Improving Vertical Handover Performance with PHY-Mode Recommendations based on localized Link State Measurements

Daniel Bültmann, Matthias Siebert, Jijun Luo

***Abstract*— Cooperation amongst heterogeneous mobile radio systems will be an indispensable feature of 'beyond 3G'. One key mechanism thereby serving as enabling technique for system integration will be the Vertical HandOver (VHO) between different radio networks. Optimal handover control thereby is very important for which the present paper investigates the possibilities of handover optimization by providing mobile terminals with additional information about the target system. This includes prediction of the expected link quality and additional cell information such as the best modulation and coding scheme to use. Exploitation of available data will improve handover latency as well as overall system throughput.**

***Index Terms*— System Integration, Vertical Handover, Link Adaptation, Coverage Detection**

I. Introduction

FOLLOWING the evolution from 2G, over 3G and beyond, one will realize that the immanent drivers for this development are the users' basic needs for mobility and communication. The Always Best Connected dogma will be of great importance for mobile users in the future. It is not very likely that one single system will ever be able to deal with all demands of modern communication: Quality of Service requirements, security, maintainability, operation and deployment costs, spectrum scarceness, convenience, politics and health are only a few aspects that cannot all be optimized in parallel due to their partly contradictory objectives. Instead, the cooperation and bonding of dedicated technologies, each of which optimized for a specific task, entails a promising alternative.

This paper investigates new means to improve vertical handover performance by providing external handover triggers to mobile terminals that carry additional information on the target system, like an initial PHY-Mode recommendation (for WLAN), or the cell scrambling code (for UMTS). This additional information is provided by the Hybrid Information System (HIS) described in [4]. The basic idea is illustrated in Figure 1. Feeding clients provide position-based link quality measurements to the HIS that are stored for further evaluation to a database. Based on this data the HIS can provide information to information clients, such as vertical handover recommendations link quality prediction and additional information on further available communication systems.

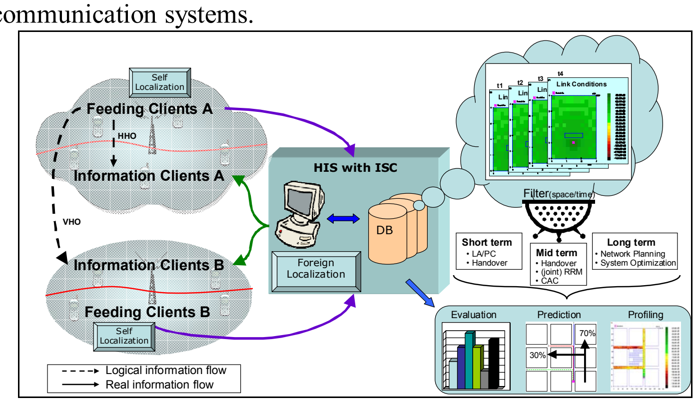

Figure 1: Vertical Handover Control using the Hybrid Information System

It was shown in [5] and [6] that it is possible to generate vertical handover triggers using position-based measurements. This paper goes one step further and investigates the improvement when the mobile terminal is given an initial PHY-Mode recommendation for the target cell based on the link state maps of the HIS.

II. Measurement Reports in WLAN 802.11

For the transport of system information between terminal and base station it is reasonable to use formats, which are already standardized. While in GSM and UMTS a lot of measurement procedures are defined, the legacy WLAN 802.11 standard does not provide any of this. However, having realized the enormous

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importance of feedback signaling, additional standard supplements have been specified. Supplement standard 802.11h [1] introduces some basic measurement and reporting structures. Nevertheless, this supplement does not define any inter-RAT measurement procedures. Hence, there is no standardized way of performing a handover from WLAN to other cellular mobile radio networks.

Instead, the extension 802.11h concentrates on dedicated procedures for system inherent spectrum management. Here, the focus is on two services: Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC). For either, a transfer of measurement data to the access point is considered. IEEE 802.11h specifies *Basic Reports*, *Clear Channel Assessment* (CCA) *Reports* and *Received Power Indicator* (RPI) *Reports.* Additional measurement and reporting procedures with respect to radio measurements such as *Channel Load Report*, *Noise Histogram Report*, *Beacon Report*, *Frame Report*, *Hidden Node Report*, *Medium Sensing Time Histogram Report* or *Station Statistics Report* are specified in IEEE 802.11k [2].

The aim of this paper is to derive an accurate algorithm that allows for initial PHY mode recommendation during vertical handovers. For the here considered case, the exploitation of RPI histograms is appropriate. To compile an RPI Histogram report, the observing station performs measurements during well defined measurement durations. For the whole measurement duration, the measured RPI is classified in one of the 8 levels according to [1]. In the end, the fraction of time for each level can be evaluated and reported.

