an office environment, attenuation may limit the cell size to only a few meter whereas in sub-urban or rural areas, the latter will most likely be larger by a factor in between 100 and 1000. In both cases, the dwell time of a mobile user in a cell may be in the order of only a few seconds which emphasizes the need for an efficient scheme providing a seamless handover: the interim in between the reception of two consecutive data fragments should be limited during an handover process as network providers and manufactures aim at providing VoIP services over WLAN as an alternative to "traditional" telephone systems. [3]

As the mobile's velocity influences the handover frequency, it is still an open issue if a seamless, i.e. interruption-free, handover is possible for any given velocity of a mobile user. The following analysis focuses on one aspect of the handover process: the decision when to switch from the old AP to the new one based on a radio-signal-measurement-based (RSM-based) decision scheme. Therefore, the discussion and the results are entirely *independent* of any employed MAC protocol. In particular, the influence of the mobile user's velocity, channel characteristics, as well as technological aspects of the radio signal measurement (e.g. low-pass filtering and applying a hysteresis margin in the decision process) are evaluated. Additionally, a special focus is set towards cellular radio networks with minimal overlapping radio coverage areas.

The paper will be structured as follows: Section II summarizes related work. Afterwards, Seciton III derives the analytical model of the handover delay and the overlapping of adjacent radio cells required for a seamless handover. Therefore, the underlying channel model is introduced (III-A). Afterwards, Section III-B presents the handover delay associated with the RSM-scheme, i.e. low-pass filtering and employing a hysteresis margin. The latter is used to determine the required overlapping for a seamless handover (III-C). Finally, Section IV discusses the results based on a high-speed train scenario (IV-A) as well as based on the handover frequency which is entirely independent of the application scenario. Effects of the hysteresis margin and the channel parameter are revealed and the possibility of dynamically adapting the hysteresis margin according to the velocity is evaluated (IV-B). Section V summarizes the results.

The detailed analytical derivation of the handover delay and required overlapping as well as an extended discussion of the results is available in form of a technical report. [4] [1]

II. RELATED WORK

Current research does mainly focus on the MAC and higher layers when analyzing handover delay. IEEE TGr recorded state-of-the-art 802.11 devices to cause a handover delay in between 1 and 10 s not including additional 3–14 s for the 802.11i 4-way handshake. [5]–[7] Even though scanning is the predominant factor, handover decision criteria and physical layer aspects are not investigated as the IEEE considers those to be implementation specific vendor issues. Analogously, with respect to a WCDMA network, 3GPP provides a model for a network controlled handover filtering [8] but does not constrain the effects, i.e. the implementation of the physical layer by the standard. [9] This leaves the focus on tuning MAC specific parameters involved in the handover process. [10]

As physical layer implementations are vendor specific, comparably few authors have elaborated so far the impact of mechanisms used in the physical layer on the handover delay. Zhang and Hoffmann show that the hysteresis margin and the signal threshold triggering the handover have an influence on the number of unnecessary handovers, but do not include the handover delay a.k.a. the connection interruption caused due to the employed decision mechanisms in their analyses. [11] First approaches to study the effects of signal averaging time and the hysteresis level on handover performance can be found in [12] and [13]. Even though the results indicate the influence on the handover delay, in order to derive their resutls, Zonoozi and Dassanayake imply to have knowledge on future, i.e., upcoming, radio signal strengths. Applying parameters describing the radio channel characteristics according to real world scenarios is still an open issue.

III. DERIVATION OF HANDOVER DELAY AND REQUIRED CELL OVERLAPPING

A. Channel Model

The underlying channel model represents an ideal AWGN channel. Literature commonly derives from this channel model

[1] A pre-version of the report is available via e-mail from the author.

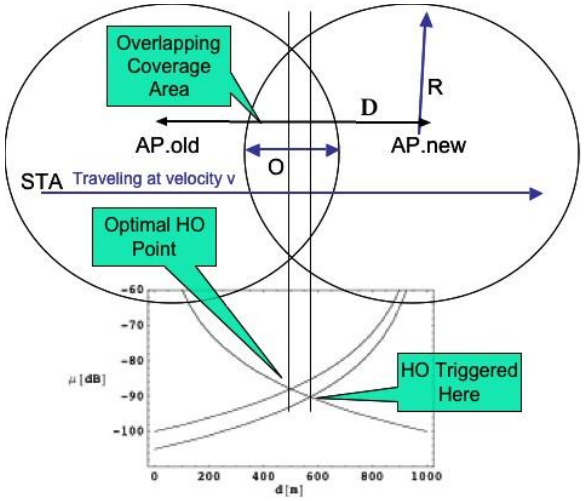


Fig. 1. Basic Handover Scenario

the signal power μ in [dB] received by a mobile from an access point to be $\mu(d) = K_1 - K_2 \log(d)$ where d is the distance of the mobile to the AP. K_1 represents the gain of the transmission and reception antennas as well as the wavelength dependent part of the channel model whereas K_2 represents environment-specific attenuation characteristics. [14]

