Interworking of WLAN and 3G systems

M. Lott, M. Siebert, S. Bonjour, D. von Hugo and M. Weckerle

Abstract: Interoperation of different fixed and mobile networks is one key feature of systems beyond 3G, specifically between wireless local area networks, covering hot-spots with high data rates, and mobile cellular systems with full coverage. This comprises the vertical handover, i.e. the handover between systems with different air-interfaces, which are investigated in the paper. In contrast to several approaches that investigate solutions for the IP layer, the focus of the paper is on mechanisms on the link layer to improve the handover, respectively scanning other air-interfaces, measurements and appropriate triggers from the link layer that are considered in the handover decision process. Finally, the benefits for the handover performance are indicated and the potential of the proposed new concepts is highlighted.

1 Introduction

Following the increasing user demand of ubiquitous high bandwidth services and using the BRAIN (broadband radio access for IP based networks) air-interface as the broadband extension to 2nd/3rd generation mobile systems [1], the integration of services offered via either of these access networks has become increasingly important. Within the IST projects BRAIN and MIND (mobile IP-based network developments) [2], different solutions for broadband access based on an all-IP approach have been derived. One challenge is the co-operation and particularly the management of the handover within and between the systems. A handover between base stations/access points (BS/AP) of the same technology is called ‘horizontal handover’ (HHO), whereas the handover between systems with different air-interfaces is called ‘vertical handover’ (VHO). In Fig. 1 these two handover types are shown for UMTS, GPRS and HIPERLAN/2 (H/2).

Methodologies for measurements and measurement-based decisions for the HHO are known from existing systems. These schemes, as well as new ones, have to be applied for the VHO. Many research activities are focusing on this problem. For example within the European IST (Information Society Technologies) projects WINEGLASS [3], MobyDick [4] or SUITED [5], recommendations and approaches based on already available information and specifications are presented. Furthermore, these projects focus on the realisation of mobility management on the IP level, and discuss topics like enhancements to the IETF ‘standard’ Mobile IP (MIP) [6] and quality of service (QoS) provisioning by means of differentiated services (DiffServ) and/or integrated services (IntServ).

However, the focus in this paper is on the mechanisms and functions provided by the data link layer of H/2 and UMTS for vertical handover. It is mentioned that, although H/2 was chosen as an exemplary WLAN technology, the mechanisms described in the following are applicable to other WLAN derivatives, such as IEEE 802.11. The conducted work aims at presenting a link-layer (layer 2, L2) assisted and network-layer (layer 3, L3) controlled vertical handover between UMTS and H/2, and *vice versa*.

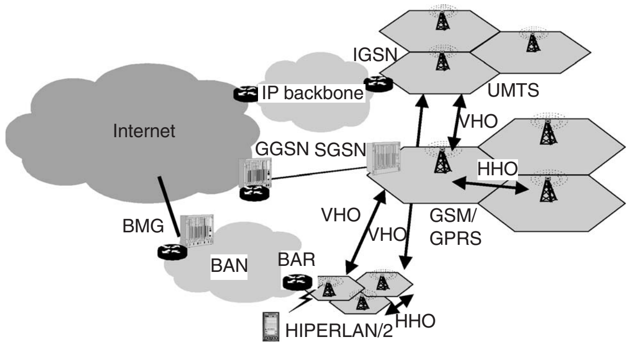

Fig. 1 *Horizontal and vertical handover in MIND*
VHO: vertical handover
HHO: horizontal handover
BMG: BRAIN mobility gateway
BAN: BRAIN access network
BAR: BRAIN access router
GGSN: gateway GPRS support node
IGSN: Internet GPRS support node

Furthermore, new proposals to enhance the VHO based on location awareness of the mobile stations will be presented. This is closely related to research activities of the IST project CELLO [7]. In CELLO location-based measurements, handover decisions and collection of these data are proposed. In this paper, we go one step further by explaining how measurements have to be combined with the location of a station, and how these measurement reports, which do not necessarily need to be achieved from self-driven scanning, can support handover decisions and improve system performance.

2 Mobility management

Mobility in IP networks has been studied to solve the large-scale or general issue where a mobile host (MH) changes the IP address quite rarely. This mobility is called

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macro-mobility and is solved by the IETF standard Mobile IP [6]. To minimise mobility signalling and moreover to achieve seamless handover (i.e. fast and with few packet losses), new mobility protocols have been introduced by IETF and others. This family is called micro-mobility. Examples are cellular IP, HAWAII or BCMP (BRAIN candidate mobility protocol) [1], a new micro-mobility protocol that has been developed in BRAIN.

