Enhanced Measurement Procedures for Vertical Handover in Heterogeneous Wireless Systems

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Abstract–**This paper presents an approach to realize integration of heterogeneous systems. Vertical Handover thereby is seen as a key feature to allow for interoperability. In order to properly perform handover decisions, interference information with respect to the target system need to be available. For this, dedicated scanning procedures are necessary causing problems if a mobile[1] is using continuous transmission and reception schemes like in UMTS FDD mode. To overcome this problem, different methods are mentioned, whereby a special focus is put on the compressed mode, since alternative means of making measurements are not yet considered within 3GPP. However, it is shown by means of simulations, that applying the compressed mode has a negative impact on the overall system performance. Therefore, another approach is introduced that relies on integrating measurement reports of other systems to support the VHO decision process. The proposal features by continuous operation during information gathering and facilitates reduced power consumption.**

I. INTRODUCTION

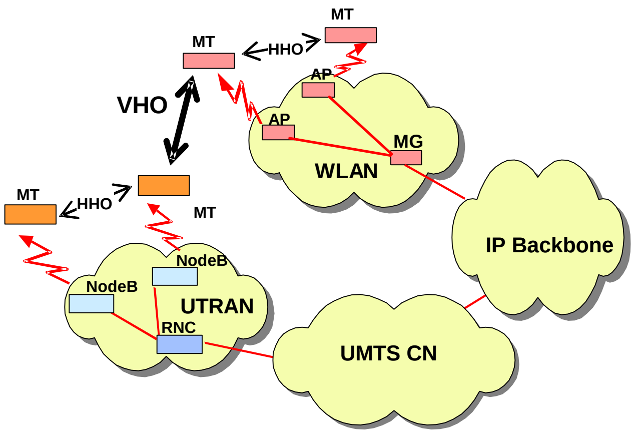
With the parallel deployment of 3G cellular networks like the Universal Mobile Telecommunication System (UMTS) and Wireless Local Area Networks (WLANs) like ETSI HiperLAN/2 or IEEE 802.11, the mobile user will face a variety of (additional) wireless services in the very near future. If it is possible to exploit the complementary character of both systems, the expected trunking gain promises to allow for an overall performance, higher than the accumulated performance of the stand-alone UMTS and WLAN systems. Respective efforts to integrate UMTS and WLAN are carried out in specific working groups, (e.g., of 3GPP and ETSI/BRAN) [1][2][3].

The following Section II introduces the challenges of system integration with focus on the vertical handover. A special question thereby is, whether the handover is network- or mobile driven and controlled. In the latter case, the mobile needs to have detailed information about the existence of a possible complementary system and conditions like interference, Received Signal Strength (RSS) and Bit Error Ratio (BER). For this, respective scanning procedures are necessary, which are presented in Section III. Since a mobile usually cannot scan another system during active association, Subsection III.A and B deal with methods to allow for necessary measurements without service interruption. Especially, the downward vertical handover from UMTS to WLAN and the application of the compressed mode are highlighted. It is shown in Subsection III.C that the application of the compressed mode may have a negative impact on the overall performance within the current system and therefore is not a preferable method for information gathering based on scanning. Thus, another solution of information gathering is proposed here, which is presented in Section IV. Finally, a summary and conclusion are given in Section V.

[1] Though the UMTS terminology for a mobile phone is *User Equipment* (UE) the notation *mobile* (phone) is used to express that the mentioned device is a multi-mode terminal.

II. VERTICAL HANDOVER IN HETEROGENEOUS SYSTEMS

A first step to realize interoperation between heterogeneous systems is to provide a framework for Vertical HandOver (VHO) execution. An exemplary VHO scenario is shown in Figure 1.



