Location Aided Handover Support for Next Generation System Integration

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Abstract: **This paper presents a new approach for system integration of future wireless networks based on the evaluation of foreign party based measurements to support (vertical) handover. For the new proposal, referred to as Hybrid Information System (HIS), it is suggested to collect information about the current state within the covered cell to provide this information to other mobiles that are willing to handover. The presented approach offers a great potential since scanning procedures can be minimized or even avoided. An underlying assumption is, that information offered by the other system was recorded nearby the own position. Therefore, a correlation investigation of nearby recorded radio reports is undertaken considering state of the art localization techniques used to map measurements and position. It is found by simulations and analysis that neither distance nor load represents a disqualification criterion for the presented idea. In a subsequent application of the HIS, the handover performance is evaluated. It is shown that HIS supported handover have the feasibility to improve efficiency of handover execution.**

Keywords: Location Aided Handover, System Integration, Hybrid Information System

1. Introduction

People's basic needs for communication and mobility are the key drivers for the emerging of different wireless technologies. Being used to high data rates while at home or in the office, the mobile user starts expecting more and more wired-like services while on the move; a challenge that obviously will not be fulfilled by 3G deployments only.

An auspicious solution to this problem is seen in broadband wireless systems like Wireless Local Area Networks (WLANs) supporting higher data rates compared to 3G systems. Due to the high bit rates and the free frequency licensing WLAN technology was partly seen as a competitive technology to 3G networks. However, due to rather limited cell sizes, it seems utopian to realize a nationwide coverage solely based on WLAN deployments. This is why many experts consider WLAN and 3G mobile networks as complementary technologies to be integral part of future 'beyond 3G' systems.

2. Current System Integration Efforts

From industry point of view, various telecommunication operators already today have recognized the need for offering an integrated overall mobile wireless solution. Rather than pushing only 3G solutions, which one intuitively could assume due to high license and deployment costs, hybrid installations are promoted ("For us, WLAN is a strategic supplement to our overall offering" Dr. Michael Paetsch, marketing director Vodafone D2 [1]). Joint techno-economic studies like in [2][3] point out 'that adding WLANs to the roll out of UMTS, even where licences were not paid for, is not a significant cost' [4]. Besides economic arguments, further technical arguments like the facility to offer attractive integrated packages of services, pricing and advanced network functions such as hybrid UMTS/WLAN up-/downlink drive operators to favour integrated solutions. Global players like Vodafone [1] or Swisscom [5] started to equip hot spots in hotels and airports with public WLAN technology. However, the current degree of integration is not very sophisticated, and no concurrent or enhanced usage of integrated services, like e.g. vertical handover, is feasible yet.

Therefore, from research point of view, further challenges have to be overcome in this field, mirrored by a large number of projects like e.g. MIND [2] or ANWIRE [6] and specific working groups in e.g. ETSI/BRAN [7] or 3GPP [8]. A detailed collection giving an overview of publicized R&D projects can be found in [9], while a deeper analysis and comparison of system integration efforts of selected projects is found in [10][11]. A basic requirement for interoperability between heterogeneous mobile radio networks is the possibility to detect and survey other networks. Therefore, dedicated scanning procedures are applied by the different systems. In case of UTRA-FDD (UMTS) the compressed mode (CM) has been specified for that purpose. Unfortunately, as shown in [12], especially the CM has a negative impact on the overall system performance. Furthermore, even in systems that allow for the detection of parallel RANs without a second receiver or arrangements like the CM the scanning has drawbacks like additional power consumption for measurements and signalling of measurement reports if network controlled handover is envisaged. The next section delineates a system that provides the necessary information without the mentioned drawbacks and allows for a lot of new concepts regarding location assisted algorithms for Radio Resource Management (RRM).

3. Hybrid Information System

Another way to gather information is to exchange measurement reports with other systems. The overall idea hereby is to store existing measurement reports from each system together with positioning information in a respective database. This approach offers a great economic potential since scanning procedures can be minimized. In detail, each system collects data about the current state within the covered cell and provides this information (via the database) on request to mobiles that are willing to change their current serving BS in a cellular system, respectively Access Point (AP) in a WLAN. For the horizontal handover the information provisioning may be realized by means of broadcast channels that a BS periodically transmits and that indicate potential BSs in the neighbouring cells. However, usually system specific broadcast channels do not include information about overlaying or neighbouring systems of a different type. Thus, it is proposed that this information will be provided as well.