Mobility management includes several problems that can be partly solved and studied separately. These are routing, idle host management, path updates and local seamless handover, which is closely related to micro-mobility. In this paper, the handover will be investigated in detail concentrating on two components: measurement provisioning by the link layer and handover decision process.

2.1 Handover management

Handover management refers to the impact of handover on the mobile host. To offer a good quality of service to the user, the handover management should come up to the following aims [1]:

- Minimise packet loss and delay during a handover (seamless handover).
- Make use of any "triggers" available (e.g. information from the mobile host or from the network that a handover is imminent), so that action can be taken in advance of the actual handover (planned handover).
- Allow the possibility of transferring context (QoS, security, header compression state, link layer states) but also any buffered packet (tunnelling) from the old to the new access router.
- Ensure that a planned handover can fall back gracefully to an unplanned one (in case it fails), and that the same actions can happen (transferring buffered packets and context).
- Allow inter-technology handover if the mobile host supports different technologies (vertical handover).

The terms 'horizontal' and 'vertical' come from the overlay network structure that has networks with increasing cell sizes at higher level as indicated in Fig. 2.

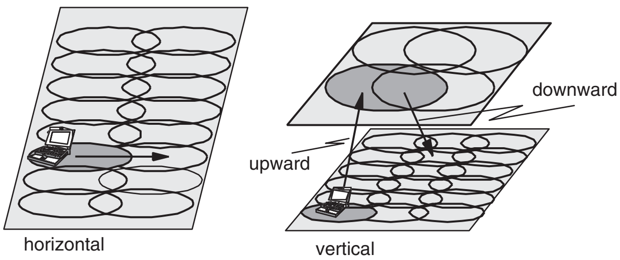

Fig. 2 *Horizontal (HHO) and vertical handover (VHO)*

VHOs are further classified into two categories: a downward VHO is a handover to a wireless overlay network with a smaller cell size and usually higher bandwidth per unit area, whereas an upward VHO is a handover to a wireless overlay network with a larger cell size and usually lower bandwidth per unit area.

The possibility for a vertical handover means that an additional dimension of choice is introduced since the two system types also offer complementary services. Therefore, an MH might be triggered to perform a vertical handover, even though the link quality on the current system has not decreased. Consequently, further intelligence is necessary to decide which kind of handover shall be performed and when.

2.1.1 Measurement support in UMTS and H/2: The current H/2 standard only defines a mean to evaluate the link quality by received signal strength (RSS) measurements. To allow an MH to perform a measurement, the MH absence procedure is defined in the standard [8]. It is used by the MH to announce that it is temporarily not available. During this time, no data exchange between the MH and the current AP is possible. The MH informs the AP that it will be absent and indicates the absence duration.

In the UMTS standard, three types of measurements are available to obtain the link quality: 1, 'intra-frequency' (same mode); 2, 'inter-frequency intra-system' (frequency division duplex/time division duplex); and 3, 'inter-frequency inter-system' (UMTS/GSM). Measurements of an MH in another system or another mode can be performed in the FDD-mode by means of the compressed mode and in the case of a TDD-mode during idle time slots [9].

3 Handover in systems beyond 3G

In future mobile systems, the support of different air-interfaces will be a basic requirement. Before an HO execution to another system, the respective frequencies have to be scanned and a decision with respect to the system/frequency has to be made, which will be described in the following Sections.

3.1 Measurement provisioning

3.1.1 Required changes in UMTS and H/2: For the VHO preparation special measurement procedures for inter-system measurements are provided in the UMTS specification, which have to be extended to cover H/2 also. However, the measurement of UMTS or GSM when operating in a WLAN, e.g. H/2, is not sufficiently supported. In particular, the measurement duration supported by H/2 is not appropriate to perform measurements in UMTS or GSM [8]. Therefore, it is proposed to increase the absent period that is specified in H/2. The currently specified 6 bits for the absence time allow signalling of up to 63 frames, which corresponds to 126 ms. If some additional bits of the 18 bits available for future use are reserved for this purpose, the range of allowed measurement times can easily be extended.

