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Energy-efficient Handoff Decision Algorithms for CSH-MU Mobility Solution

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***Abstract*—Vertical handoff (VHO) is the key feature to increase the seamless services availability (i.e., cloud services) in a heterogeneous network environment that especially plays an important role in emergency use cases for reliable information retrieval. For precise handoff decisions, latest proposed vertical handoff decision algorithms (VHDA) are, however, too complex and do not consider the restricted access to decision metrics of mobile phones with limited system resources. For addressing this issue and to benefit earlier from seamless service provisioning, we present feasible client based VHDA solutions ensuring context-aware QoS (i.e., high throughput, low power consumption) for specific use cases. Unlike related approaches, our solutions run completely locally on mobile phones without any required modifications on network side. In terms of performance analysis, we design a comprehensive simulation model for comparing the suggested VHDA solutions with different complexity levels. Moreover, we analyze the impact of an energy model, which is derived from experimental measurements, on handoff decision quality and the improvement of battery usage. Simulation results illustrate that VHDAs with energy model enhance the QoS of handoff decisions in terms of high throughput and low power consumption compared to a less approach.**

I. Introduction

A. Motivation

In recent years, the popularity of mobile Internet is growing steadily with the successful progress in the development of mobile communication technologies like UMTS/HSPA, LTE and WiFi. This trend is clearly shown by the fact that, e.g., each inhabitant in Germany possesses 1.3 SIM cards on average for its mobile phone or Tablet-PC [1]. Despite the given heterogeneous networks and although latest mobile phones have at least two wireless interfaces, hardly anyone of the service providers supports Vertical Handoff (VHO) technology for providing seamless service provisioning across the today's existing network infrastructure due to the high integration costs. VHO enables, e.g., emergency personnels seamless access to emergency services and context-aware information over different mobile access technologies while moving to an incident scene. Context-aware QoS provisioning (e.g., high throughput, low power consumption) is a key challenge to guarantee the success of an emergency operation management.

Due to the importance of VHO in emergency use cases [2], we proposed a cost-effective *Client based Secure Handoff for Mobile Units* (CSH-MU) solution that not only performs better compared to standard mobility approaches (e.g., NEMO/MIPv6, mSCTP), but it also offers a less expensive option without any required changes in the underlying network layers [3]. The software based CSH-MU solution runs completely locally on mobile phones that is responsible for the handoff execution.

For high quality of handoff decisions and for achieving good context-aware QoS, CSH-MU needs an energy-efficient *Vertical Handoff Decision Algorithm* (VHDA) that has to completely deploy on a mobile phone like CSH-MU. However, latest VHDA approaches are too complex and require changes on client as well as on network side. Moreover, limited access to decision metrics (e.g., SINR=Signal to Noise and Interference Ratio) in mobile phones is not considered.

Apart from that, the realization of a feasible VHDA solution for CSH-MU guaranteeing ubiquitous connection to services becomes even more challenging when contrasting context-aware QoS parameter, e.g., high throughput and low power consumption have to be fulfilled simultaneously.

B. State-of-the-art Analysis

Current VHDA solutions introduced like in [4] propose fuzzy logic based VHD algorithms that are one of the most popular methods. Further up-to-date VHDA approaches are based on combination functions (with, e.g., SINR and throughput) [5] or on service history of user traffic for precise handoff decision. The latter performs better than existing VHO algorithms such as Simple Additive Weighting (SAW) and Multi-dimensional Adaptive SINR based Vertical Handoff algorithm (MASVH) [6]. However, neither of them tackles the issue of power consumption and particularly with regard to limited resources in mobile phones. In [7], the authors formulate the network selection decision process as a Multiple Attribute Decision Making (MADM) problem where the power consumption is only considered as one of the metrics for deciding handoff. An analysis of the power consumption coupled with different applications (time- and non-time-critical) based on received signal strength (RSS) as evaluation criteria is, however, not provided. The authors in [8] regard the power consumption in their suggested cost function based VHDA for WWAN/WiFi integrated networks. This proposed VHDA is implemented on network side and the expected power consumption is only calculated on behalf of the WiFi access points and WWAN base stations. Another approach developed a neural network based algorithm that is distributed on client and network side for optimizing the radio resource usage of an integrated network [9]. In consideration to the property of CSH-MU, the complexity of the previously presented VHDA solutions is too high that delays the readily use of these algorithms on mobile phones with limited resources [10].