The feeding of the mentioned database with the joint interference-position information from the own system is of special interest. No additional signalling between the mobiles and the BS shall be necessary for the database setup since the respective information should be available at the BS anyway (e.g. in the context of power control and link adaptation related signalling). Mobiles that consider switching to a different system may request related information within their own system to reach a decision, whether a handover should be initiated. The databases of the different systems can be connected via a fixed backbone network for effective and fast data-transfer.

With this approach a scanning of neighbouring systems becomes obsolete and the disadvantages inherited with the compressed mode can be avoided. Besides a continuous connection with the BS/AP in the serving system, the new approach increases the stand-by time of the mobiles because power consuming measurements can be avoided. For example consider GSM as alternative system. To perform the scanning several possible frequency channels have to be searched and measured to come to a proper decision, which is not only time-consuming but requires considerable battery power, too. A more detailed description of the HIS principle is included in [12].

4. Enabling Technologies and Properties

4.1 Localization techniques

From a physical localization point of view, in principle there are three techniques to be distinguished: 1. Triangulation, 2. Proximity and 3. Pattern Recognition. In case of triangulation, trigonometric methods are used for the position determination, which can be differentiated in distance-based lateration (example: Global Positioning System, GPS) and angle- or direction-based angulation (example: Phase-sensitive antennas) methods. The second type, proximity based localization, is based on the determination of the place of an object, which is 'close' to a well-known place. In the third type of localization techniques pattern recognition methods are applied, which can be further separated into optical pattern recognition (scene analysis) and non-optical pattern recognition. For both recognition techniques, optical and non-optical, dedicated mapping schemes are applied such as the Database Correlation Method [13] based on e.g. Hidden Markov Models [14].

Four different localization categories can be distinguished according to the active elements in positioning.

- Network-based (all necessary measurements are performed by the network, resp. base station).
- Mobile-based (terminal holds responsible for the position determination)
- Mobile-assisted (hybrid solution of the two aforementioned methods)
- Foreign system-based/assisted (exploiting metrics whose origin is not the actual mobile radio system itself)

The first three methods rely on system inherent signal exploitation, whereas the last category applies additional non-specific mobile radio communication system techniques to perform localization. In case of network-based localization no changes to the UE are necessary and legacy devices can be employed. In the mobile-based localization approach the base stations need to transmit on a regular basis. Disadvantages of the mobile-based localization obviously are given by increased complexity due to higher challenges on calculation power and equipment leading to the conclusion that this method is not applicable for legacy terminals. In the case of mobile-assisted localization, the terminal measures reference signals of incoming BSs and transmits the data back to the network. The final computation can take place in the network, e.g. a central server station. However, this burdens a lot of traffic to the network if explicit measurement signalling is triggered. Additionally, the evaluation of the position is delayed compared to the mobile-based implementation. The major advantage is the possibility to use existing GSM or already specified UMTS measurement reports [1][2]. Besides this, if respective reports are exploited that are conveyed to the base station anyway, e.g. in the context of power control adjustment, the aforementioned disadvantage of additionally introduced overhead is not valid anymore. The last category, foreign system based/assisted localization comprises radar location techniques or satellite navigation systems. They inherit the same challenge like mobile-assisted techniques, i.e. how to convey the position information to the network.

4.2 Accuracy and Precision of localization approaches

The aim of localization is to determine locations accurately and precisely. Having a look at manufacturers' instructions of e.g. GPS devices, one will find statements on both accuracy and precision, e.g. receivers can locate positions to within 10 meters (accuracy) for approximately 95 percent of measurements (precision, reliability) or accuracies of 1m-3m for 99% of the time. Thus, accuracy as used here means the granularity with which objects may be located while precision means the reliability that a located object really resides at the determined position. Obviously, accuracy and precision are closely dependent on each other and one will intuitively agree that if applied for the same system less accuracy may result in increased precision and vice versa.