Considering the relation in between the two access points AP.old and AP.new as illustraged in Fig. 1, the signal strength received from the respective AP can be expressed as

$$\mu_0(d) = K_1 - K_2 \log(d) \tag{1}$$
$$\mu_1(d) = K_1 - K_2 \log(D-d) \tag{2}$$

where D represents the distance in between the APs and d the distance of the mobile to AP.old.

B. Handover Delay

1) Low-Pass Filtering: In a wireless communication environment, rapid fluctuations of the received signal level may occur due to distortion or short-term shadowing of mobiles moving at high velocities. These effects are usually eliminated by calculating a sliding average over a number of past signal measurements. Such an averaging may be achieved by a causal, non-recursive low-pass filter which, for the time-continuous case, can be analytically described by

$$\mu_{i,avg}(d,b) = \frac{1}{b}\int_{d-b}^{d} \mu_i(x)\,dx \tag{3}$$

for $i \in \{0,1\}$ referring to the radio signal received from AP.old and AP.new correspondingly. The point at which the handover is triggered is described by

$$0 = \mu_{1,avg}(d,b) - \mu_{0,avg}(d,b) \tag{4}$$

which yields to the experienced handover delay

$$\delta_{avg} = \frac{d - D/2}{v} = \frac{T}{2} \tag{5}$$

assuming that the mobile moving with a velocity v needs $T = b/v$ seconds to overcome the averaging interval's distance b.

2) Hysteresis Margin: A hysteresis margin h is a commonly used approach to avoid an oscillation of the connection in between two adjacent APs if the radio signal strength of the received signals is almost the same. Accordingly, a handover is only triggered if the radio signal is as least h dB stronger than the old one

$$h = \mu_1(d) - \mu_0(d) \tag{6}$$

Applying Eq. (1) and (2), the associated handover delay δ_{hyst}, including its upper bound, is given by

$$\delta_{hyst} = \frac{d - D/2}{v} = \frac{D}{2v}\,\frac{-1+e^{h/K_2}}{1+e^{h/K_2}} \leq \frac{D}{2v} \tag{7}$$

3) Total Handover Delay: The effects of low-pass filtering and applying a hysteresis margin are independent of each other. Thus, the total handover delay is $\delta_{tot} = \delta_{avg} + \delta_{hyst}$ which is given by:[2]

$$\delta_{tot} = \frac{T}{2} + \frac{D}{2v}\,\frac{-1+e^{h/K_2}}{1+e^{h/K_2}} \leq \frac{T}{2} + \frac{D}{2v} \tag{8}$$

C. Required Cell Overlapping

The handover delay given in Eq. (8) assumed nearly zero overlapping of adjacent radio cells. As in reality, coverage areas overlap which is even a desired aspect in order to avoid an interruption of ongoing connections during the handover process. The following analysis derives the ratio in between the cell overlapping and the cell's diameter

$$p = \frac{O}{2R} \tag{9}$$

for which the experienced handover delay is zero (p_X if a delay of X seconds is an acceptable threshold).

The minimum required overlapping can be expressed as a function of the handover delay δ_{tot} given in Eq. (8). $O/2$ has to be at least as large as the distance travelled by the mobile within δ_{tot} according to its velocity v:

$$O/2 \geq v\,(\delta_{tot} - X) \tag{10}$$

Second, the cell's radius R can be expressed using the distance in between the access points d and with the overlapping zone O (ref. to Figure 1):[3]

$$R = \frac{D}{2} + \frac{O}{2} \tag{11}$$

Using Eq. (8), (9), (10), and (11), we obtain

$$\frac{Tv - D + 10^{h/K_2}(D+Tv)}{2^{(h+K_2)/K_2}\,5^{h/K_2} D + (1+10^{h/K_2})Tv} \leq p_X \tag{12}$$

for which an upper bound exists assuming a small overlapping region O compared to the distance in between the two APs, i.e. if $O \ll D$:

$$p_X \leq 1 - \frac{2}{1+10^{h/K_2}} + \frac{v(T-2X)}{D} \tag{13}$$

[2]The result resembles those presented in [13] even though the latter assumes knowledge on future signal strength levels which is unlikely to be found in an implementation.