MT: Mobile Terminal; AP: Access Point
RNC: Radio Network Controller
MG: Mobility Gateway

Figure 1: Vertical Handover in a heterogeneous system environment

The successful execution of a (seamless and fast) VHO is essential for a satisfying operation of next generation heterogeneous networks, in which a user and the applied service should be as far as possible unaware of the underlying enabling infrastructure. Service continuation should be guaranteed in case of user movement between different network environments with as little intervention required from the customer as possible.

Issues related to VHO comprise HO triggers, protocol and architectural procedures, provision of system information, Quality of Service (QoS) signaling and scanning procedures. Specifically, the latter ones shall be focused on within this paper.

Depending on the driving network devices, responsible for initiation, decision, control, and execution of a VHO, a distinction between Network Controlled HandOver (NCHO) and Mobile Controlled HandOver (MCHO) can be made.

The NCHO is of special interest for an efficient resource management and particularly favorable, if the different technologies are maintained by the same operator. In this case an intersystem optimization can be achieved with the help of a central instance considering the overall performance of the whole system while keeping the complexity of the single terminal to a moderate extent.

If the HO is mobile controlled (MCHO), the user has the freedom to potentially select the most suitable standard satisfying his needs in terms of offered service, energy-consumption or reduction of possible charges.

If the involvement of the mobile within the HO decision process is of a less decisive nature and the terminal confines itself to providing link quality reports to the network, the term MCHO is replaced by MAHO (Mobile Assisted HandOver). However, regardless whether the mobile is a more active (MCHO) or passive (MAHO) element in the HO decision process, one earlier mentioned related issue always needs to be performed, which is the scanning of appropriate neighboring frequencies in the same, or in case of a VHO, in a different system.

III. Scanning in UMTS and WLAN

A basic requirement for interoperability between UMTS and other networks like the Global System for Mobile Communications (GSM) or WLAN is the possibility to detect and survey other networks. Scanning UMTS when registered in WLAN is supported by the inherent separation of users in the time domain arising from the Time Division Duplex (TDD) mode. E.g., in the HiperLAN/2 standard the absence procedure is defined to allow a terminal to perform measurements. It is used by the terminal to announce that it is temporarily not available. During this time, no data exchange between the terminal and the current Access Point (AP) is possible.

For UMTS, which supports both TDD and FDD (Frequency Division Duplex) operation, a respective distinction needs to be done: Due to the slotted access in TDD, a scanning of other frequencies, the other mode or another radio access technology is easily feasible during idle slots and therefore similar mechanisms as for scanning when registered in WLAN can be deployed. Against this, the FDD mode with its continuous reception and transmission scheme, offers no time slots for the mobile to switch to other frequencies for scanning.

To overcome this problem, different solutions may be applied like

- a second receiver for scanning,
- installation of a single wide-band receiver,
- establishment of a quasi-continuous transceiver scheme.

However, the aforementioned possibilities imply other drawbacks. A second receiver directly affects design characteristics like prize, size or power consumption. If instead a one-transceiver solution shall be realized, a possible realization would be the usage of a single wide-band receiver that receives not only the actual system frequencies but the entire contemplable band. However, this solution also suffers from extreme challenges, e.g. with respect to the supported dynamic range and sensitivity. Therefore, the third mentioned possibility looks most promising.

By establishing a quasi-continuous transceiver scheme, the continuous reception and transmission in FDD mode shall be relaxed to allow for scanning during created idle time-slots. One constraint for mobile communication systems thereby is that the current supplied data or speech service shall be maintained with as less restrictions as possible.

A. Compressed mode

A basic requirement for interoperability between UMTS and other networks like GSM or WLAN is the possibility to detect and survey a respective other network. To avoid the use of a second receiver or the complete disconnection in the home network the Compressed Mode (CM) [4][5] is employed. Thereby, the same information bit-rate as in normal operation is transmitted, but the actual transmission occurs only during a fraction of the radio frame. By compressing the data stream during a few slots, an idle period of at most 14 slots [6] can be achieved for the necessary intersystem measurements.

