Cost-Effective and Feasible Handoff Application for Mobile Phones

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***Abstract*—Heterogeneous networks with different wireless technologies increase the availability of Internet services (i.e., cloud services). However, latest mobile phones with at least two interfaces only access these services either via WiFi or UMTS/HSPA. From user's view, an optimal use of heterogeneous networks with today's mobile phones includes seamless data transmission using vertical handoff (VHO) solutions. Caused by high technical and economic costs there exist no usable solutions for readily seamless data transfers. To benefit earlier from seamless service provisioning, we present a feasible client based handoff management solution for mobile phones (CSH-MU) with embedded vertical handoff decision algorithm (VHDA) that considers mobile device's power consumption for WiFi and UMTS communication. As proof of concept and for performance evaluation, a prototype is tested on different mobile phones in a real test bed for TCP and UDP based applications. The results show that the proposed solution is not only a feasible, but also a readily usable solution for mobile phones as well as outperforms network based solutions in terms of handoff delay. A further advantage is the cost-effective and immediate integration in current mobile phones without requiring any changes in the used wireless network technologies (e.g., UMTS, WiFi).**

***Keywords*-Vertical Handoff; Energy-Efficient; Client based Mobility Solution.**

I. INTRODUCTION

A. Motivation

The success of an emergency operation management is closely related to the availability of information about the large scale disaster situation (i.e., size and details of corrupted area, actual traffic data, injured persons). The high coverage area of cellular networks is not sufficient in disaster situations caused by high traffic and possible network failures. Therefore, different options for mobile communication and data transmission are necessary. For instance, an emergency WiFi network can be established in a short time and ensures a high WiFi availability for accessing emergency services in the corrupted area [1]. Furthermore, a continuous data transmission is indispensable for the success of an emergency operation management where a seamless vertical handoff has to be handled in a cost-effective, energy-efficient and transparent manner. The latter guarantees that Emergency Personnels can focus on their actual areas of responsibility. There exists plethora of mobility solutions (e.g., MIPv6/NEMO, mSCTP, IEEE 802.21, SIP) which are, however, coupled with high cost for technical integration. As a result, no service provider offer seamless data transfer and wireless applications over the today's available heterogeneous network environment (e.g., UMTS/HSPA, IEEE 802.11).

In view of these restrictions, a client based solution for seamless service provisioning in emergency use cases allows a cost-effective integration without requiring any changes in the architecture of client and network technologies. Tran et. al present a *Client based Secure Handoff for Mobile Units* (CSH-MU) in [2] and [3] that outperforms related solutions (e.g., MIPv6/NEMO). In contrast to our study the results are based on experimental tests using laptops instead of mobile phones. To complete and enhance this handoff management application, embedding a readily usable *Vertical Handoff Decision Algorithm* (VHDA) for mobile phones is needed that permits a simple installation of CSH-MU with embedded VHDA (aCSH-MU) in expandable operating systems (e.g., Android, iOS). However, the variety of well explored vertical handoff decision algorithms [4] is too complex for the immediate use of mobile phones. Moreover, these approaches are based on decision criteria that are not accessible for mobile phones (e.g., interference). The regard of restricted system resources is essential for efficient mobile applications. Besides, an embedded VHDA may not increase the power consumption of mobile phones and affect negatively the handoff performance of CSH-MU.

B. State-of-the-art Analysis

Existing mobility solutions are not applicable in real environment using mobile phones caused by high integration cost [3]. Therefore, a client based mobile solution for seamless vertical handoff management can enhance the usability of seamless service provisioning. In [2] and [3], the authors present a *Client based Secure Handoff for Mobile Units* (CSH-MU) solution that provides a service for seamless handoff combined with low integration cost for laptops and requires no changes in the network infrastructure. However, the proposed CSH-MU framework does not include any VHDA. Moreover, the applicability and performance of this solution have not been analyzed yet on mobile phones with limited system ressources.