Alternatively, a multi-mode terminal with more than one transceiver might be the solution to simultaneously measure on different frequencies and in different systems. The multi-mode terminal comprises two link layer stacks as they are proposed for GSM-UMTS integration [10] and as they would also be applicable for H/2-UMTS interoperability. Both stacks thereby could be activated at the same time or one in stand-by. During paused transmission occurring regularly in packet transmission mode (discontinuous transmission, DTX), results of the scanning are reported to the common higher layers to decide for HO initialisation.

3.1.2 Location-aided measurement provisioning: An alternative approach to provide measurements relevant for a handover decision is proposed in the following. It relies on measurements that have been performed by other MHs communicating on the target frequency or in the target system, their location, and the location of the MH that intends to make a VHO. In future systems it can be expected that the location of a terminal is adequately known, e.g. with the support of methodologies provided by cellular networks based on RSS, travelling times (time-/time difference-of-arrival, TOA/TDOA) or directions (angle-of-arrival, AOA) of waves emitted from or received at different base stations [11]. Alternatively, satellite systems like Global Positioning System (GPS) or Galileo can provide the precise location information.

Comparing the position related measurement reports taken by third parties with the current location of the MH it is possible to forecast the quality of the connection (RSSI, received signal strength indication, BER, bit error ratio, etc.) to the new BS/AP and the interference conditions, respectively, even without having performed any measurement by the MH itself. A handover based on this decision is what we refer to as location-aided (vertical) handover. However, differences will exist if the velocities of the MH having performed the measurement and the MH performing the HO are not identical, because of different Doppler frequencies and the impact of fading on the interleaving. However, the differences are expected to be small since the main impact factors such as the radio channel and the interference level at one geographical location are independent of the velocity. Nevertheless, to improve the correspondence of the measurement values the velocity can be introduced in the measurement report, too. A more important aspect might be the time when the measurement has been performed. The longer this measurement lies in the past, the less accurate this measurement reflects the current situation, especially if interference is considered. Therefore, the time of measurement should also be introduced in the measurement report. In the following the location-aided VHO is explained in more detail. Each active MH reports about the current link condition; see step 1 in Fig. 3. Together with the measurement report the location of the reporting MH is stored in a data base (DB) (step 2). An MH that intends to perform a VHO sends a request to its BS/AP; see step 3. The AP/BS in turn acquires the corresponding measurement report from the DB, depending on the current location of the MH (step 4), and signals the HO decision (or related information that allow the MH to take the decision) to the MH (step 5). The MH can then perform the VHO, which is marked by step 6 in Fig. 3.

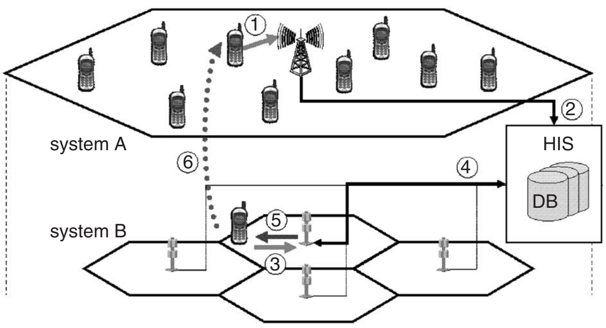

Fig. 3 *Exchange of HO reports between systems*

In this basic approach, which is referred to as a hybrid information system (HIS) [12], measurements that are inherently available for each system are made available to heterogeneous systems as well. Depending on the level of integration into the HIS, MHs may act as feeding clients without even being aware of this task. For example MHs sending information for power control implicitly provide information on the link conditions.

3.2 Exchange of measurement reports

In the case where the handover decision process is located in a higher layer (above the link layer), the measurement reports should be transferred to the network layer. Moreover, when the measurement reports are collected in each system, it is necessary to send them to the entity where the handover decision will be made. A common central entity is introduced for that purpose in the common radio resource management (CRRM) architecture to combine UMTS and GSM/GPRS [13] and the joint RRM (JRRM) architecture to combine UMTS and WLAN [14], respectively. Furthermore, the access networks have different understandings on how to provide QoS, and a common view is required to decide on handover. The simplest idea is to use the definition of QoS used in the IP layer. This can be realised with the help of an appropriate interface between the link and IP-based network layers, the IP-to-wireless (IP2W) interface, which has defined in BRAIN [1]. In MIND, an IP convergence layer (IP CL) for H/2 has been specified [15]. With these enhancements, measurements or a qualitative indication of the link quality can be easily provided to the IP layer in a standardised manner, independent of the underlying link technology, as shown in Fig. 4.