However, CM may not only be used for 'passive' behavior in terms of scanning during cleared away idle slots. CM may also be used for further functions such as HO support by information exchange/signaling with a new target base station during a transmission gap of the actual connection. Up to now, alternative means of making the measurements are not yet considered within 3GPP.

In the following, three compress-methods will be introduced and an influence on intra-cell interference is discussed.

B. Transmission time reduction methods

1) Puncturing: In UMTS rate matching is applied which repeats or punctures bits in the transport channel to fit in a physical channel. In the case of bit-repetition, e.g. 12,2kbps for speech in UTRA-FDD [7], the amount of data can easily be reduced by puncturing these bits.

2) Higher Layer Scheduling: Another possibility is the disposition of data e.g. in terms of scheduling by higher layers. By setting restrictions only a subset of the allowed Transport Format Combinations (TFC) is used. Hence, the amount of data for the physical layer is known and an idle gap can be generated.

3) Reducing the spreading factor: A last method to compress data and gain some idle time is to decrease the spreading factor by 2 (and double the transmitting power) around the gap. This can only be done if the spreading factor is more than 4 and a further power increase is feasible.

All these methods are depicted in Figure 2.

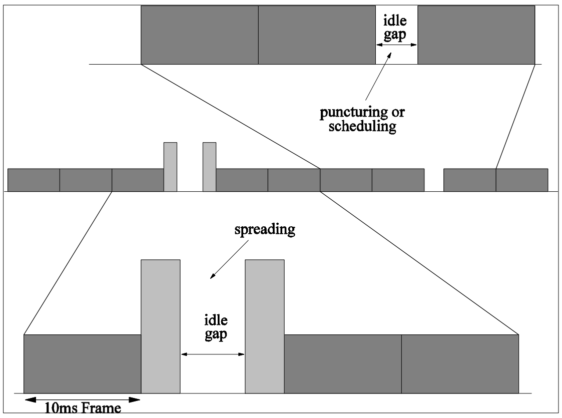


Figure 2: Compressed mode transmission

C. Influence of the Compressed Mode on the Interference

In the following, the influence of compressing data on the overall interference situation is investigated. Although three different methods of CM have been presented, the focus shall be put on reducing the spreading factor because if the spreading factor is reduced by e.g. 2, the transmission power has to be increased by 3dB. Thus, this compression may have a direct impact on other transmissions, since the overall interference in a cell is affected. Furthermore, power control as applied by other devices for compensation could lead to unstable system behaviors. To achieve the same link performance as without CM, puncturing forces the mobile to raise its transmission power, too. Hence, it will have a similar impact on the interference as reducing the spreading factor.

Within the following, a special focus shall be put on DL interference. To estimate the influence of CM on the overall DL interference, a cell with an omnipresent interference level, which is varied between I_o =-100dBm and I_o=-80dBm, is considered. In a first step, a scenario of two mobiles and a BS is considered. Since one mobile demands for idle periods to perform scanning, the supplying base station is expected to apply CM and thus increases the interference level temporarily (interferer) such that the other mobile's reception is respectively disturbed (victim). The path loss model for this scenario, a modified Okumura-Hata-Model for vehicular test environments, is taken from [9]:

$$L(R) = 128.1 + 37.6 \cdot \log(R)\,[\text{dB}], \qquad (1)$$

where R is the distance between victim and interferer in km and L is the resulting path loss in dB.

The interfering transmission initially has a fixed transmission power of P_{TxNorm}=-10dBm. Afterwards the interferer (BS) raises its transmission power to P_{TxCM} =-7dBm to allow for a CM transmission with a reduced spreading factor. The subsequent interference after increasing the transmission power

$$I_{CM}(R) = 10 \cdot \log\left\{10^{I_0/10} + (1-n) \cdot 10^{[P_{TxCM} - L(R)]/10}\right\} \qquad (2)$$

is compared to the interference while being in normal mode of operation

$$I_{Norm}(R) = 10 \cdot \log\left\{10^{I_0/10} + (1-n) \cdot 10^{[P_{TxNorm} - L(R)]/10}\right\} \qquad (3)$$

where n denotes to the "orthogonality" of the signals in the cell ($0 \le n \le 1$) and is assumed to be 0,7 for this investigation.