There exists a wide variety of different and well studied VHDAs with different complexities (i.e., run time). A survey about latest VHDA is given in [4] and concludes that VHDAs are not yet applicable for the use in mobile phones in a real environment. Well studied methods for vertical handoff decisions are based on Fuzzy logic [5], Markov processes [6] and cost-functions [7]. Besides, there exist new approaches like Kalman filtering [8] for handling fluctuating data of RSS and other decision criteria. However, still important is the energy-efficient feasibility on mobile phones (i.e., smartphones) and a cooperation with CSH-MU. The mentioned VHDAs do not consider the restricted resources of such phones (e.g., accessible decision criteria and power consumption). The development of VHDAs for mobile phones has to be strictly oriented on such accessible decision criteria and may not increase the power consumption.

For this reason, power consumption of mobile phones using different wireless access technologies should be considered in VHDA. The authors in [9] analyzed the power consumption of three radio interfaces of a mobile phone. A more detailed measurement for UMTS and WiFi is presented in [10]. The results show that turning on two radio interfaces at the same time consumes very high power. Therefore, vertical handover decision algorithms have to act as energy-efficient as possible. In [11], experimental results of VHDAs based on RSS and throughput illustrate that the handoff delay can increase to high values, whereby the mobile device's power consumption is not analyzed.

Regarding the restricted resources of mobile phones, especially power consumption and accessible decision criteria, for designing a readily usable solution running only on client side without requiring any changes on network side are the key challenges addressed in this paper. Therefore, the power consumption for active data transmission is analyzed in real measurements. Moreover, the reliability and performance of the proposed solution is tested in a real environment using two different mobile phones. The integration on mobile phones is realized in a cost-effective manner (e.g., installation of an application for Android, iOS).

The paper is structured as follows: In Section II, we present the mobile handoff management system architecture with focusing on the embedded VHDA. This algorithm considers the power consumption of UMTS and WiFi that are analyzed in real measurements. Section III describes the performance analysis of our implemented prototype as proof of concept. Moreover, the results of complexity (e.g., run time and storage) and handoff delay are discussed followed by a conclusion in Section IV.

II. System Architecture of Client Based Handoff Management

This section introduces the components of our proposed mobile service solution. The solution running on client side only is adapted to the framework called *Client based Secure Handoff for Mobile Units* (CSH-MU) by Tran et. al [3] that is responsible for the interface switching during handoff. Therefore, the focus lies on the embedded vertical

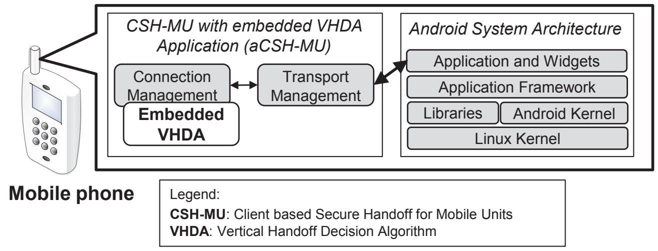

Figure 1. VHDA integrated in CSH-MU system architecture

Table I
Minimum and Maximum Values for RSS used for Normalization obtained from measurements

RSS	Minimum [dBm]	Maximum [dBm]
UMTS	-113	-51
WiFi	-98	-7

handoff decision algorithm (VHDA) preferring WiFi caused by its lower power consumption in average, which is derived from results presented in Section II-A. Figure 1 shows the architecture specially designed for mobile phones.

The CSH-MU consists of two main modules and works beyond the application layer (ISO/OSI reference model). This feasible solution runs completely on client side and requires no changes on network side or at the used hardware of mobile phones. The first *Connection Management* (CM) module controls the wireless status (UMTS, WiFi) of mobile phones. For enhancing the handoff decision, the VHDA is embedded in this CM module where CM forwards decision criteria (e.g., RSS) to the VHDA. In case of handoff, the CM interacts with the *Transport Management* Module (TM) to resume the communication over a new network interface. The TM module controls the connection and data transmission to different service providers. More specific details of CSH-MU are given in [2].

A. Feasible Embedded Vertical Handoff Algorithm

We use a field-tested vertical handoff approach based on RSS that prefers WiFi. According to power measurements with mobile phones, presented in Section II-B, we assume that WiFi performs better compared to UMTS in terms of lower power consumption due to higher throughput. Since the RSS of UMTS and WiFi cannot be compared directly due to their diverse range of transmission, the RSS of both networks has to be normalized as follows:

$$N_{RSS}^{i} = \frac{RSS_i - RSS_{i,min}}{RSS_{i,min} - RSS_{i,max}} \quad (1)$$
$$\text{with } i = \{\text{UMTS, WiFi}\}.$$

Table I specifies the minimum and maximum values for RSS used for normalization. The values are determined from the experimental test bed (see Section II-B).