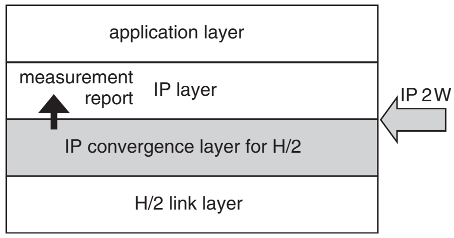

Fig. 4 *IP2W and IP CL for H/2*

With the help of the IP2W interface the service parameters, e.g. QoS parameters, are delivered from the old to the new network and are interpreted by the different radio technologies in an appropriate and harmonised manner. This, of course, requires a proper QoS mapping between IP QoS and access-network-specific QoS parameters, as it is proposed in the specification of the IP CL for H/2 [15].

3.2.1 Storage of measurement reports:

The measurement reports provided to the BS/AP will be collected and then stored in special network entities, the DBs (see Fig. 3), which might be located in the mobile switching centre (MSC), radio network controller (RNC) or AP controller (APC). These DBs are owned by the operator and provide interfaces to the other systems over an IP backbone network. A DB can serve one whole domain and several BSs, respectively RNCs and MSCs. The exchange of measurement reports is concentrated on the points of relevance and avoids heavy traffic in the fixed network.

In Fig. 3, we can see MHs of both standards, UMTS and H/2, that report their measurements to the respective DB. DBs are wireline connected for DB data synchronisation and thus information about the interference situation within the coverage area of both standards can be obtained via one single air-interface only. Note that the above-mentioned two cellular structures are not spatially separated but have an overlaying nature. An MH that is to execute a (V)HO can request information for both standards and subsequently take a decision.

3.3 Handover support by means of triggers

The main task of the link layer (L2) is to organise the medium access and to enable secure data transfer by means of error-detection techniques. To fulfil these tasks, it evaluates the information gained from the physical layer.

The process of this evaluation is based on various *a priori* information, algorithms and system requirements, which can be subsumed as triggers. Some examples are provided in [16].

In the following, we describe the main triggers for handover. We thereby introduce a classification in physical-based L2 triggers, which are physical probes that can be measured and statistically evaluated, and algorithm-based L2 triggers, that are outcomes and decisions of procedures performed within layer 2.

3.3.1 Physical-based L2 triggers: Similar to the horizontal handover case, the link layer(s) involved in a vertical handover will rely on physical parameters, known from measurements, and their derivatives. The most important ones are: (*a*) the signal strength, which is measured by means of the RSSI or RSCP (received signal code power) and is reported from the physical layer; and (*b*) the interference level, which may be caused by foreign systems or the local system. Furthermore, the carrier-to-interference ratio, which can be derived from the aforementioned parameters and the BER, respectively packet error ratio (PER), are important physical-based triggers.

3.3.2 Algorithm-based L2 triggers: Complementary to the physical-based L2 triggers, algorithm-based triggers could also be classified as a kind of 'higher level trigger' since they are not purely related to L1 issues. In fact, within their appearance, they are taking physical-based triggers into account and use them within more complex handover decision processes. In particular, for the vertical handover these kinds of triggers offer an extra dimension, namely the cross-system perspective. One example is the QoS violation trigger. To support higher layer demands with respect to delay, throughput, etc., the link layer should indicate QoS violation, e.g. bandwidth shortage, to the higher layer. Therefore, the network layer is challenged to choose the most suitable BS/AP or different access system, respectively change it by performing a horizontal or vertical HO. Another example is the connection admission control and connection forwarding (CAC & CF) trigger. The handover decision depends on actual, requested and expected traffic in such a way that incoming requests are not refused straight away if the capacity limit is to be reached. Instead, L2 could indicate that there is not enough bandwidth available and L3 might in turn give over certain (lower prioritised, less challenging) connections to another system in order to still be able to accept the incoming request (load balancing).

Further examples for algorithm-based triggers are location-based triggers, which take into account the distance to the BS/AP or cell borders, and velocity-based triggers. The latter ones are already proposed within UTRAN standardisation in the HCS (hierarchical cell structure) scenario via rules for fast-moving terminals. If the velocity is too high, handover to macro cells is prioritised to provide efficient radio resource control by saving capacity in micro cells for local low-mobility users.