In the context of emergency management services (e.g., fire brigade, paramedical units, police etc.), the provisioning of latest context-aware information in real time is critical to the mission success [2]. To benefit earlier from seamless service provisioning, this mandates the development of a deployable VHDA solution for CSH-MU that enhances the throughput and reduces the power consumption at the same time. As like CSH-MU, the aimed VHDA must run completely on mobile devices without assuming any changes on network side.

The remainder of this paper is structured as follows: In Section II, we present our deployable VHD algorithms. After this, the energy model is introduced deriving from experimental measurements in Section III. To ascertain operational and functional boundaries, we develop a comprehensive simulation model that analyzes the impact of an integrated energy model example in proposed VHDAs on the handoff decision qualities in terms of throughput and power consumption (Section IV), followed by a conclusion.

II. Client based Handoff Decision Algorithms (VHDA) for CSH-MU Mobility Solution

The presented VHDAs consider the property of CSH-MU and only apply decision metrics that are accessible by mobile phones. The power consumption values, used in two VHDAs, are based on the energy model developed in Section III.

A. Fuzzy VHDA as Reference for Comparison

The Fuzzy VHDA consists of three main steps: Fuzzification of metrics, membership value evaluation, and handoff decision. Figure 1 highlights the procedure of the Fuzzy algorithm. For saving system resources of mobile phones, potential target networks have to be preselected by the following equation:

$$(RSS_{current} < T_i) \cap (RSS_{target} > RSS_{current} + H_i) \quad (1)$$

A handoff decison process is only initiated if the RSS of current network ($RSS_{current}$) is lower than a certain threshold T_i, which depends on the kind of network. Additionally, the second part of the equation compensates short term fading and prevents the ping pong effect by adding H_i to the RSS of current network.

1) Step 1: Fuzzification of Metrics: Heterogeneous metrics must be normalized with the following function:

$$N(x) = \frac{x - x_{min}}{x_{max} - x_{min}}. \quad (2)$$

The normalization process is required for enabling the comparison of values from different wireless access technologies (i.e., UMTS, WiFi). Each metric is set for the parameter *x*. Following accessible metrics are chosen for the Fuzzy algorithm: received signal strength (*RSS*), throughput (*D*), and CPU load (*CPU*).

2) Step 2: Membership Value Evaluation: Each of the normalized metric $N_i(x)$ is assigned to three Fuzzy variables (Low, Medium, High) using membership functions as shown in Figure 2. Values k_1^x and k_2^x describe the borders of the Fuzzy variables, and parameter *i* presents the corresponding network (UMTS, WiFi, etc.).

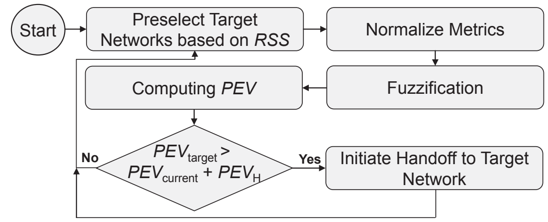

Fig. 1. Fuzzy-Logic based Vertical Handoff Decision Algorithm

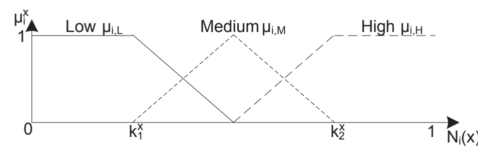

Fig. 2. Membership Functions for Decision Metrics

The membership degree of each metric, which is obtained from the membership function, is described by

$$\vec{\mu_i^x} = \left(\mu_{i,L}^x, \mu_{i,M}^x, \mu_{i,H}^x\right). \quad (3)$$

To compute the membership value mv_i^x for any metric *x* of *i-th* network, specific impact indexes $\vec{g_i^x}$ are required and defined as follows:

$$\begin{aligned} \vec{g_i^x} &= \left(g_{i,L}^x, g_{i,M}^x, g_{i,H}^x\right) \\ &= \left(\frac{N_i(x) - k_1^x}{k_2^x}, \frac{N_i(x) - k_1^x}{k_2^x - k_1^x}, \frac{N_i(x)}{k_2^x}\right) \end{aligned} \quad (4)$$

where *x* = *RSS, D, CPU*.