This is also expressed with the help of Figure 1: The abscissa depicts the relative location of an object while the ordinate shows the probability that the object really is located at the respective position. Accuracy of localization increases if delta x decreases, which means the granularity is increased (e.g. location resolution of 5m instead of 10m). The precision of the localization corresponds to the integrated surface as hatched in Figure 1. Thus one can see that if – for the same system – accuracy is increased, precision usually decreases. To arrive at a concise quantitative summary of accuracy and precision actually these terms need to be mentioned including a remaining unsteadiness expressed by an error distribution incurred when locating objects

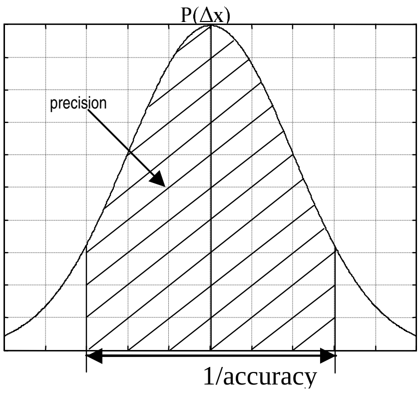

Figure 1: Relation of accuracy and precision (same system)

4.3 Measurements and Information Provision

For reaching global ubiquity with one and the same User Equipment (UE) the development and standardization of 3rd generation (3G) mobile systems was supervised by the International Telecommunications Union (ITU). Its International Mobile Telecommunications at 2000MHz (IMT-2000) project was launched to bring different approaches close enough together to make multimode devices possible. Also, the design of 3G networks like UMTS considered coexistence with 2G GSM. Such, new UEs have a backup in the old network so that the system coverage is guaranteed even if only “Hot Spot” areas are equipped with UMTS base stations. To provide interworking of all these varying networks and support handover between them, scanning of other cells and radio access technology (RAT) is necessary. While TDD mode systems like TD-CDMA or GSM can employ the idle periods to survey them, in UMTS UTRA-FDD mode this is not possible. Here, either a multi-frequency receiver must be utilized or the compressed mode has to be applied to force slots to be freed for measurement actions.

UMTS Measurements

In UMTS, three kinds of handover are standardized: the horizontal (cell to cell), the intra-system (e.g. TDD to FDD) and the inter-RAT (e.g. UMTS to GSM) handover. This leads to different measurement classes, respectively. First, the intra frequency measurement is employed in the case of horizontal handover to monitor the Primary Common Pilot Channel (CPICH) in FDD and the Primary Common Control Physical Channel (P-CCPCH) in TDD mode of the own cell and the neighbouring cells. Parameters for these measurements may be the Received Signal Code Power (RSCP) and E_c/N_0, where E_c denotes to the received energy per chip and N0 to the power spectral density in the band. To qualify the performance of the current link estimations on the block error rate (BLER) are evaluated, too. Second, the inter frequency measurements survey the surrounding cells on different frequencies (other carriers) to find a possible target for a handover. The measurement values are similar to intra frequency measurement values. And third, the inter-RAT measurements are provided for the inter-RAT handover which is only standardized for GSM-UMTS/UMTS-GSM handover yet. Here, the Received Signal Strength Indicator (RSSI) is observed.

802.11 Measurements

In the IEEE standard 802.11 [15] for Wireless Local Area Networks (WLAN) the use of measurement reports for information exchange between Access Point (AP) and Station (STA) is not standardized. However, the supplement standard 802.11h [16] introduces some basic measurement and reporting structures. Nevertheless, inter-RAT measurement procedures are not defined. Hence, there is no standardized way of performing a handover from WLAN to other cellular mobile radio networks.

For intra-system monitoring three different measurement reports are available. The Transmit Power Control (TPC) contains the current transmitted power for an effective power control, the Clear Channel Assessment (CCA) determines the current state of use of the wireless medium and the Received Power Indicator (RPI) measures the received power level for a specified duration of time. The reported RPI histogram thereby distinguished 8 classes (0-7) of reception levels separated in 5dB steps starting from -87dBm $\leq$ RPI $\leq$ -57dBm and reports the fraction of time during which signal power equivalent to the respective class was observed.

5. Applicability of the HIS

One important assumption so far was that a mobile willing to change may request from the database location information about the radio conditions at its current position in the envisaged target system. A basic precondition thereby is that the respective entry for exactly the same position was added to the database by another mobile earlier. However, even if a formerly active mobile has provided this information, it is still not sure that the respective data really mirrors the link condition of the position in question since this is only possible if a localization precision of 100% was applied. Depending on the applied localization technique, certain inaccuracies therefore need to be considered and modelled. From field trials as described in [17] it is known that a respective accuracy in positioning of up to 20m may be reached for UMTS, whereby a remaining imprecision of 67% stays. To model this, a scenario as shown in Figure 2 was investigated. The aim here was to figure out in how far the localization inherent imprecision affects a possible realization of the HIS. If namely the applied localization is either very inaccurate or very imprecise, it is most probably that foreign party based measurements cannot be used to predict the measurements received by a station itself. In the middle of the upper part of Figure 2, the mobile at its real position (A) is shown. Localization accuracy is modelled by a radius for the estimated position varying between 0-20m since 20m is an adequate accuracy to be reached for localization in UMTS systems [17]. We thereby assume the radius as normal distributed, while the applied angle is uniformly distributed, resulting in a 2-dimensional normal distribution with a correlation factor of zero. A precision of 67% in this context means that for this percentage the distance between estimated and real position is equal or less to 20m. For the other cases, a respective higher distance may occur. Summarizing this one can state that ‘accuracy’ expresses the granularity, with which terminals may be localized, and precision is a measurement for the reliability that the alleged located mobile really resides in the respective area.