The last example for algorithm-based triggers is the *a priori* knowledge-based trigger. Often the MH holds information that is not based on actually performed measurements. For example, a street map or a map of positions of BSs/APs or information concerning areas with handover problems or areas where MHs have worse connectivity to certain systems can be beneficially exploited. Beside this, the MH could record periodically recurring events and use this information for future HO triggers (mobile profile). For example, if a user takes the same route to his work every day, there will be the same sequence of HO to serving BSs/APs. If this sequence is stored somehow, it can be used the next time to predict HO, which again allows for executing planned and forward HO (cognitive radio).

Ideally, all triggers, whether physical-based or algorithm-based triggers, should be weighted and combined in an appropriate manner, e.g. by means of multi-criteria combination or fuzzy logic, and used as indicators for a (V/H)HO. If the resulting value/criterion exceeds a threshold, the HO is initiated. However, the time-variance of the resulting values leads to instabilities in the decision process. Specifically, terminals at the border of two cells have difficulties in assigning themselves to the one or the other. Owing to the overlapping character of the coverage areas, an MH moving along the cell border would permanently try to switch to the neighbouring AP as soon as the respective signal quality exceeded that of the present one. This so-called HO ping-pong effect is prevented by introducing a hysteresis, which means an HO is only allowed if the signal of the new BS/AP is significantly stronger than the present signal. More sophisticated algorithms also include a time dimension within their decision-making. This means that either the new, stronger signal must be present for at least a minimum amount of time before switching is allowed, or the return to an old BS/AP after HO is not allowed for a certain period. However, this is related to some averaging processes, which are applied to most of the values retrieved by measurements to avoid too much fluctuation in the decision process.

The decision to perform an HO in systems beyond 3G can be manifold. As explained in the preceding Section, certain triggers like the RSSI, BER, current location and distance to alternative BS/AP and others can be taken into account. Furthermore, with the information contained in a DB a more appropriate handover scheme can be realised, also considering aspects such as load balancing. Further issues may focus on optimising an MH's power consumption (power saving) due to working in the least power consuming standard/mode and the optimum usage of the total available spectrum, which also includes the minimisation of all kinds of (signalling) overhead.

There are relations between these objectives. That is why situations that realise one goal at the expense of others have to be avoided. For example, reducing power consumption by keeping network interfaces off when not in use increases handover latency. Similarly, zero-latency handover could be achieved by simply sending and receiving data across all network interfaces simultaneously at all times, but this results in an inordinate waste of bandwidth and power. The ultimate goal is to balance low latency handover with the unavoidable costs that arise from implementing them; cf. Fig. 5.

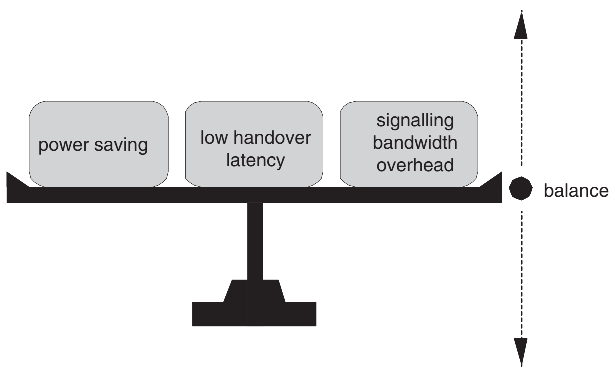

Fig. 5 *Interaction between VHO objectives*

To optimise the handover procedure all available information will be collected in the DB and will be accounted when an HO decision has to be performed.

For a NIHO (network initiated HO) the network (HO instance in the network, e.g. the RNC in the case of UMTS) has to be aware of the supported air-interfaces of the MH to propose an HO to a different system. For this purpose the BS and MH exchange the capabilities of the MH to support different air-interfaces during the registration procedure.

If the MH should make the HO decision (mobile initiated HO, MIHO), the information from the DB will be transferred to the MH in the down-link from the AP/BS. This exchange will be initiated by a respective request of the MH. Since the MH is only interested in the information relevant for its current position, only a very small subset of the content in the DB will be exchanged between the AP/BS and MH for that reason. More precisely, only the entries that correspond to the current position of the MH have to be transferred. As an answer the MH will obtain the neighbour cell information and alternative systems that can be used at this location. In addition, for the unplanned HO case, the MH is still in the position to start scanning another potentially available system in case of suddenly losing the connection to the serving AP/BS.