Impact indexes state how membership degrees will take into consideration of the calculation of membership value mv_i^x for *i-th* network that is given by:

$$mv_i^x = \vec{g_i^x} \cdot \left(\vec{\mu_i^x}\right)^T. \quad (5)$$

3) Step 3: Handoff Decision: To select the best fitting network, this step calculates the *Performance Evaluation Value* (PEV) for each network *i* that is defined as follows:

$$PEV_i = \vec{w} \cdot \left(mv_i^{RSS}, mv_i^D, mv_i^{CPU}\right)^T \quad (6)$$

where

- $\vec{w} = \left(w^{RSS}, w^D, w^{CPU}\right)$ describes the weights of each metric $x = RSS, D, CPU$.
- sum of all weights must fulfill the following condition:

$$w^{RSS} + w^D + w^{CPU} = 1. \quad (7)$$

After computing all PEVs, the target network with the highest PEV is chosen and compared with the PEV of the current network. A handoff to target network is only initiated if the following condition is satisfied:

$$PEV_{target} > PEV_{current} + PEV_H \quad (8)$$

where PEV_H ensures stable handoff decisions.

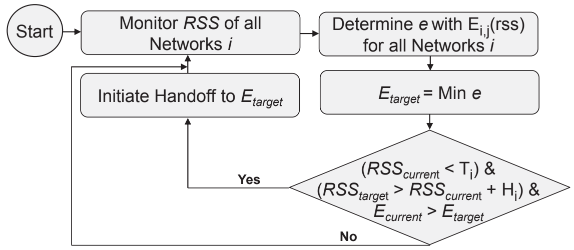

Fig. 3. E-RSS based Vertical Handoff Decision Algorithm

B. Enhanced Fuzzy (E-Fuzzy) with Energy Model

The Fuzzy VHDA described in Section II-A does not regard an energy model as handoff decision criteria. In order to consider the accurate client side's power consumption, a specific energy model derived from real measurements is integrated into the original algorithm as follows:

The energy function $E_{i,j}(rss)$ with network i and application j (TCP and UDP based applications) returns a power consumption value e in mA based on RSS. This value e is normalized depending on the minimum e_{min} and maximum e_{max} power consumption value (see equation 9).

$$N(E) = \frac{e - e_{min}}{e_{max} - e_{min}}. \quad (9)$$

To obtain the membership degree $\vec{\mu_i^E} = \left(\mu_{i,L}^E, \mu_{i,M}^E, \mu_{i,H}^E\right)$, new membership functions have to be developed defining as follows:

$$\mu_{i,L}^E(x) = \begin{cases} -5 \cdot x + 3 \text{ if} & x \in [0.4, 0.6] \\ 1 \text{ if} & x \in [0, 0.4] \\ 0 \text{ if} & x \in [0.6, 1] \end{cases} \quad (10)$$

$$\mu_{i,M}^E(x) = \begin{cases} 5 \cdot x - 2 \text{ if} & x \in [0.4, 0.6] \\ -5 \cdot x + 4 \text{ if} & x \in [0.6, 0.8] \end{cases} \quad (11)$$

$$\mu_{i,H}^E(x) = \begin{cases} 5 \cdot x - 3 \text{ if} & x \in [0.6, 0.8] \\ 1 \text{ if} & x \in [0.8, 1] \\ 0 \text{ if} & x \in [0, 0.6] \end{cases} \quad (12)$$

For instance, equation 10 defines the membership degree for the Fuzzy variable *Low*. As long as the input value x is less or equal 0.4, the membership degree is the highest with $\mu_{i,L}^E(x) = 1$, whereas other Fuzzy variables are equal 0. But if the input value is located in the interval [0.4, 0.6], the membership degree for *Low* is then determined by the linear equation $-5 \cdot x + 3$ with the borders $k_1^E = 0.4$ and $k_2^E = 0.8$. These borders are derived from a specific energy model that will be introduced in Section III where values from $k_2^E = 0.8$ indicate a high power consumption and values below $k_1^E = 0.4$ mean a low power consumption.