A simple propagation model according to equation (1) is applied. Due to averaging in the time domain, effects like fast fading are considered to be averaged. The received signal power Pr is calculated as follows:

$$P_r(d) = \begin{cases} P_s \cdot g_s g_r \left(\dfrac{\lambda}{4\pi d_0}\right)^2 & d \le d_0 \\ P_s \cdot g_s g_r \left(\dfrac{\lambda}{4\pi d_0}\right)^2 \left(\dfrac{d_0}{d}\right)^{\gamma} & d > d_0 \end{cases} \quad \text{for fixed } d_0 = 1m \qquad (1)$$

Ps is the transmit power which was chosen to 100mW. No antenna gain was considered such that $g_{s,r}$ have been set to 1. λ is the wavelength and d is the distance between sender and receiver. The reference distance d_0 is chosen to 1m. Realistic values for γ are between 2 for free space propagation and 5 for strong attenuation. Here a value of 2.4 is chosen.

As described, one means to gather measurement reports according to 802.11h is the Received Power Indicator (RPI) histogram. Figure 2 shows these RPI levels as a function of distance assuming free space propagation. A transmitting AP thereby is assumed at position 0 meters, while a receiving station being X meters away would recognize the respective RPI level.

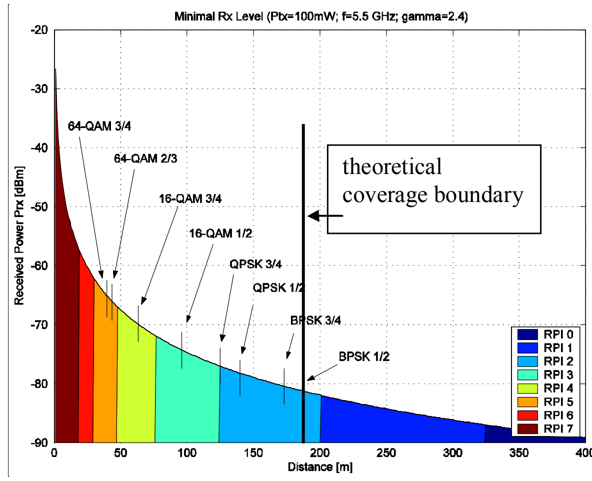

Figure 2: RPI levels for simple propagation model and sensitivity borders for PHY-modes

Each combination of modulation and coding scheme (PHY Mode) requires a minimum sensitivity for successful reception. The according thresholds are shown in Figure 2, too.

The resulting boundaries are best-case boundaries. Interference significantly decreases the distances, which may be supported by a given PHY-Mode. As can be seen from Figure 2, MR which include measured RPI levels to the access point of at least RPI 2 indicate that transmission is just possible applying BPSK1/2. Due to the minimum sensitivity requirement as specified in [3], the coverage area of a cell is bounded by a sharp theoretical maximum distance. However, real radio conditions certainly will feature by a fuzzier cell border.

III. Impact of Selecting inappropriate PHY Modes

To investigate the impact of selecting inappropriate PHY Modes when performing vertical handover towards 802.11 the scenario depicted in Figure 3 was evaluated. Four mobile terminals have been placed within the area covered by the 54 Mbit/s PHY Mode. These mobile terminals offer generate load in the order of the cell's capacity limit. A fifth mobile terminal enters that cell at different distances to the AP. This mobile transmits using the highest supported PHY Mode at that position. That way each entry PHY Mode was investigated by evaluating the overall system throughput.

Table 1 shows the services that mobile terminals use during this simulation along with resulting offered load. Each of the centre mobile terminals maintains a Voice over IP/Audiostream connection plus file transfer with high load requirements. The arriving mobile terminal is assumed to enter the cell maintaining a Voice over IP/Audiostream connection started in UMTS. Additionally it starts a file transfer as soon as it enters the cell. There is no mobility within this scenario, all stations are fixed.