4 Performance estimation

In the following the advantages and disadvantages of the approaches introduced above will be emphasised. After covering the impact of a VHO on the performance of a hybrid system, the benefits and drawbacks of the proposed approaches are mentioned. Finally, a rough estimation of the efficiency of the VHO method is performed.

4.1 Impacts of the VHO approaches on the system performance

In general, the combination of local and wide area wireless networks as H/2 and UMTS will result in a more efficient allocation of transmission capacity fitting the user's actual needs. In particular, from a network operator's point of view the common management of available resources in terms of UMTS- and H/2-frequencies allows for a more flexible utilisation and for a higher throughput. Moreover, the performance of both systems should improve due to the handover of certain users to the alternative air-interface (trunking gain, see also [14]).

MHs in W-CDMA macro-cells, which are located near the BS, are substantially affected by intra-cell interference on the downlink due to the high transmission power required for MHs situated far away, unless the orthogonality of the different user codes is completely preserved [17]. In H/2, the increasing pathloss for MHs far away reduces the SIR (signal-to-interference ratio) value and in turn only allows utilisation of the lower modes of modulation. Thus, where an UMTS BS is collocated with an H/2 AP, terminals situated next to this site should – either based on a network decision or on its own measurements – switch to the WLAN technology to benefit from the most suitable link-conditions. On the other hand, users at the edge of the H/2-cell might switch to UMTS, providing a better performance for higher terminal speeds as long as the data rate of UMTS is sufficient. The combination of both systems avoids low performance connections, enabling the overall capacity and throughput to be enhanced. Moreover, with the suggested VHO approaches it is expected to minimise potential deterioration of service quality due to delay and data loss, as is especially required in heterogeneous networks [18].

4.1.1 Location-aided VHO:

In addition to the common VHO approaches, the new proposed location-aided handover scheme supports seamless and spectral efficient mobility support without the need of the MH to perform power- and time-consuming measurements. This will not only reduce operational costs but also the basic investments for the terminal, which is advantageous from a user's as well as a network operator's point of view. Moreover, the duration of the handover process is reduced as no synchronisation beforehand and averaging of measured signal strength is needed nor the time required for frequency switching, which amounts to half a frame length in the case of H/2. Last, but not least, due to the mainly network-based processing of data assisting the handover, the signalling load on the scarce radio medium is reduced.

Nevertheless, there are also drawbacks with the location-aided VHO approach. Especially in the case of sparse distribution of users with high user data rates, the reliability of the information performed by foreign stations might decrease. However, with lower numbers of users in the target system the probability increases that the terminal will find sufficient resources in the new system. This tradeoff between the number of measurement reports that are needed for a good forecast in the target system, which increases with more users, and the available bandwidth, which increases with decreasing numbers of users, results in a self-healing behaviour.

To estimate the potential of the location-aided VHO the following scenario has been investigated. A mobile is connected to a first system, e.g. UMTS, and approaches the coverage area of a second system, e.g. H/2, with a higher date rate. To maximise the throughput a VHO to H/2 is envisaged as early as possible, i.e. when the mobile is entering the coverage area of H/2. Owing to foreign-based measurements the HIS holds information on the link budget for each location within the target system, i.e. H/2. Depending on the update interval of the location for the MH, the VHO can be triggered more or less accurately. Figure 6 provides the complementary distribution function (CDF) for the distance D to the optimal handover point ($D=0$) as a function of the location update interval for a velocity of the MH equal to 15 m/s [19].