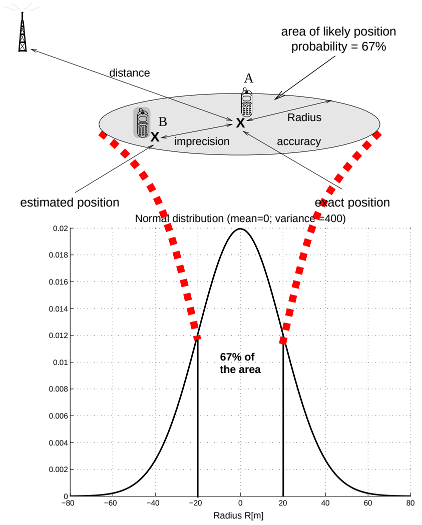

Figure 2: Modelling of fuzzy localization

For the simulation a scenario as shown in Figure 3 was chosen. The underlying assumption is that the mobile, which is currently connected by UMTS (not shown in Figure 3), would like to make use of information offered via the HIS to determine whether a handover to the present WLAN system is desirable. Due to inaccuracies in the localization in UMTS, the terminal thus will not ask the HIS for the radio situation in the WLAN at its actual position A, see Figure 3, but for a different location B. Therefore, a measure is needed addressing the similarity of radio conditions for the two positions A (real terminal’s position after handover) and B (position, for which terminal requested information). To evaluate this similarity, a cross correlation of respective WLAN measurement reports as they are stored within the HIS is evaluated. For this, the normalized correlation C_n is calculated by (1) [18], whereby f_1 denotes measurements at position A, f_2 refers to measurements at position B.

$$C_n = \frac{\sum_{n=0}^{\infty} f_1(n) f_2(n)}{\sqrt{\sum_{n=0}^{\infty} f_1^2(n) \sum_{n=0}^{\infty} f_2^2(n)}} \qquad (1)$$

As exemplary WLAN system, IEEE 802.11a [15] was chosen, whose protocol stack was standard-conformal implemented within the Wireless Access Radio Protocol 2 (WAPR2) simulator, an event-driven simulation tool of the Chair of Communication Networks, Aachen University. The feeding of the HIS with measurement reports was implemented following the specification of 802.11h [16] using dedicated management frames to provide requested measurement reports (RPI Histogram). For the link budget, a simple one slope pathloss model with a pathloss factor of γ=2,4 was chosen and an omnipresent background noise of -95dBm was assumed. The measurement duration was chosen to 5ms and the recorded measurement reports were transmitted to the HIS every 20ms. To determine whether the distance between AP and mobile is significant for the applicability of HIS, the mobile (position A) moves away from the AP during the simulation.

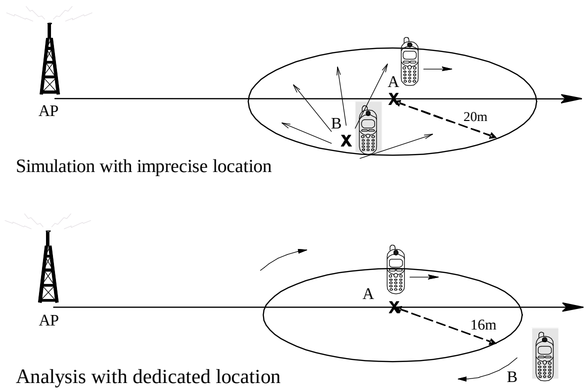

Figure 3: Simulation/Analysis of inaccuracies of localization in HIS

An arbitrary position B with respective accuracy and precision as described previously is drawn every meter the terminal position A has moved from the AP and radio conditions are being correlated. The results of the simulation are shown in Figure 4, represented by the cloud of correlation spots. For verification of the simulation results an analytically derived curve is also added, derived from a scenario as also shown in Figure 3. Calculating the expected value for the parameter couple accuracy and precision (20m, 67%) results in a distance value of E_D(A,B)=16m. To model the equally distributed angle as done for the simulation, the estimated position B is assumed to round the 16m circle of position A, once for each distance D(AP, A). The corresponding correlation due to formula 1 is also shown in Figure 4, indicated by the solid curve. Obviously, analysis and simulation match quite well shown by the simulation spots being placed around the solid curve’s position. Both results point out that the correlation of radio condition at real and estimated position increases with rising distance from the access point.