The network with the highest N_{RSS}^{i} value is marked as target network and is going to be chosen for active data

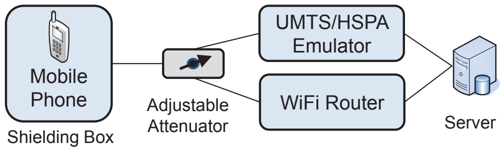

Figure 2. Test bed including WiFi and UMTS for the analysis of power consumption

transmission if the following condition is fulfilled:

$$(N_{RSS}^{current} < T_i) \cap (N_{RSS}^{target} > N_{RSS}^{current} + V_i). \quad (2)$$

The parameter $N_{RSS}^{current}$ describes the normalized RSS of the current network. To avoid ping-pong effects, the decision process concerns the parameters T_i and V_i. The threshold T_i is defined and assigned with different values for UMTS and WiFi. This avoids unnecessary handoffs during optimal stable connections. For example, T_{WiFi} is assigned to -69 dBm and T_{UMTS} to -88 dBm, whereby T_i is the lower bound of upper third RSS values. The parameter V_i is used to consider RSS fluctuations and is set to $+3$dB as it is often used in practice [12]. For our VHDA, we assume WiFi networks are always preferred due to higher throughput, lower cost and power consumption on average. The next section discusses the average power consumption derived from real measurements using a mobile phone.

B. Discussion of Power Consumption using WiFi and UMTS/HSDPA

To proof the energy-efficiency of WiFi, we measure the power consumption of a mobile phone (Samsung Galaxy S I9000) during active downloads using TCP and UDP via WiFi and UMTS/HSDPA. A developed Android application protocols the remaining energy level (in mAh) and controls the download activity. Figure 2 depicts the experimental test bed for analyzing the power consumption.

For minimizing outdoor effects and fluctuations of RSS, the mobile phone is placed in a shielding box. The adjustable attenuator is used to control the moderation of RSS. So it is feasible to simulate different conditions of RSS. Therefore, the power consumption is analyzed under different influences of UMTS power control. An overview of the used equipment in the measurement test bed is given in Table II.

For analyzing the power consumption, the range of RSS is divided in three equal sized intervals for each network (WiFi, UMTS), which are defined as follows:

$$\text{good}: \begin{array}{ll} \text{UMTS} & RSS \in [-88, -51] \text{ dBm} \\ \text{WiFi} & RSS \in [-69, -50] \text{ dBm} \end{array} \quad (3)$$

$$\text{medium}: \begin{array}{ll} \text{UMTS} & RSS \in [-102, -89] \text{ dBm} \\ \text{WiFi} & RSS \in [-89, -70] \text{ dBm} \end{array} \quad (4)$$

$$\text{worse}: \begin{array}{ll} \text{UMTS} & RSS \in [-113, -103] \text{ dBm} \\ \text{WiFi} & RSS \in [-98, -90] \text{ dBm} \end{array} \quad (5)$$

The intervals are considered by analyzing the measured throughput. A maximum throughput can be achieved at *good* RSS, whereas the interval *medium* still contains maximum throughput, but is associated with an increased power consumption caused by UMTS power control. At *worse* RSS the throughput decreases to minimum. For instance, the interval *good* contains RSS values indicating good link quality and contains one third of overall RSS values. The interval *good* implies the values set for parameter T_i in VHDA.

Table II
SPECIFICATION OF THE EQUIPMENT USED IN THE TEST BED

Test Bed Specification	
Mobile Phone	Samsung Galaxy S I9000, Android 2.3.3
Shielding Box	Rohde & Schwarz CMW Z10
Adjustable Attenuator	Trilithic Asia
WiFi Router	Linksys WRT54GL, 54 Mbit/s
UMTS/HSPA Emulator	Rohde & Schwarz CMU200 UMTS/HSPA Emulator (DL: 7.2 Mbit/s)
Server	Dell Latitude E6420XFR Intel Core i7-2620M 2.7 GHz 4 GB RAM

Table III
AVERAGE POWER CONSUMPTION OVER FULL RANGE OF RECEIVED SIGNAL STRENGTHS (SEE FIG. 3)