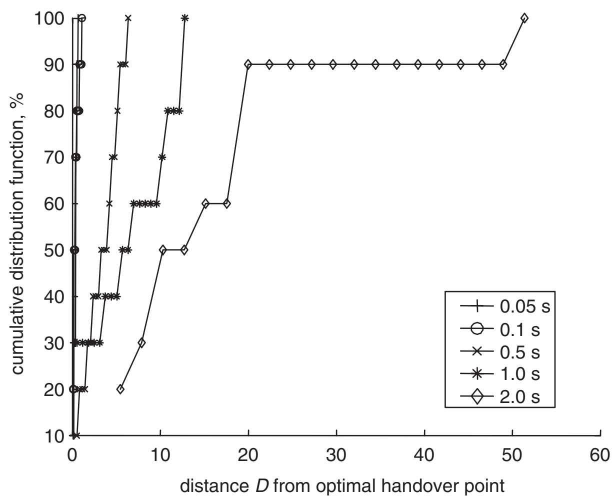

Fig. 6 *Impact of location update interval on optimal handover execution*

For CDF values equal to 100%, all handovers have been executed, e.g. for an update interval of 1 s, all handovers have been executed within a distance of $D = 12.5$ m. This distance corresponds to 0.83 s during which an MH is still connected to UMTS instead of exploiting the much higher throughput capacity of H/2. Assuming a maximum possible data rate of 384 kbit/s for UMTS and $\sim$30 Mbit/s for H/2 (taking into account the overhead and the highest bit rate for H/2 equal to 54 Mbit/s), this results in a difference in the throughput of $\sim$25 Mbit. Alternatively, the MH frequently has to scan the H/2 system, which reduces the available time being connected to UMTS. Still, the MH will not find the optimal handover point $D = 0$ since a permanent scanning of candidate systems is not feasible. From this estimation we can conclude that the location-based VHO is a very promising approach for interworking between UMTS and WLAN.

4.1.2 Information provisioning and handover decision: All measurement reports and criteria for the HO decision process are collected and stored in the DBs. Therefore, different already known and novel triggers from the link-layer have been proposed. In particular, triggers/information such as the velocity and the location, which can be provided by the DBs, as well as those based on *a priori* knowledge, will improve the VHO decision and system performance. With an appropriate weighting and combination of all these parameters, the most efficient HO decision will result. Nevertheless, this requires extensive evaluation and calculation beforehand and a lot of exchange of measurement data. However, the main effort with respect to calculation and data exchange is concentrated in the fixed network, where resources are not the limiting factor.

4.2 Efficiency of VHO implementation

To assess the overall improvement due to implementation of VHO enabling mechanisms between different radio networks, we have to estimate the increased effort in terms of additional measurement and signalling overhead as well as required hardware complexity against the gained capacity and throughput of a common resource management.

Considering the disadvantages of the new approach listed above, we see that the additional information required is either already available as a regularly transmitted signal level and SIR data or is foreseen for future 3G releases as in the case of terminal location determination. The only actually new entity is the database to be deployed in a rather decentralised manner to allow the network to appropriately propose a VHO decision and the corresponding signalling traffic transported via the core network.

Assuming a typical user density of 50 per UMTS cell, an update of the information every 2 s, and a required data amount of $\sim$20 bytes to be transmitted per user, the additional signalling traffic amounts to 4 kbit/s, which is $<1\%$ of the average data throughput per UMTS cell. In relation to the much higher capacity of a WLAN cell and to the fixed wired connections, this percentage decreases even more.

The advantages are mainly related to end-user terminals, which may be reduced in complexity. Furthermore, any handover can be expected to be planned, as the required information is available in advance, thereby enhancing the overall performance.

Thus, in a first-order approximation, the performance of VHO between local and wide area radio networks is improved, especially when a newly proposed approach to utilise location-related network-stored pre-processed data is applied to enhance the handover process.

5 Conclusion

The integration of services delivered over 2G/3G networks and over broadband radio access networks has been identified as an important feature for future radio systems. This comprises as one major cornerstone the vertical handover, i.e. the handover between different radio technologies, which has been investigated in this paper in an all-IP based network environment.

Several requirements for the vertical handover have been listed. To enhance the performance of the vertical handover, several triggers have been introduced, which are provided by the link layer and have to be provisioned by appropriate scanning of the different air-interfaces. Furthermore, new and even more unconventional ones, such as location-based triggers, velocity-based triggers and *a priori* knowledge-based triggers, have been introduced and the advantages and potentials that arise with their intelligent combination have been highlighted.

An evaluation of the presented approaches with respect to resource requirements and signalling overhead as well as implementation efforts indicates their benefits and potentials for efficient vertical handover in next-generation systems. In particular, for the location-aided VHO approach, which is based on measurement provisioning solely conducted by mobile hosts that are operating on the respective frequency and in this cell, a reduction in signalling over the air can be expected. Moreover, a reduced latency as well as increased stand-by time and reduced hardware complexity in the user terminals will result.

Although this work has been restricted to cellular mobile systems, such as UMTS and wireless LAN, represented by H/2, it is worth mentioning that the approaches can be adopted to any other existing or future air-interface, e.g. low-range personal area networks (PANs), WLAN based on IEEE 802.11, or broadcasting systems as DAB and DVB-T.

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