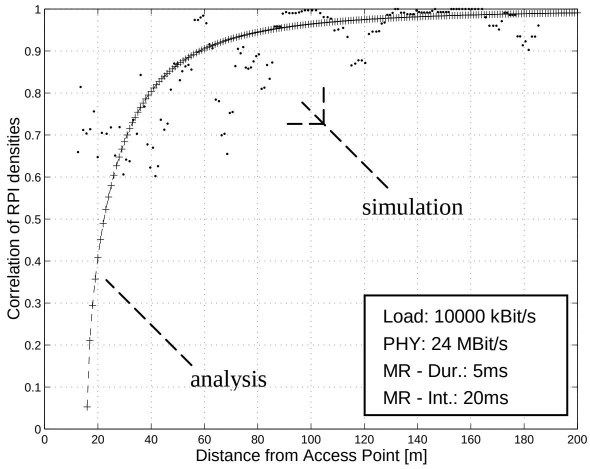

Figure 4: Distance dependent correlation in HIS

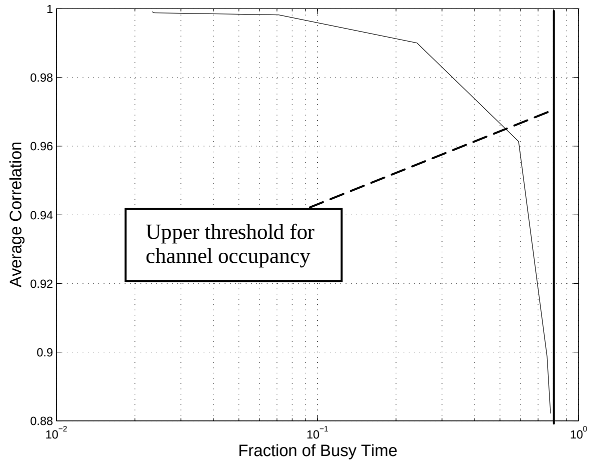

Figure 6: Dependency of HIS reliability on offered load

This can be explained with properties of radio wave propagation: Due to negative exponential attenuation characteristics, discrepancies in location estimation thus are more harmful close to the sender than far away. On the other hand this means, that applicability of foreign system based measurements, a key proposal of HIS, is most likely to be applied at the cell border.

Besides the fact that correlation improves at the cell edge, it is necessary to investigate whether the method itself is sufficient reliable to serve as a basis for handover decision. For this, Figure 5 shows the CDF of the correlation values for this scenario. One can see that almost 80% of the recorded correlations show a mapping of 0.8 or better and about 66% still reach a correlation value of at least 0.9. Such, one can objectively conclude that the localization estimation inherent imprecision most probably does not represent a disqualification criteria for HIS. This is an interesting observation having in mind that the main intention of HIS is to support (vertical) handover execution, a system function that mostly appears far away from the supplying AP.

Another question to be answered is whether the correlation of link budget at estimated and real position is dependent on the actual load in the scenario. For this, the same scenario as shown in Figure 3 was chosen and the offered load was successively increased.

Using a fixed PhyMode of 16QAM1/2, this is equal to increasing the fraction of busy time, as shown in Figure 6. One can see that the correlation is dependent on the busy time such that it gets worse with increasing load. The reason for this lies in the way, 802.11h reports measurements. As described in Section 4.B, measurements are reported and evaluated as RPI histogram with 8 classes. Obviously, if only little traffic is generated, most of the reported measurement period account for RPI class 0, which means, only background noise is recorded. Since this was assumed to be omnipresent, it is evident that there is no difference in signal reception at position A and B and thus the corresponding correlation C denotes to 1. If the amount of traffic is piecewise increased, the RPI density is distributed differently and the respective overall correlation decreases. However, one can state that even for saturation the channel is not permanently busy due to 802.11 inherent idle times (SIFS, DIFS) and back off procedures. Such there is an upper threshold for channel occupancy (depending on the scenario, participating terminals, packet length, RTS/CTS the maximum fraction of busy time varies, but this is not scope of this paper). However, for the upper threshold of channel busy time as found here, approximately 80% of time, a final overall correlation value of 0.88 adjusts, which means, information gathered from HIS are sufficient reliable, hardly influenced by the offered load.