Figure 3 shows the interference deviation (I_{CM} -I_{Norm}) between these two modes with respect to the distance between victim and interferer, or more precisely between victim and base station since the DL is regarded here. For a distance of 50m, the impact is between 0,2dB and 2,5dB, depending on the background noise, which means that the influence of the CM cannot be neglected.

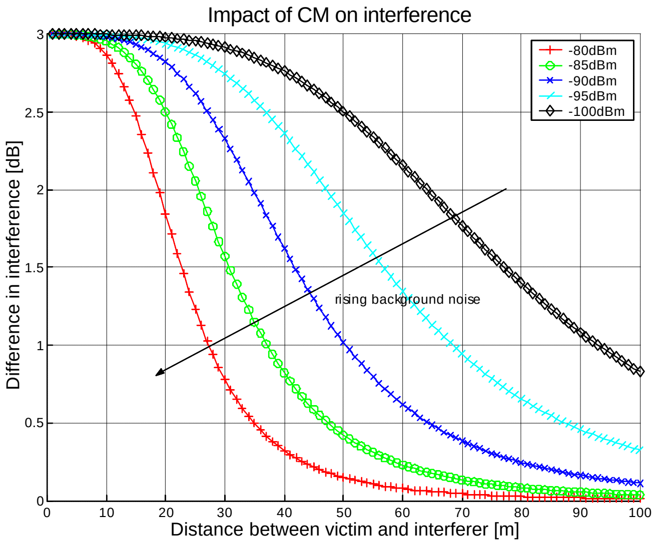


Figure 3: Interference increase due to Compressed Mode transmission (selected interference levels)

Moreover, one can see that the impact of the CM decreases with rising background noise. This is due to the fact that the fractal part of the overall interference caused by the application of the CM is outweighed by the influence of the background noise.

For the above investigations only one mobile applying CM was considered. The load in a cell was modeled by varying the background noise. However, an important component when it comes to interference calculations is power control in UMTS. Hence, to estimate the impact on the overall interference in a cell or respectively the DL transmission power, power control has to be taken into account.

The impact of the feedback of power control in conjunction with CM on the overall transmission power in DL in a UMTS cell is investigated with the help of the following scenario as shown in Figure 4.

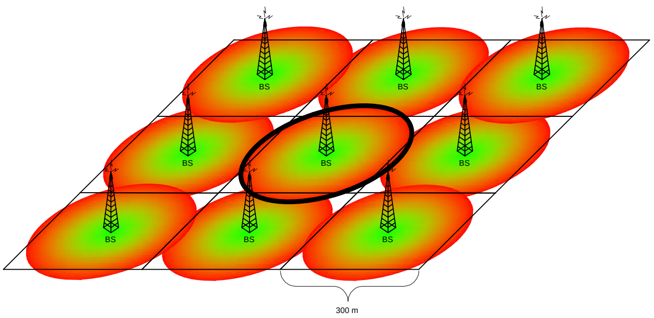


Figure 4: Simulation Scenario with evaluated cell in the middle, 8 interfering cells around

It is assumed an UMTS cell with an area of 300x300 meters. The cell is uniformly loaded, e.g. mobiles are uniformly distributed, resulting in an equidistant spacing between a mobile and its closest neighbor of 50m, which means a number of 48 mobiles in the cell. Inter-cell interference is modeled by eight surrounding cells with identical cell dimensions. Only continuous speech transmissions in DL are regarded. Therefore a C/I target of -18dB [11] at the mobiles is chosen. Since especially the feedback of power control on the varying interference is to be investigated in this scenario no mobility is applied to the mobiles.