Table 1: Scenario Service Parameters

Service	Bit rate Uplink	Bit rate Downlink
Centre Mobile		
VoIP/Audiostream FTP	128 kbit/s 64 kbit/s	128 kbit/s 5000 kbit/s
Entering Mobile		
VoIP/Audiostream FTP	128 kbit/s 64 kbit/s	128 kbit/s 1152 kbit/s

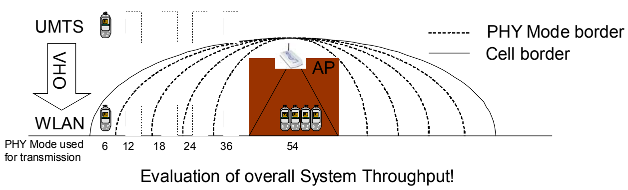

Figure 3: Scenario for Evaluation of Throughput Loss

Figure 4 shows the reached downlink system throughput as a function of the entry PHY Mode compared to the system throughput reached without the mobile entering the cell. It can be seen that there is a significant impact on the reached system throughput when choosing low entry PHY Modes. A mobile terminal entering the cell with PHY Mode 6 reduces the reached system throughput (i.e. all connections including connection of the arriving mobile) by approximately 4 Mbit/s. Without the newly arriving terminal the reached system throughput was approx. 16 Mbit/s.

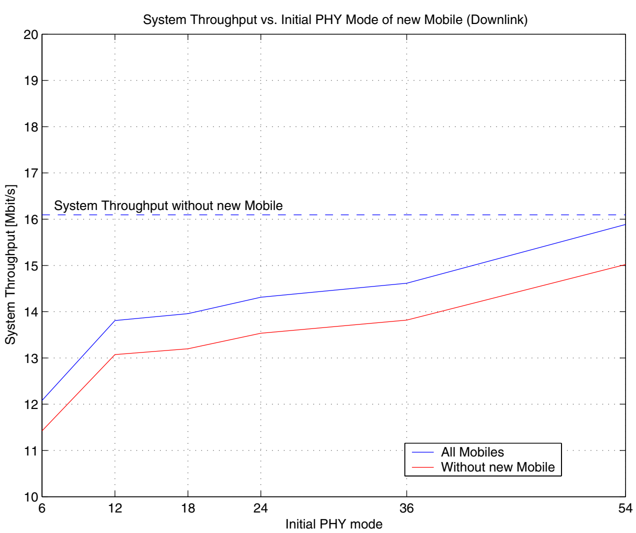

Figure 4: System Throughput Loss due to Disturber Mobile (Downlink)

System throughput decreases to 12 Mbit/s after the additional mobile terminal has arrived. Mobile terminals already communicating within the cell experience a loss of 4.5 Mbit/s. This is shown by the second curve denoting the reached system subtracted by the reached throughput of the entering mobile terminal.

As a result it can be stated that the cell capacity is most beneficially exploited, if VHO are triggered close to the cell centre. This shows that an initial PHY Mode recommendation made by the Hybrid Information System as will be described in Section IV makes sense in order to reduce unwanted throughput loss.

IV. HIS Assisted Link Adaptation

Measurement reports gathered by mobile terminals within a complementary communication system may be used to aid the link adaptation of mobile terminals performing vertical handovers towards that system. The Hybrid Information System is able to estimate the expected link quality in destination systems and to supply a recommendation for an appropriate transmission scheme along with the handover recommendation itself.

This chapter evaluates such an initialization method for 802.11 by means of simulation. The link adaptation implemented within the protocol stack simulator is modified to take a PHY Mode recommendation from the HIS. A Manhattan scenario is investigated where a mobile terminal enters the 802.11 cell from a shadowed area and initially may transmit data using the 24 Mbit/s PHY mode.

A. Description of implemented Link Adaptation Algorithm

The impact of initial PHY Mode recommendation by the HIS on system performance was evaluated by using a windowed Link Adaptation algorithm. The 802.11 control plane monitors the link state by keeping an history of received ACKs and NACKs. Whenever an ACK or NACK is received this information is stored to three different ring buffers to allow for distinction between short, mid- and long-term changes of the link state. These buffers are illustrated in Figure 5. It can be seen that whenever an ACK or NACK is received this information is put in first position of all three ring buffers.

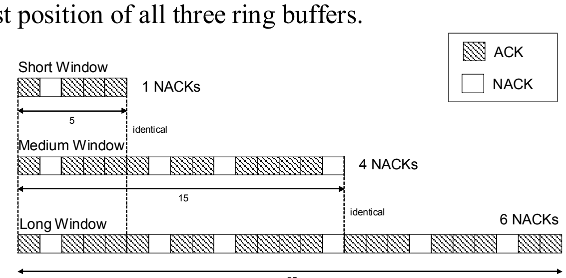

Figure 5: Windowed Link Adaptation Algorithm

Every time the ring buffers are updated a decision is made whether to switch to a higher PHY Mode, to a lower PHY Mode or to do nothing at all. This decision is found by calculating the ratio of NACKs within all windows according to:

$$R_{s,m,l} = \frac{N_{NACK_{s,m,l}}}{W_{s,m,l}} \quad (1)$$

Thereby $R_{s,m,l}$ denotes the ratio of NACKs within the respective window and $N_{NACKs,m,l}$ the number of NACKs found within that window. The window size $W_{s,m,l}$ is 5, 15 or 25. Only if all windows are filled the decision to switch to a higher PHY Mode is made by calculating a compound ratio R using:

$$R = \frac{5}{10}R_s + \frac{3}{10}R_m + \frac{2}{10}R_l \quad (2)$$

If this ratio is below 0.044 the PHY Mode is changed to the next higher one, if above 0.45 the PHY Mode is switched down. Otherwise no changes are applied. If windows are not completely filled only the short and medium windows are taken into account. If R_s is above 0.6 or R_m is above 0.4 the PHY Mode is switched down. Otherwise no changes are made.

To investigate the impact of PHY Mode recommendation on fast and slow Link Adaptation algorithms the window sizes used by this implementation were changed by multiplying the window size with a factor f. Figure 6 shows results of preliminary simulations carried out to determine the link adaptation dynamicity. The evaluated scenario consists of one mobile terminal communicating with the AP. Since the dynamicity of the link adaptation algorithm depends on the arrival rate of ACKs and NACKs the offered load was adjusted such that the channel is not able to carry all the traffic even when using the 54 Mbit/s PHY Mode.

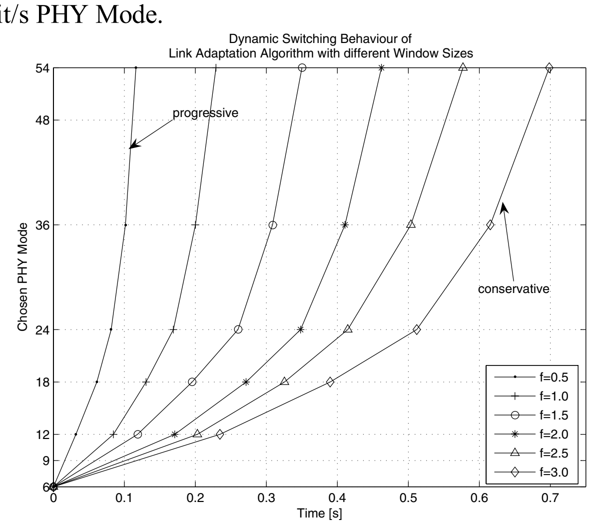

Figure 6 Speed of implemented Link Adaptation

Figure 6 shows the chosen PHY Mode over time for different window sizes as indicated by f. All six simulations start with an initial PHY Mode of 6 Mbit/s. It can be seen that the larger the window size is, the longer it takes to reach the 54 Mbit/s PHY Mode. The fast and slow switching characteristic is also referred to as progressive and conservative behavior.

B. Scenario Description

For evaluation of PHY Mode recommendations the Manhattan scenario as shown in Figure 7 was used. Four buildings have been placed around one AP. Table 2 gives an overview of the simulation parameters. One mobile terminal moves from behind the top left building into the coverage area of the AP and enters the WLAN cell. The link quality at that point is good enough to support a higher PHY mode than the lowest 6 Mbit/s PHY mode.

Table 2: Simulation Parameters

Parameter	Value
Size of Buildings	50x50 m
Street Size	25 m
Attenuation exponent γ	2.4
Wall attenuation	11.8 dB
802.11 Error Model	C/I Table based Random Error
Mobile Velocity	20 km/h
MR Interval	200 ms
Measurement Duration	10 ms

V. HIS ASSISTED LINK ADAPTATION

For the given scenario, the Hybrid Information System does not only trigger the optimum place of handover, moreover it may recommends an initial PHY mode by evaluating the stored link state maps within its databases. A detail of that map is shown in Figure 3. Link quality had previously been measured by feeding clients according to the Received Power Indicator (RPI) measurement type defined by IEEE 802.11h [2]. Highest link quality is available at the AP's position (lower right corner of Figure 8) and decreases to the left.

With respect to the minimal received power levels needed by each PHY mode, a conservative PHY Mode recommendation would be QPSK 3/4. This initial PHY Mode is sent to the mobile terminal during vertical handover.