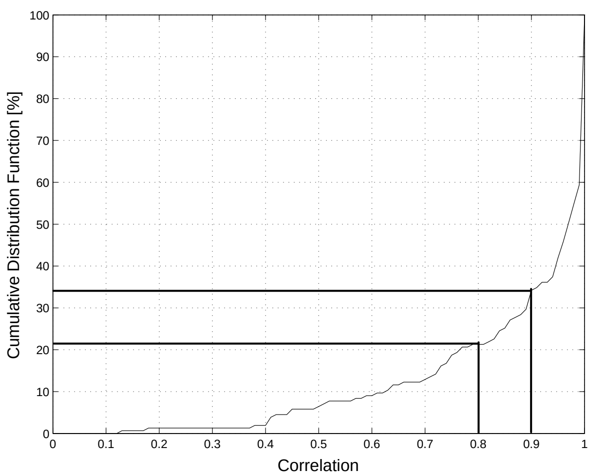

Figure 5: Reliability potential of applied HIS

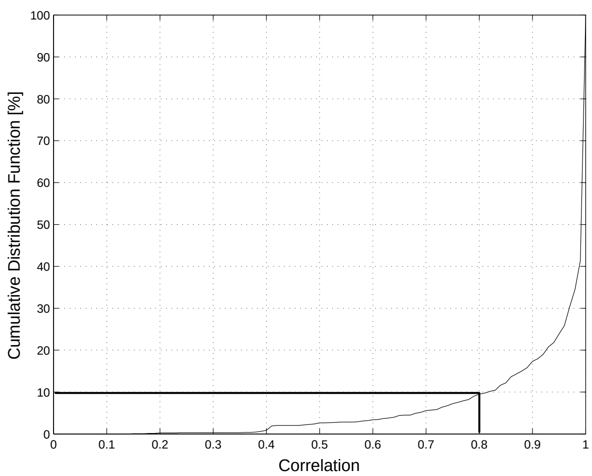

Figure 7: Reliability of HIS for various traffic loads

This fact is also expressed by Figure 7, considering all kind of loads offered during the simulation runs. One can see that 90% of the correlation values denote above 0.8. Such, one can objectively conclude that as for the distance investigation, the offered load most probably does not represent a disqualification criterion for HIS.

6. Applying HIS for handover support

As stated in Sec. 2, a sophisticated integration of heterogeneous wireless networks is only feasible if the presence or absence (coverage) of respective RANs (handover candidates) with respect to the current location of a mobile with an active connection is known. Therefore, scanning procedures usually are applied in current systems to detect the presence of RANs in the surrounding of the mobile. If a complementary RAN is detected, information is gathered to decide on a VHO to this RAN. Instead of scanning, in this paper HIS provides this information to the mobile, e.g. by means of in-band signalling. Two cases have to be distinguished for VHO: Upward VHO and Downward VHO.

Upward VHO refers to the case where a mobile changes its point of access from a RAN with small cell radius (pico cellular) to a RAN with bigger cell radius (macro cellular), e.g. from WLAN to UMTS. This kind of handover is time critical since the active connection of the mobile would break if the coverage of the WLAN ended before the handover to UMTS is executed. However, in this case the mobile has an unambiguous criterion, when scanning should be started namely with decreasing link quality. Hence, the upward VHO serves as a means to maintain an active connection and scanning, with its negative impact on the overall system performance, can be restricted in time and thus is less harmful. However, with HIS there is no need for scanning at all.

In contrast to this, the downward VHO is very likely to be used to enhance the performance of a currently employed service. A subscriber using a high bit rate data service in UMTS will presumably try to handover from UMTS to WLAN to increase the maximum possible throughput. The timelier the handover can be performed, the greater is the gain for the subscriber in terms of higher throughput. This in turn means that a continuous scanning has to be performed to timely detect a possible handover candidate. Against this, the HIS tracks the position of the mobile and will announce possible handover candidates if the mobile approaches the coverage area of a respective RAN. The time consuming continuous scanning procedure can thus be entirely inhibited. To quantify the gain of a timely downward VHO the following scenario has been investigated: A mobile is connected to system 1 (AP 1) with the data rate TP1 and approaches the coverage area of a system 2 (AP 2) with a higher date rate TP2>TP1. To achieve maximum throughput, a VHO to AP2 is aspired as early as possible. Obviously, the earliest possible