C. Enhanced RSS (E-RSS) VHDA with Energy Model

A RSS VHDA is extended by an energy model to enable energy-efficient handoff decisions and is referred to as *Enhanced RSS* (E-RSS). Figure 3 illustrates the procedure of the E-RSS VHDA. The algorithm monitors periodically the RSS of all networks. Based on the RSS, the power consumption value e for network i and application j is determined using the energy functions $E_{i,j}(rss)$ that are based on real measurements as described in Section III. The network with the lowest power consumption value is marked as E_{target} presenting a potential target network for handoff.

After normalizing the RSS of current and target network, a handoff is only initiated if the following three conditions are fulfilled:

1) Received signal strength of current network $RSS_{current}$ is below a threshold: $RSS_{current} < T_i$.
2) Received signal strength of target network RSS_{target} is higher than current network including variation H_i: $RSS_{target} > RSS_{current} + H_i$.
   H_i is +3dB same like used for RSS VHDA.
3) Power consumption value of target network E_{target} is lower than the current network $E_{current}$: $E_{target} < E_{current}$.

III. Design of Energy Model for Handoff Decisions

In order to enable energy-efficient handoff decisions, the VHDAs need an energy model. For this purpose, this section introduces a test bed allowing to derive an energy model for a certain mobile phone without requiring any hardware changes or external measurement devices. This method is a first completely software based approach for measuring power consumption on devices without the use of internal or external power measurement tools. Using this method has the nice property that mobile phones with non-exchangeable batteries (e.g., iPhone) can also be applied. Furthermore, the results achieved are highlighted and discussed.

A. Test Bed Description

The energy model should be able to determine the power consumption values for each state depending on the current received signal strength and the achievable maximum throughput of the corresponding network. The following five states are measured for developing an energy model:

- *IDLE*: All wireless interfaces are disabled.
- *TCP* and *UDP via UMTS*: UMTS interface active, WiFi interface deactivated, download with maximum achievable throughput
- *TCP* and *UDP via WiFi*: WiFi interface active, UMTS interface deactivated, download with maximum achievable throughput.

Here, only relevant states for handoff decision (i.e., power consumption of TCP and UDP based applications over UMTS or WiFi) in one typical use case (download data with maximum throughput) are considered. The conceptual layout and network configuration of the test bed is depicted in Figure 4.

An Apache HTTP-server [12] and a Java UDP server [13] are running on a laptop that presents a server and is connected via LAN either to a UMTS/HSPA emulator or to a WiFi Router. In order to minimize environmental interferences, the mobile phone Samsung Galaxy S I9000 is put into a shielding box. The desired RSS on client side is controlled and configured by means of an adjustable attenuator (see Fig. 4) that muffles (in dB) the communication channel between the mobile device and wireless access technologies.

For emulating TCP/UDP based applications, which download data from a server, an Android application (App) has been

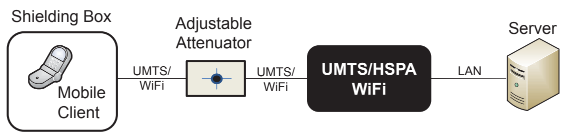

Fig. 4. Test Bed for Measurements of Power Consumption and Throughput

TABLE I
SPECIFICATION OF THE EQUIPMENT USED IN THE TEST BED

Test Bed Specification	
Shielding Box	Rohde & Schwarz CMW Z10
Mobile Device	Samsung Galaxy S I9000, Android 2.3.3
Adjustable Attenuator	Trilithic Asia
UMTS/HSPA	Rohde & Schwarz CMU200 UMTS/HSPA Emulator (7.2 Mbit/s)
WiFi Router	Linksys WRT54GL, 54 Mbit/s
Server	Laptop Lenovo R61 Intel Core 2 Duo T8300 2,4 GHz, 2 GB RAM

implemented. During active data transfer, this App also measures the power consumption on mobile device that captures the following parameters per second: energy level, current CPU load, received signal strength, received and sent bytes. Note, the App is only used for developing the energy model. Each state is measured for 600 seconds and repeated six times. For all measurements of power consumption, only necessary background services (e.g., touch input) are running, no further applications are active, and the AMOLED backlight is fully active. Moreover, the data rate is as high as possible during all measurements. The detailed technical specification of all the network/user equipment employed in the test bed is given in Table I.