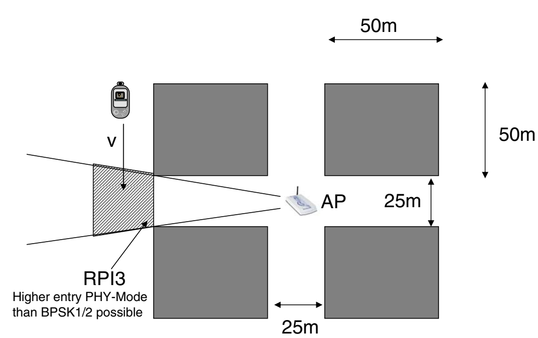

Figure 7: Scenario Description

For comparison this scenario was simulated for vertical handovers where no recommendation was made to the link adaptation algorithm. These mobile terminals initially start with the 6 Mbit/s PHY mode when entering 802.11.The link adaptation algorithm that is compared against is based on packet loss measurements averaged using different window sizes. The larger the averaging window the slower it reacts to link quality changes.

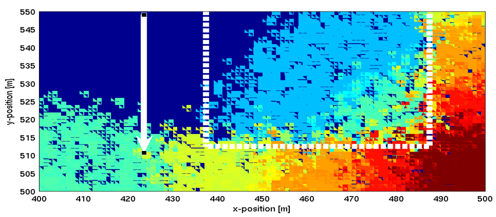

Figure 8: Contents RPI Measurements Database

To evaluate the gain of this the mobile terminal offers enough traffic upon entering the WLAN cell to congest the link to the AP. The gain of this handover schema can then be defined as the additional data volume that can be transferred in comparison to vertical handover schemes that do not recommend an initial PHY mode to the mobile terminal

Table 3: Additional transfer volume for initial PHY-Mode recommendation:

Longest Window Size of Link Adaptation	Additional Transfer Volume
25 (f=1)	56 kB
50 (f=2)	110 kB
75 (f=3)	156 kB

Figure 4 shows the throughput over time for this scenario. At time 0 the handover is triggered by the Hybrid Information System. The solid line shows the throughput in case the mobile terminal is given an initial PHY mode recommendation of 18 Mbit/s. The other curves show the throughput performance with no initial PHY-Mode recommendation for different LA algorithm speeds (f=1 progressive, f=3 conservative).

Table 1 shows the additional transfer volume that can be transmitted in the same time when using PHY-Mode recommendation.

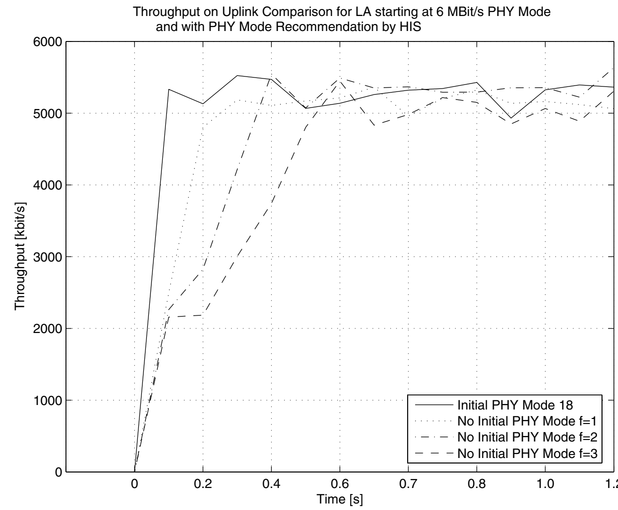

Figure 9: Throughput Gain for Initial PHY-Mode Recommendation

VI. SUMMARY

The Hybrid Information System can not only be used for handover decision making but is also able to provide mobile terminals with additional information to improve the quality of that handover. It was shown that the Hybrid Information System can support link adaptation by recommending an initial PHY mode to mobile terminals. The impact of selecting inappropriate PHY modes on cell capacity was analyzed and the benefit of the HIS assisted approach was evaluated for different speeds of a link adaptation algorithm.

REFERENCES

[1] IEEE 802.11h, February 2003. Draft Supplement to IEEE Std 802/11, 1999 Edition.

[2] IEEE 802.11k, "Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications Amendment 7: Radio Resource Measurement", D2.0, February 2005

[3] IEEE 802.11a, Draft Supplement to IEEE Std 802/11, 1999 Edition.

[4] Siebert, et al., "Hybrid Information System", Proceedings of IEEE Semiannual VTC2004-Spring, Milan, Italy, May 2004

[5] Siebert, Bültmann, Lott, "Inter-System Handover and Coverage Detection for 3G/WLAN Cooperation", In Proceedings of 11th European Wireless Conference 2005, p.p. 328-336, Nicosia, Cyprus, 04/2005

[6] Bültmann, Siebert, Lott, "Performance Evaluation of Accurate Trigger Generation for Vertical Handover", In Proceedings of 16th PIMRC 2005, Berlin, Germany