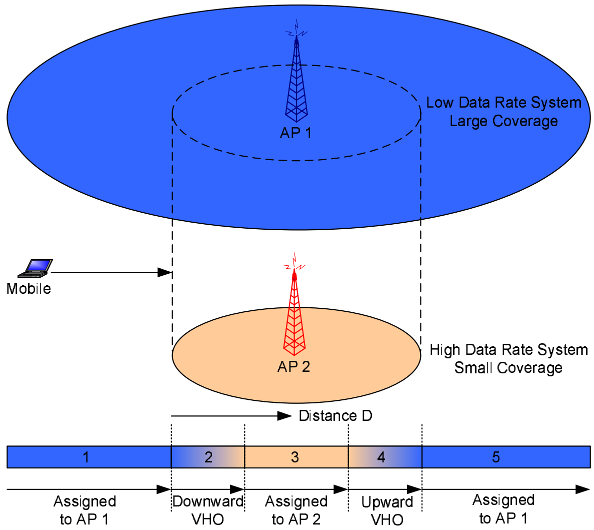

Figure 8: Simulation Scenario with VHO trigger by HIS

time is when entering the coverage area of AP2 (D=0, ‘optimal handover point’). Staying connected to AP1 though AP2 would be available therefore directly is related to losses in terms of throughput. It was stated earlier that due to performance reasons a permanent scanning of candidate systems is not feasible. Thus, the solution is to provide the trigger to handover via the HIS. Due to foreign party based measurements the HIS holds information on the link budget for each position within its administration area and by evaluation of the estimated position of the mobile, a VHO may be triggered. Obviously, the time interval for the location updates is an important parameter in this consideration.

Figure 9 gives an impression of the dependency of the distance D from the optimal handover point (D=0) on the location update interval. One can see that, depending on the update interval, the VHO handover maybe triggered more or less accurately. For CDF values equal to 100%, all handovers have been executed, e.g. for an update interval of 1s, all handovers have been executed after a distance of D=12,5m. An interesting effect can be seen for twice the update interval (2s).

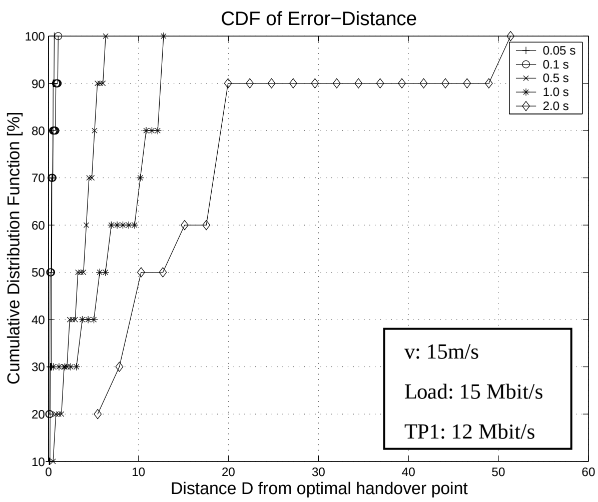

Figure 9: Impact of the location update interval on optimal handover execution

Here 90% or the handovers are executed within a distance of D=20m, but a remaining number of connections refuses to handover and stays connected to AP1 for another 30 meters before switching. Obviously, the trigger for handover was either not sent due to positioning malfunction or it was sent, but did not reach the mobile due to possible collisions. Such, in these cases the mobiles stay connected to AP1 until the next trigger 2s later (corresponding to 30m for v=15m/s) is evaluated.

7. SUMMARY AND CONCLUSION

Within this paper a new approach, called Hybrid Information System (HIS), supporting system integration efforts for next generation wireless mobile communication systems is presented and investigated with respect to its applicability to serve as a decision basis for vertical handover execution. Based on the observation that there is a vital interest on migration of services as offered by upcoming Wireless Local Area Networks (WLANs) and 3G systems (UMTS), the Hybrid Information System (HIS) offers an interesting concept to support information exchange between heterogeneous systems. One main aim is to employ foreign (vertical) system based measurements in order to avoid complex self-conducted scanning procedures of one or several complementary networks. One essential enabling technology for the applicability of HIS is the proper localization of the mobile with sufficient high granularity and precision. Therefore this paper summarizes and classifies localization methods as applied today and gives an overview of their respective properties. Due to field trials, realistic localization accuracies and precisions are known and served as underlying assumption for subsequent simulations and analysis concerning the applicability of HIS. A further section describes in detail, which specific measurement procedures and reports are available due to respective standards in order to serve as an input for HIS. Since that information shall be used in a hybrid system context, it is necessary to investigate how reliable they are. Due to location estimation inherent imprecision, one cannot simply overtake other measurements but needs to consider their fuzziness with respect to the local position. Therefore, a model of imprecise localization was presented that together with an objective measure, the correlation of radio link between real and estimated position, shall allow to come to a statement concerning the applicability of HIS. It was shown by simulations and analysis that the concept entails a distance dependency that is even advantageous since functionality is best at the cell edge where handovers take place most. Additionally, it was investigated whether the current cell load has a negative impact on the concept applicability but the sensitivity was proven to be fractional.