[3]$D/2$ divides the overlapping zone into two equal portions.

IV. Discussion of Results

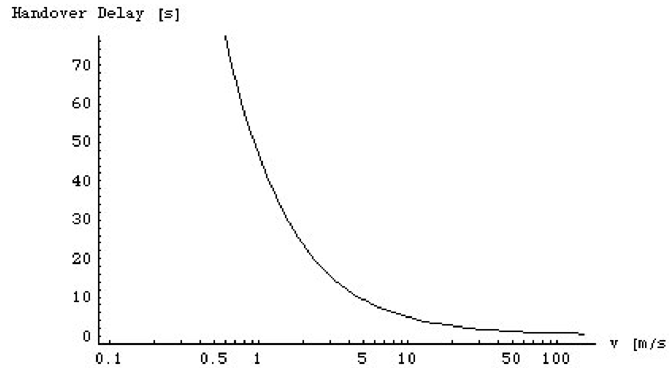
The discussion is twofold: First, parameters of a current project which develops a next generation WLAN system [1] including support for high speed vehicular systems (e.g.: the high velocity train Transrapid) will be applied to the analytical models. In a second step, application scenarios will be generalized by introducing the handover frequency associated with the user behavior for each scenario. Using the handover frequency, the influence of the hysteresis margin and the channel characterization parameter on the required cell overlapping guaranteeing a zero-delay handover will be discussed. Finally, the effect of dynamically adapting the hysteresis margin to the mobile's velocity is analyzed.

A. High Speed Train Scenario

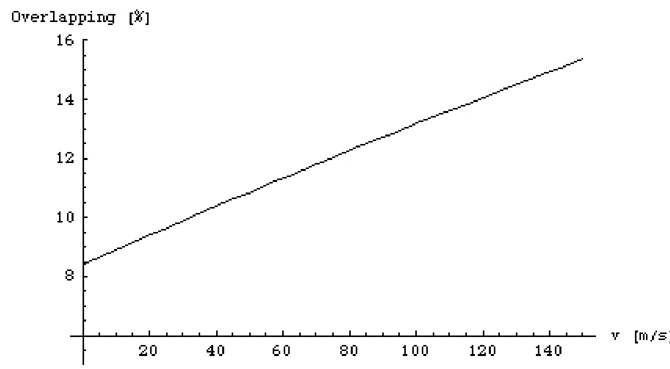
The WIGWAM project [1] develops a next generation WLAN providing 1 Gb/s throughput and supporting mobile users traveling at 500 km/h. The distance in between the base stations is $D = 1\ km$ and the channel is characterized with $K_2 = 50\ dB$. With respect to the hysteresis margin and averaging interval, $h = 4\ dB$ and $T = 600\ ms$ are typical values. [15] These parameters represent, e.g., a high-speed train scenario in which the WLAN is used to transmit signals controlling the train's engine or breaks. The security and availability constraints towards such a system are extremely high and yield to a zero handover delay requirement even if the overlapping region of adjacent radio cells is neglectfully small. This can be the case if due to whether conditions, i.e. heavy rain, the channel attenuation increases and the overlapping region shrinks.

Fig. 2 illustrates the decreasing experienced handover delay for higher velocities if the overlapping region of two adjacent radio cells is neglectfully small. The result is somehow expected since the mobile has to overcome a certain distance in order to recognize, according to its employed mechanism averaging the measured RSS, when the radio signal drops below the critical value necessary for successful communication. The faster the mobile travels, the shorter is the time needed to overcome this distance. Nevertheless, the handover delay is still around 630 ms for a velocity of 500 km/h which is unacceptable for a system requiring highest possible availability nor for a wireless network providing real-time voice services for which the IEEE considers 50 ms as a tolerable maximum delay. [16] Even though plotted, handover delays caused by a radio-signal-measurement-based handover decision are unlikely to exceed 45 s as given for a velocity of 1 m/s. Most likely, any upper layer handover decision scheme will employ a time-out less than 45 s which eventually will cause the mobile to scan for new potential access points if communication stalls.

In order to reduce the handover delay, the overlapping area of adjacent radio cells has to be increased. Supporting a maximal velocity of 500 km/h, an overlapping of at least 15% of the cell's diameter is required to make a zero-delay handoff possible (Fig. 2).[4] The latter does not drop below 8.4 %, even for extremely low velocities ($v \to 0$). For the envisioned application field in which extremely high availability of the wireless system is the predominant factor, both lower limits are hardly acceptable.