B. Discussion of Resulting Energy Model

In order to derive an energy model usable in vertical handoff decision algorithms from experimental measured data, the polynomial curve fitting method provided by the mathematical tool MATLAB [14] is applied that looks for coefficients of a polynomial function of degree *n* fitting the measured value in a least square sense. Furthermore, we also present a model for the obtained maximum throughput with different RSS.

In Figure 5, the energy functions for UMTS and WiFi are compared to each other based on normalized RSS (i.e., 1:=good, 0:=bad). The range of RSS is -63 to -112 dBm for UMTS and -55 to -95 dBm for WiFi which are occurring RSS in reality. It is clear that the power consumption of UDP via WiFi is very high at very good signal strength due to the higher throughput of WiFi compared to UMTS. On the other hand, the power consumption of UDP over UMTS is higher than via WiFi at very low signal strength since mobile phones try to keep a maximum throughput by increasing the transmission power for maintaining sufficient link quality. The same observation regarding higher power consumption via WiFi caused by higher througput is also shown and validated by the authors in [15] and [16]. For measuring power consumption, these authors apply external measurement devices.

When comparing the throughput functions $D_{i,j}(rss)$ of UMTS and WiFi defined for less than 100% throughput (see

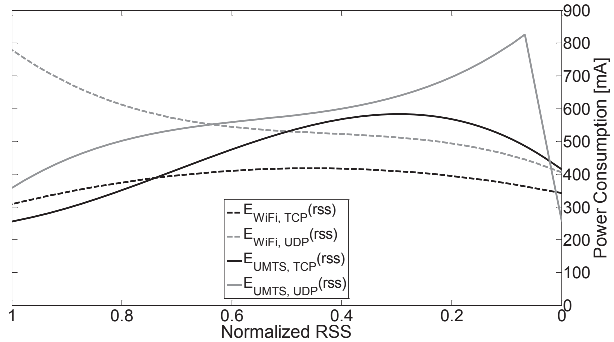

Fig. 5. Comparison of Power Consumption for UDP/TCP based Applications via UMTS/WiFi based on normalized RSS (1:=good, 0:=bad)

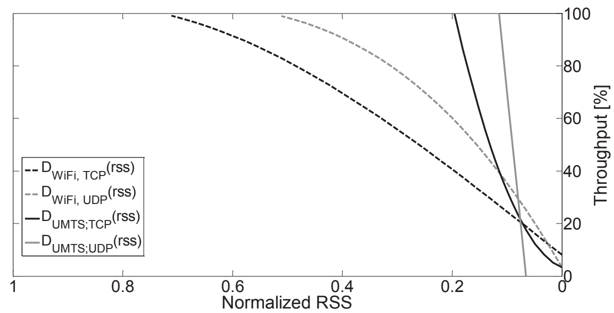

Fig. 6. Comparison of Throughput for UDP/TCP based Applications via UMTS/WiFi based on normalized RSS (1:=good, 0:=bad)

Fig. 6), the results illustrate that the throughput of TCP always drops down earlier and slower in both cases for UMTS and WiFi compared to UDP. In case of deteriorating signal strength and changing modulation schemes, UMTS tries to hold a good link quality as long as possible by increasing the transmission power. Consequently, the high throughput of TCP/UDP via UMTS can be obtained longer than via WiFi. However, this results in a higher power consumption as shown in Figure 5.

Using the depicted functions $E_{i,j}(rss)$ allow to compute the power consumption (in mA) depending on the signal strength *RSS* in case of an energy-efficient vertical handoff decision with a maximum achievable throughput.

This section presented a specific energy model based on experimental results using the mobile phone Samsung Galaxy S I9000. Note that a generic energy model should be developed in a manner that is usable for common mobile devices. However, the power consumption of mobile devices can be optimized significantly if an exactly fitting energy model is designed for specific mobile devices. Considering our software based method for measuring power consumption and the obtained results, we have shown that our approach can also achieve same tendencies as obtained with external measurement tools. For instance, a high throughput using WiFi at very good link quality produces a higher power consumption than via UMTS.