Average Power Consumption	**TCP**	**UDP**
UMTS	520 mA	520 mA
WiFi	337 mA	464 mA

A linear function is derived by polynomial fitting of the measured energy level using Matlab [13], based on the assumption of a linear battery discharge. The gradient of the linear function is synonymous with the average power consumption in mAh/s (= 3600 mA). Figure 3 compares the average power consumption of UMTS and WiFi depending on different RSS intervals. As evident from this figure, the average power consumption for TCP download applying UMTS and WiFi is nearly equivalent in the interval *good*. In contrast, the UDP download over UMTS is more energy-efficient than WiFi due to higher throughput. Considering the *medium* interval of RSS, the average power consumption increases for TCP traffic and UDP traffic using UMTS. In case of UMTS, the impact of power consumption is enhanced at *worse* RSS conditions since the UMTS power control rises the transmission power of the mobile phones. The power control is responsible for preserving the quality of the connection as good as possible to enable a high throughput.

Table III lists the average power consumption over full range of RSS based on Figure 3. The results show that the power consumption for UMTS is higher than for WiFi caused by high transmission power regarding *worse* RSS of UMTS. This fact confirms the use of the above described VHDA preferring WiFi.

Note, there exist specific cases where the use of WiFi is related to a lower throughput and a higher power consumption compared to UMTS. But the focus of the application still lies on a readily mobile solution. The optimization

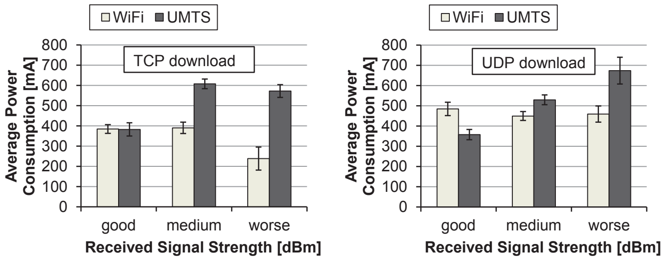

Figure 3. Average power consumption for different intervals of RSS for UMTS and WiFi during active TCP/UDP download

of VHDA and the identification of all specific cases (i.e., interference by other users, fluctuating throughput, different applications) will be addressed in future work. In spite of these facts, the applicability of our proposed solution is given for emergency situations where WiFi networks are used as alternative technology [1].

III. Performance Evaluation

This section discusses the impact of the embedded VHDA in terms of complexity and handoff delay. The complexity is evaluated by means of run time and needed storage. The handoff delay caused by handoff execution is denoted as the time gap between the handoff decision and the completion of interface switching (e.g., UMTS to WiFi) from client's point of view. The experimental results are compared to standard mobility solutions (i.e., mSCTP, MIPv6).

A. *Real Test Bed for Proof of Concept*

Figure 4 shows the test bed under real conditions used for performance evaluation. The experimental tests were performed in the library of the TU Dortmund university that contains a public WiFi access point (SSID: ITMC-WPA2) and is overlapped by the German cellular network provider T-Mobile. For active data transmission, a server is located within the university network at the chair of communication networks institute (CNI). The mobile phones (Samsung Galaxy S I9000 and Samsung Galaxy S I9100) with especially developed Android applications for CSH-MU and embedded VHDA download data from this server continuously.

To force different combinations of RSS, the mobile phone moves with walking speed (3-4 km/h) from the window front to the internal staircase of the building and vice versa for ten minutes while downloading data.

B. *Complexity of Proposed VHDA Solution*

During experimental tests, we protocol the run time of the embedded VHDA and the assigned storage of our proposed solution. Figure 5 shows that average run time and storage are sufficient for the restricted resources of different mobile phones. Due to this fact, the feasibility of our handoff management solution is given. Moreover, the increasing performance of mobile phones is suitable