(a)



(b)

Fig. 2. High Speed Train Scenario: (a) velocity-dependent handover delay and (b) required minimal overlapping for seamless handover

B. High Handover Frequency Scenarios

In order to evaluate the limitations of a RSM-based handover decision scheme for different application scenarios, the latter are categorized by introducing the associated handover frequency

$$f \stackrel{def}{=} \frac{v}{D} \tag{14}$$

As f can be found as a genuine factor in Eq. (13) and Eq. (8), this relative velocity with respect to the cell's diameter classifies best the effects of the considered RSM-scheme on mobile users.

[4]Loss of connectivity is still possible due to MAC protocol specific signaling involved in the handover process but not unavoidably caused by the RSM-based handover decision scheme.

TABLE I
EXEMPLARY HANDOVER FREQUENCIES

Use Case	Cell Diameter D [m]	Mobile's Velocity v [m/s]	Handover Frequency f v/D [Hz]	Cell Trans. Time $1/f$ [s]
High Speed Train (e.g.: Transrapid)	1000	150	0.150	6.67
High Way	2000	40	0.020	50.00
	2000	20	0.010	100.00
	500	40	0.080	12.50
Pedestrian	1000	10	0.010	100.00
(outdoor)	500	10	0.020	50.00
	500	3	0.006	166.67
Pedestrian	30	6	0.200	5.00
(indoor)	30	3	0.100	10.00
	5	6	1.200	0.83
	5	3	0.600	1.67

1) Categorization of Use Cases: Apart from the just considered high-speed train scenario, vehicles moving on a high way, as well as pedestrians in an in- (office) and outdoor environment are considered. In addition, upcoming wireless network architecture are included to determine typical values for the handover frequency. The latter networks, e.g. radio-over-fiber systems [17], [18], tend to move towards smaller cell sizes as they aim at providing extremely high throughput using higher frequency bands, i.e. 30 or 60 GHz. These extremely small cell sizes require an optimized overlapping region as it minimizes the resources deployed for such a network. Table I lists the parameters assumed for each scenario.

Handover frequencies range in between 1 mHz and 1200 mHz. Expectingly, the smallest one is associated with a pedestrian user. So is the largest handover frequency. This is due to the fact, that an even extremely small velocity may cause a tremendously high handover rate while moving within buildings as the radio cell coverage within an office environment is rather small, sometimes even limited to a single room for, e.g., radio-over-fiber-based network architectures currently under research.

2) Influence of Hysteresis Margin and Channel-Characterizing Paramater: The handover frequency can be used to illustrate the required radio cell overlapping in percent of the cell's diameter as a function of h/K_2 (Fig. 3). Usually, hysteresis margins in between 3 and 5 dB are used and a radio channel describing parameter K_2 in between 15 and 50 dB is common. [13]–[15] The corresponding area of the plot in Fig. 3 is surrounded with a square. It illustrates that even for small handover frequencies, the required minimum cell overlap to guarantee a seamless handover has to exceed 15% whereas large handover frequencies, as experienced in a high speed train scenario but also in an office environment built of pico-cells, require an cell overlapping of at least 63%.

3) Dynamical Adaptation of Hysteresis Margin to the Mobile's Velocity: The previous results induce that a mobile should use a mechanism to estimate its current velocity

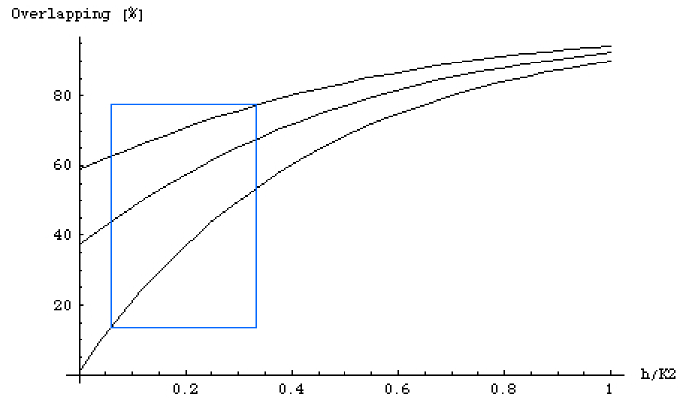


Fig. 3. Minimum Cell Overlapping (in % of cell diameter) for Zero-Delay Handover as function of h/K_2 (down to top: $f = 0.006$, 0.500, and 1.200 Hz; square surrounds results according to typical values of $h/K_2 \in [0.06, 0.33]$)