IV. PERFORMANCE EVALUATION

This section presents the results of the performance analysis using the proposed VHDA solutions (i.e., Fuzzy, E-Fuzzy, E-RSS). In our analysis, Fuzzy VHDA is used as reference for

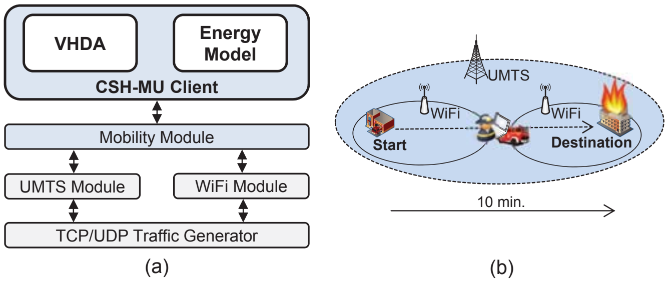

Fig. 7. a) Module structured Simulation Model b) Simulated Emergency Use Case Scenario

comparison.

A. Simulation Model and Test Case

For analyzing the impact of an integrated energy model on handoff decision quality, a simulation model is developed applying the discrete event-based simulation environment of OMNeT++ 4.1 [17] that models a moving client downloading data seamlessly via TCP/UDP in a heterogeneous network environment (i.e., UMTS, WiFi).

Figure 7a illustrates the simulation model consisting of seven modules. The CSH-MU client, which is responsible for handoff executions, includes the VHDA for handoff decision and the energy model. The mobility module simulates the movement of the CSH-MU client for a given scenario example (see Fig 7b), where the client movement is described by a two dimensional Cartesian coordinate system with x and y-axis. Moreover, this module applies the Rayleigh fading channel model [18] to simulate the multipath propagation for computing the received signal strength on client side (mobile phone with CSH-MU client). During the simulation process, the UMTS and WiFi modules provide information about the current RSS and throughput to the mobility and VHDA modules per second. The CSH-MU client always starts from the origin of coordinates (O(0,0)) and moves with a speed of 4m/s to a destination (see Fig. 7b).

This speed allows to consider a simulation scenario with overlapped existing UMTS Node B and WiFi access points. Consequently, more variations of RSS from different wireless access technologies can be taken into account for the vertical handoff decision process. The simulation ends after 10 minutes when the client reaches the destination point.

The position of UMTS Node B ((U(2000,0)) and WiFi access points (W_1(1000,0),W_2(3000,0)) are defined by coordinations and it is assumed that an overlapping service area is covered by UMTS (range = 2000 m) and WiFi (range = 200 m). Depending on the link quality, the TCP/UDP traffic generator sends data with a specific throughput over different wireless access technologies.

Table II gives an overview of the used parameter settings for E-RSS. According to [11], the hysteresis threshold H_i is allocated to +3dB in practice for UMTS and WiFi. The minimum and maximum values of E-RSS for UMTS and WiFi are derived from an ideal model using the free-space path loss model. In terms of Fuzzy and E-Fuzzy VDHAs, each decision metric requires minimum and maximum values for the normalization process (see Table III). Table IV illustrates the values of the borders that are deduced from the experimental results presented in Section III-B. In this simulation scenario, PEV_H is set 0.3 since it provides the best quality of handoff decision. The vector $\vec{w} = \left(w^{RSS}, w^{D}, w^{E}, w^{CPU}\right)$ is defined for the E-Fuzzy algorithm as follows: $\vec{w} = (0.45, 0.1, 0.35, 0.1)$. The weight of RSS is set to 0.45 since a good RSS is essential for high throughput and low power consumption under assuming optimal conditions. Unlike E-Fuzzy, the following weight vector is given for the Fuzzy algorithm: $\vec{w} = \left(w^{RSS}, w^{D}, w^{CPU}\right) = (0.4, 0.4, 0.2)$.

TABLE II
PARAMETER SETTINGS FOR E-RSS VHDA

UMTS	Value		WiFi	Value
RSS_{min}	-105 dBm		RSS_{min}	-96 dBm
RSS_{max}	-30 dBm		RSS_{max}	-41 dBm
T_{UMTS}	-73 dB		T_{WiFi}	-69 dB

TABLE III
THRESHOLDS FOR NORMALIZATION OF DECISION METRICS

Decision Metric x	x_{min}	x_{max}
RSS_{UMTS}	-105 dBm	-30 dBm
RSS_{WiFi}	-96 dBm	-41 dBm
D_{UMTS}	0 Mbit/s	7.2 Mbit/s
D_{WiFi}	0 Mbit/s	54 Mbit/s
E	226.8 mA	820.8 mA
CPU	0 %	100 %