The simulation is split into two phases. Within the first phase no CM is applied to the transmission and as matter of fact the mobiles will be in a stable equilibrium after a certain time. Subsequently the mobiles operate in CM as follows. Each mobile uses CM every 10 (5, 3, 2) radio frames corresponding to f_{CM}=10Hz (20Hz, 33Hz, 50Hz) with a transmission gap of 7 slots. As a result 10% (20%, 33%, 50%) of the users are in CM at the same time. The transmission power in the respective radio frame has to be increased by 3dB around the gap.

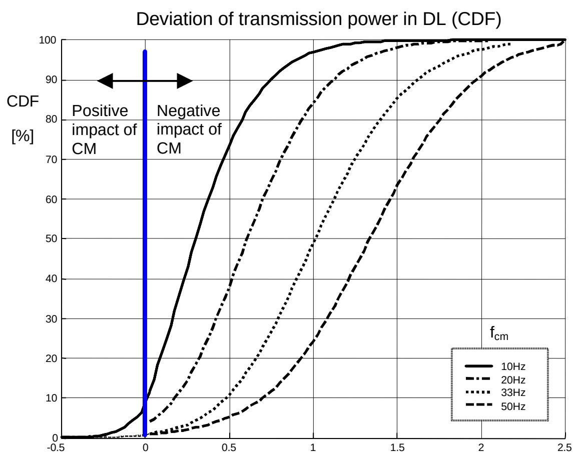


Figure 5: Power deviation due to CM application

Figure 5 depicts the cumulative distribution function (CDF) of the difference of the overall transmission power in DL with and without CM and for varying f_{CM}. Although the CDF is plotted from -0,5dB to 2,5dB, a minimum deviation of -0,62dB and a maximum deviation of 3,34dB have been evaluated, see Table 1, though with very rare occurrences. The mean difference computes between 0,36dB and 1,37dB, depending on how frequently the CM is used. As a result the mean interference in a cell will rise by the same amount if CM operation is applied. Note, that due to the nature of code division multiplex, the increase of DL transmission power for a certain connection directly affects interference as seen by other connections, for which these terms have been used equally in this context.

Table 1: Characteristic values if CM is introduced

f_{CM}	Mean deviation	Max deviation	Min deviation
10 Hz	0.36 dB	2.55 dB	-0.54 dB
20 Hz	0.66 dB	2.68 dB	-0.62 dB
33 Hz	1.06 dB	3.27 dB	-0.49 dB
50 Hz	1.37 dB	3.34 dB	-0.61 dB

Furthermore, the results indicate that depending on the variation of f_{CM}, up to 10% of the time the CM may also have a positive impact on the overall interference within the scenario. This is due to the fact that other links inherently benefit by the transmission gaps introduced due to CM application. Nevertheless, for at least more than 90% of the time, the overall interference gets worse.

Another important fact is, that though the percentage fraction of deviation values above 0,75dB amounts less than 10% for f_{CM}=10Hz (whereby this fraction increases up to 90% for higher values of f_{CM}), this impact cannot be neglected due to interference reasons on the one hand. On the other hand and even more problematic is the fact that for proper operation respective headroom corresponding to the maximum interference increase needs to be reserved for the terminals. In the scenario as examined here, this would correspond to a maximum value of 3,34dB in order to serve all mobiles. This in turn means that the cell coverage is reduced by the same amount or that the mobiles need a link-margin that is increased by approximately the respective maximum deviation.

Altogether one can say that CM, as a means to allow for scanning other systems, features by some positive and a number of negative aspects as listed in the following:

± no additional hardware needed;
± only so far foreseen means by 3GPP to allow for making measurements;
- complexity of changing specified FDD parameters;
- fast power control is interrupted due to CM gaps;
- part of interleaving gain gets lost;
- only applicable if not already working with maximum power and lowest spreading factor;
- mobiles' transmitters often need over dimensioning;
- causes additional interference.