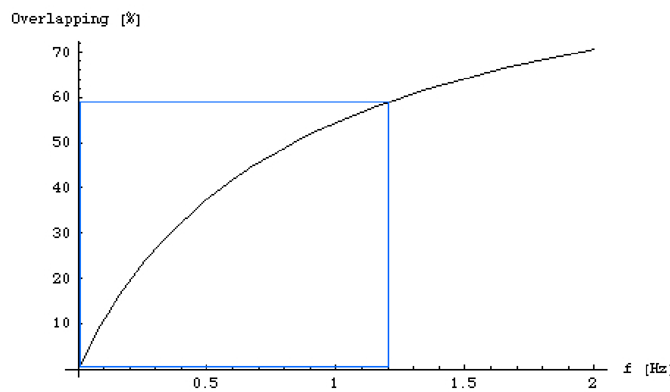


Fig. 4. Minimum Cell Overlapping (in % of cell diameter) for Zero-Delay Handover as function of Handover Frequency f ($h \rightarrow 0$; square surrounds results according to application scenario specific values of $f \in [0.006, 1.2]$)

(as described in [19]–[22]) in order to dynamically adapt the employed hysteresis margin h according to the speed as decreasing h would also reduce the overlapping region required for a seamless handover. This seems feasible, as for a mobile traveling at an increased speed, the latter is rather unlikely to reside for a significantly long period in an area where its connectivity could oscillate between two access points due to an experienced equilibrium of the received signal strength. Fig. 4 plots the requirement towards the minimum cell overlapping to enable a zero-delay handover for the limiting approximation $h \rightarrow 0$.

For extremely low handover frequencies, the required overlapping for a zero-delay handover can theoretically be reduced by one magnitude to 0.7% with respect to a static hysteresis margin. In contrast, the improvement is neglectfully small for application scenarios characterized by a high handover rate (decrease from 63% down to 59%). As large overlapping regions are predominantly required by the latter handover frequency, a dynamical adaption of the hysteresis margin according to the mobile's current velocity can only be suggested in a second or third iteration in order to optimize the handover delay associated with a RSM-based decision scheme.

V. SUMMARY

A. Conclusions

Analyzes shows that the handover delay and the minimal overlapping of adjacent radio cells required for a seamless handover depend on mechanisms employed in a state-of-the-art RSM-based handover decision scheme, namely low-pass filtering and employing a hysteresis margin. The effect of low-pass filtering is independent of the mobile's velocity. The speed at which the radio cell is traversed, the cell's diameter, and parameters characterizing the radio channel influence the delay and required overlapping if a hysteresis margin is employed.

A RSM-based handover decision does not scale well for highly mobile users being served by a radio network with relatively small cell sizes as the overlapping required for a seamless handover is inverse proportional to the cell's diameter and proportional to the mobile's velocity ($p \propto v/D$). Determining the handover frequency ($f = v/D$) for various application scenarios showed that a RSM-based handover decision scheme is not suitable for upcoming network architectures, e.g. radio-over-fiber networks, and does even has its limits on today's network architectures if the size of the radio cell's overlapping region matters in terms of cost and availability of the network.

Even though a dynamical adaption of the hysteresis margin according to the mobile's current velocity does theoretically reduce the handover delay a.k.a. the minimal overlapping required for seamless handover, the effects are neglect-ably small for usage scenarios characterized by a high handover frequency.

In consequence, we can state that a handover decision scheme based on radio-signal measurements employing averaging and hysteresis margins cannot provide optimal handover performance for all possible application scenarios. Especially in a cellular networks supporting handoffs at a high rate, which could be even the case for today's in-house wireless networks, one should refrain from using the analyzed handover decision scheme as the only, predominant trigger.

B. Future Prospects and Open Issues

The presented analysis leaves room for enhancements wrt.: employing other channel models; using time-discrete, digital signal averages; and a hysteresis margin adapting itself according to the interim in between the last handover and the current measurement.

Especially for the scenarios considering a high handover frequency, handover triggers which do not solemnly depend on a RSM-based decision scheme should be investigated. These schemes could for example entirely refrain from using a RSM scheme which averages radio signal strength measurements over a time period. Instead, e.g., the handover decision could be based on a cross correlation function applied to radio signal strength measurements belonging to two adjacent access points.

In addition, mechanism in which the network itself gathers and provides information on the link quality (e.g. as currently discussed by IEEE 802.11k [23]) could be used as handover triggers. But the influence of the mobile's velocity on the latter's performance is still an open issue.

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