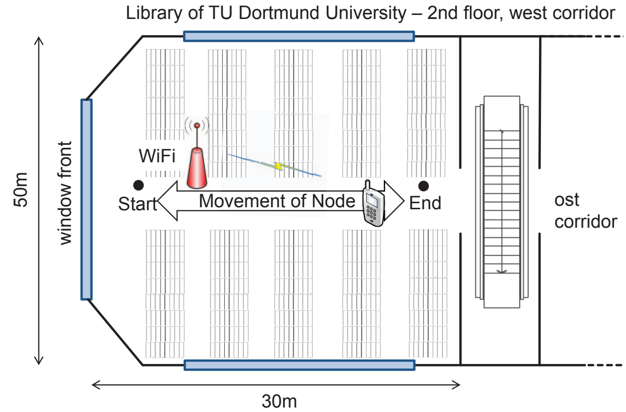

Figure 4. Real test bed for VHDA measurements using a public WiFi hotspot and public cellular network

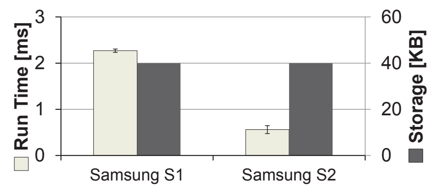

Figure 5. Average run time and storage of embedded VHDA in handoff management solution for different mobile phones. Important: The run time only includes execution time of VHDA.

for more and more complex mobile applications. However, it is important to consider the restricted resources during application development (i.e., power consumption, restricted access to decision metrics).

C. *Discussion of Handoff Delay Times*

A small handoff delay is very important for seamless data transfer and lower power consumption. Since a seamless handoff processing maintains two connections in parallel, this is related to a higher power consumption. To process handoff transparently from users of mobile phones, a small handoff delay is indispensable.

Figure 6 compares the handoff delay of our proposed solution to standard mobility solutions (e.g. mSCTP, MIPv6). The results of the standard mobility solutions are based on [2]. It should be noted that the results as shown in Figure 6 are not directly comparable due to different experimental test beds. Our results are obtained by experimental tests using mobile phones, whereas the results of the related solutions [3] are based on measurements using laptops. However, the handoff delay using CSH-MU combined with our proposed VHDA indicates a better handoff performance up to 85 % in average in case of handoff from UMTS to WiFi.

In general, the handoff delay is higher when switching to UMTS network caused by the specific signaling process of UMTS. To sum up, the CSH-MU with embedded VHDA running on mobile phones is not only a feasible and a

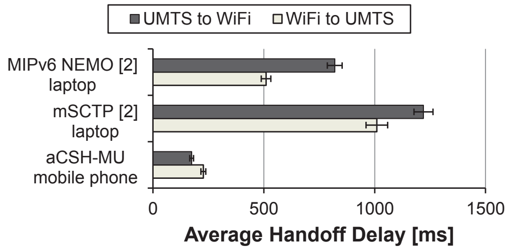

Figure 6. Comparison of average handoff delay times for different mobility management solutions

cost-effective solution, but also an efficient approach that outperforms related mobility solutions in terms of lower handoff delay.

IV. Conclusion and Future Work

In this paper, we presented a feasible handoff management solution (CSH-MU) with embedded vertical handoff decision algorithm (VHDA) based on RSS and power consumption for mobile phones with restricted system resources (e.g., limited access to decision metrics, battery life). Unlike related mobility solutions (e.g. mSCTP, MIPv6) and well studied decision algorithms, our approach can readily used on latest mobile phones as well as works without any changes in the network infrastructure. The proposed embedded VHDA optimizes the use of mobile phones especially in emergency situations and presents a novel solution for mobile phones of overall users in a heterogeneous network environment (i.e., train, airport) because of its simple integration.

Moreover, the experimental results of the analyzed complexity show that latest mobile phones are able to handle our client based mobility solution for seamless interconnection. As proof of concept, the CSH-MU with embedded VHDA has been implemented as a prototype and tested in a real environment. Confirmed by experimental results, our implemented prototype improves the handoff performance up to 85 % in comparison to other standard mobility solutions.

In future work, we plan to optimize vertical handoff algorithm by considering a more precise energy model to continuously lower the power consumption of mobile phones.

Acknowledgment

The authors would like to thank Ahmet Tosun for his technical assistance.

Our work has been partially conducted by the Sec^2 project (Secure Ad-hoc On Demand Virtual Private Storage), which is funded by the German Federal Ministry of Education and Research (BMBF) (01BY1031). Part of the work on this paper has been supported by Deutsche Forschungsgemeinschaft (DFG) within the Collaborative Research Center SFB 876 ”Providing Information by Resource-Constrained Analysis”, project A4.

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