Independent of the disadvantages of CM there are common drawbacks with scanning another system:

- additional power consumption for measurements;
- signaling of measurement reports if network controlled handover is envisaged;
- continuous standby not possible
- absence announcement necessary (when in idle mode).

Furthermore, if shadowing and mobility are taken into account the transmission power in DL might rise if CM shall be applied.

As a consequence, one can say that CM has several drawbacks with respect to scanning complementary (vertical) systems. Thus, there is a potential improvement in providing the respective information. A possible solution to this problem that avoids the aforementioned disadvantages is outlined in the following section.

IV. NEW APPROACH FOR INFORMATION PROVISIONING

Another way to gather information is to exchange data within the same or with other systems, see Figure 6 showing a high tier UMTS network encompassing a lower tier WLAN network. Information gathering within the same system is required for HHO, whereas for VHO information gathering between different types of systems is needed. Data exchange between systems offers a great economic potential since the scanning procedures can be minimized or even prevented.

The basic idea behind this approach is that each system collects data about the current state, i.e. interference distribution and location of mobiles within the covered cell, see (**1**) in Figure 6. Mobiles willing to change their association may request this information. Depending on the new target system, the mobile is supplied with state reports of the same system type (HHO) or a vertical system (VHO), cf. (**2**,**3**) in Figure 6, and subsequently may perform the (V)HO, see (**4**) in Figure 6. In such a way, the mobile benefits from measurements of another mobile of a different system. It is to note that the physical location of both mobiles is approximately the same. However, even for mobiles having only approximately the

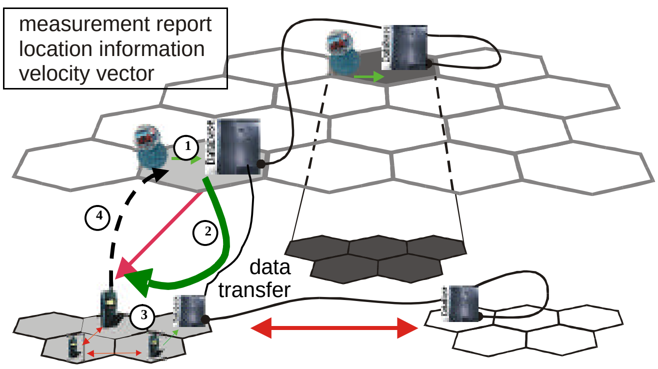


Figure 6: HO information data: Gathering and exchange between different systems

same positions it can be assumed that the interference level and long-term propagation conditions at both locations are correlated.

One could state, that this principle is only feasible for a sufficient high penetration of measuring mobiles within the target system, since otherwise no statement about the interference condition is possible. This is partly true on the one hand, but on the other hand a small penetration in the target system also means that there is a high possibility of spare resources to guarantee the required grade-of-service (GoS): Thus, we are facing a self healing algorithm here that provides a precise forecast under high and critical traffic load conditions and that gives a sufficient indication of the link conditions in the foreign system under low traffic load.

A. Database Management

The administration of collected data is managed by locally deployed databases. These databases may be physically distributed in the network. Besides time-variant interference values the database entries contain pathloss values as function of the distance and the local shadowing that are used for the calculation of the carrier power. Since these values are local interference and pathloss descriptions, a system-wide synchronization is not necessary. Nevertheless, as indicated in Figure 6, databases need to be connected via a fixed backbone for effective and fast data-transfer to allow for synchronization of overlapping areas of the same system (HHO support) and information provision for complementary systems (VHO support).

In the following, the latter case is studied in more detail: Mobiles that consider switching to a different system may request related information within their own system to reach a decision, whether a (V)HO shall be initiated. Based on this information, a mobile may subsequently decide in case of an mobile controlled or mobile initiated handover, whether a handover shall be initiated or not. If the system is network controlled, the network will take over this decision, however in both cases the respective algorithms are based on the information provided by the database(s). By employing foreign party based measurements the necessity for ongoing scanning is expected to drastically decrease or even to become obsolete and the drawbacks described in Section III are minimized.