Once the applicability of HIS was found to be sufficient safe, it was shown that a timely downward VHO execution should be aspired. Since scanning for the presence of a heterogeneous system is not appropriate in sufficient small time intervals, the handover trigger was achieved via the HIS. It was further shown that the time interval of location update hereby plays an important role. If the HIS evaluated localization is network-based, rather short update intervals and respective efficient handover can be triggered.

Besides the so far mentioned advantages, the HIS allows for a plethora of new concepts that can be applied to mobile radio networks. One can think of algorithms for dynamic electric down tilt adjusting for antennas to adapt to different loads or to increase/optimize coverage. Strictly speaking, each algorithm/concept relying on location based information of a mobile radio network can use HIS to obtain the necessary input.

Further investigations in this field need to address correlation issues in the time domain, namely how long existing measurement reports keep significance to serve as decision basis for other systems.

REFERENCES

[1] Vodafone Press Releases, 6 June 2003 Vodafone Germany, *"Lufthansa lounges in Frankfurt equipped with WLAN offering of Vodafone D2"*

[2] MIND, IST-2000-28584, http://www.ist-mind.org

[3] TONIC, IST-2000-25172, http://www.ist-tonic.org

[4] E. Mitjana et al., *"Seamless IP service provision: techno-economic study by the MIND and TONIC projects"*, IST Mobile & Wireless Summit '02, Thessaloniki, Greece, June 2002

[5] Swisscom homepage, *"Public Wireless LAN"* http://www.swisscom-mobile.ch/sp/4EGAAAAA-de.html

[6] ANWIRE, IST-2001-38835, http://www.anwire.org

[7] ETSI BRAN TR 101 957, *"Requirements and Architectures for Interworking between HIPERLAN/2 and 3rd Generation Cellular Systems"*, V1.1.1 (2001-08)

[8] 3GPP TR 22.934 V2.0.0 (2002-09), *"Feasibility study on 3GPP system to Wireless Local Area Network (WLAN) interworking"*, Release 6

[9] NEXWAY IST-2001-37944 Deliverable No. 2.1, *"Collection and Compilation of an Overview of Publicized R&D Programmes"*

[10] M. Siebert et al., *"Towards an ANWIRE B3G Wireless System Integration Architecture"*, Wireless, Mobile and Always Best Connected, Proc. of the 1st International ANWIRE Workshop, Glasgow, April 2003

[11] ANWIRE IST-2001-38835 Deliverable 1.5.1, *"Integrated System and Service Architecture"*, June 2003

[12] Siebert, Schinnenburg, Lott, *"Enhanced Measurements Procedures for Vertical Handover in Heterogeneous Wireless System"s*, 14th IEEE Int. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), September 7-10, 2003, Beijing, China

[13] H. Laitinen et al., *Database correlation method for GSM location"*, IEEE VTC 2001 Spring Conference, Rhodes, May 2001

[14] L. Rabiner, *"A Tutorial on Hidden Markov Models and Selected Applications in Speech Recognition"*, Proc. of the IEEE, vol. 77, pp. 257–286, Feb. 1989.

[15] IEEE. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. Technical report, IEEE Computer Society, 1999, ANSI/IEEE Standard 802.11, 1999

[16] IEEE 802.11h. Part11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Spectrum and Transmit Power Management extensions in the 5GHz band in Europe, IEEE, May 2003

[17] CELLO IST-2000-25382, H. Laitinen et al., Del. 3: *"Cellular Location Technology"*, Nov. 2001, http://www.telecom.ece.ntua.gr/cello/

[18] H.D. Lüke, *"Signalübertragung"*, Springer, Berlin, 2002 ISBN: 3540677682 S.75 – 85