TABLE IV
FUZZY BORDERS OF MEMBERSHIP FUNCTIONS

Decision Metric x	k_1^x	k_2^x
RSS	0.2	0.8
D	0.3	0.7
E	0.4	0.8
CPU_{UMTS}	0.35	0.85
CPU_{WiFi}	0.35	0.85

In order to judge about the performance of the proposed VHDAs, the following QoS evaluation criteria are applied. These criteria are derived from a requirement analysis of a national emergency project [19]:

- Throughput: For specific use case scenarios such as emergency scenarios, a high throughput is required to download time-critical data as fast as possible.
- Power Consumption: The proposed VHDAs have to optimize the power consumption of mobile phones.

The most important context-aware QoS criteria is presented by the throughput for fast download of high data volume. A fast information retrieval influences the success of an emergency operation management.

B. Impact of Energy Model on VHDA Performance

Figure 8 compares Fuzzy as reference with E-RSS and E-Fuzzy in terms of throughput and power consumption. It should be noted that the depicted results are obtained from our developed simulation where a client needs 10 minutes to reach a destination point. The power consumption depicted in this figure describes the total needed battery capacity (in mAh) that is required for a 10 minutes download in the chosen scenario.

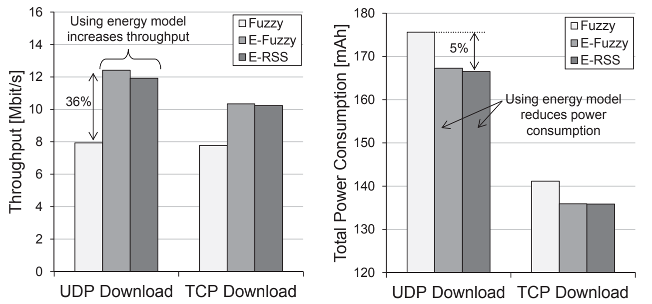

Fig. 8. Comparison of E-RSS and E-Fuzzy to the reference VHDA Fuzzy without Energy Model. Results are based on a Simulation where a Client needs 10 Minutes to reach the Target Point.

As evident from Figure 8, the use of an energy model in our proposed VHDAs (i.e., E-Fuzzy, E-RSS) improves the throughput up to 36% and lower the power consumption up to 5% compared to a less VHDA (i.e., Fuzzy) in spite of these contrasting requirements. In comparison between E-Fuzzy and E-RSS, E-Fuzzy outperforms negligible E-RSS in both cases. The reason is the benefiting property of Fuzzy that normalizes and fuzzificates the received signal strength. Consequently, this makes the fluctuations of RSS less important.

Considering the results presented in this section, the integration of a simple energy model derived from a pure software based measurement without using external hardware measurement tools in feasible VHDAs (i.e., E-RSS, E-Fuzzy) increases the throughput and lowers the power consumption. But taking into account the complexity, E-RSS is preferred to E-Fuzzy due to the lower complexity and the similarly good results as shown in Figure 8.

V. Conclusion and Future Work

For precise handoff decisions, latest vertical handoff decision algorithms (VHDA) are, however, too complex and do not consider the restricted access to decision metrics of mobile phones with limited battery life.

With this motivation, we proposed two deployable and energy-efficient VHDAs for the CSH-MU mobility solution, which only apply accessible metrics. As like the efficient CSH-MU, the suggested VHDAs run completely on mobile phones without any required changes on network side.

For designing an energy model, we presented a software based approach that can be also used for mobile phones with non-exchangeable batteries. Compared to approaches with external measurement tools, we could also achieve similar tendencies of power consumption. In spite of the predefined contrasting QoS requirements (i.e., throughput vs. power consumption), using a simple energy model example in the proposed VHDAs (i.e., E-RSS, E-Fuzzy) improves the throughput up to 36% and optimizes the power consumption up to 5% compared to a less approach without energy model. Considering the complexity of the algorithms, E-RSS is preferred to E-Fuzzy due to the lower complexity and similarly good results.

As part of the future work, we are in the process of developing a generalized energy model for different mobile phone platforms. Furthermore, simulation results will be validated by implementing an experimental test bed.

Acknowledgment

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