In order to realize the aforementioned approach, the setup and enquiry of the databases is of fundamental interest. Since the new proposal is intended to support handover preparation, the introduction of newly generated overhead thus shall be prevented. An important aspect in this context is the respective signaling, which needs to be considered more deeply.

B. Signaling for Database Provisioning

Since the introduction of additional traffic due to signaling of measurement reports for database *setup and update* shall be avoided, no explicit signaling to realize the context transfer from the mobiles to the base stations is intended. Instead, the database may be built up by employing information that is sent to the base station anyway, e.g. in the context of power control and link adaptation. Additionally, this is a conform approach and does not assume any enhancements of the different standards.

Database *enquiry* instead opens up the question how the data transfer from the databases to the mobiles can be realized. One way is to establish a new dedicated narrow-band control channel, which can be received by any system. Since this approach is not a very realistic one, it shall not be further considered in the following. A more promising way is to use resources of the actual system the MT is connected to. This could be realized by an extended cell broadcast that is enhanced to also transmit neighboring-cell and foreign system related data. For the HHO case this is partly already realized by means of broadcast channels that a BS periodically transmits. However, these broadcast channels usually do not include information about neighboring or different systems. Thus, the new topic would be that this information is provided as well to support VHO. Another approach for achieving information from the database is to rely on in-band signaling taking place in a piggybacked fashion during ordinary communication. In such a way, only the MT that is willing to change receives the necessary data. However, this approach is only possible for planned HO, where there is enough time to request and provide the data on the old link. On a sudden deterioration of the link quality, the mobile still can fall back to scanning solutions.

Summarizing the aforementioned one can state that the setup of the database is inherently accomplished whereas the downlink data provision requires explicit signaling. However, one should keep in mind that ordinary handover preparation by means of self-autonomous scanning also requires dedicated signaling, e.g. the earlier mentioned triggering of the absence procedure and in case of NCHO the transfer of measurement reports from the MT to the BS/AP.

Nevertheless, with the new approach a scanning of neighboring systems is not needed for a planned HO and the disadvantages inherited with, e.g. the compressed mode, can be avoided. Moreover, in case of a NCHO the scanning in a foreign system and the signaling between MT and BS/AP can be avoided. Especially, for this type of HO control the novel approach provides the greatest benefit compared to conventional measurement procedures and information exchange. Furthermore, it also opens up new possibilities for a fast HO since time consuming scanning and measurement procedures are not needed anymore.

Besides a continuous connection with the BS/AP in the serving system, the new approach also reduces the power consumption, respectively increases the stand-by time because power consuming measurements on other frequencies/systems are obsolete.

V. SUMMARY AND CONCLUSION

Within this paper the system integration in future mobile systems was investigated. Starting from the more general aim of integrating UMTS and WLAN systems it was stated that the first step for interoperability lies in the provisioning of a framework for VHO execution. One important aspect thereby is the scanning of the complementary system while being registered in the respective other one. It was shown, that the most challenging operation is to scan WLAN from UMTS during an active communication using the FDD mode. For this, three different methods have been mentioned, whereby a special focus was put on the compressed mode, since alternative means of making measurements are not yet considered within 3GPP. It was shown by means of simulations that applying CM has a negative impact on the overall system performance and it was concluded that CM is not a preferable means to allow for information gathering. Therefore, another method was proposed that relies on integrating measurement reports of other systems to support the VHO decision process. It is expected that the new approach allows for enhanced system disposition and QoS support since it facilitates e.g. continuous operation during (piggybacked) information gathering and less power consumption.

This novel approach inherits the mentioned advantages even in WLAN (upward HO), e.g. decreased power consumption, simplified scheduling, and no extra signaling of measurement reports if a network controlled HO is foreseen since necessary information is retrieved by normal data transmission and measurement report exchange between the systems.

Currently ongoing research focuses on further performance evaluation of this proposal.

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