A Coordinated Group Decision for Vertical Handovers in Heterogeneous Wireless Networks

Mario Pink, Michael Sprejz, Hartmut Koenig
Brandenburg University of Technology Cottbus,
Department of Computer Science
PF 10 33 44, 03013 Cottbus, Germany
e-mail: {pink, sprejz, koenig}@informatik.tu-cottbus.de

***Abstract*—Cooperation and interactions of mobile users is a characteristic feature of mobile collaborative applications. The users are located in different mobile communication networks or move in or among them, respectively. This requires horizontal and vertical handovers. The latter is required when the networks use different network technologies. Usually each mobile device independently chooses the most appropriate network for its purposes to switch to. In group-oriented applications this may lead to an uncoordinated network selection and as consequence to increased energy consumption. In this paper, we present a distributed vertical handover decision algorithm that coordinates the selection of the network among the mobile devices in order to ensure an optimal quality of service for the collaborative application and a low energy consumption of the involved mobile devices. The network selection is based on the calculation of a group benefit for each alternative network using the *Simple Additive Weighting* (SAW) algorithm. The feasibility of the algorithm is evaluated regarding varying group sizes and resource requirements.**

Keywords - Vertical handover; coordinated handover decision; mobile collaborative applications; simple additive weighting handover;

I. INTRODUCTION

The co-existence of different wireless networks offers the possibility to provide services at various locations and to make them accessible at any time. Users that move through these networks with their mobile devices, e.g., smartphones, laptops, or tablets, want to use these services in a seamless manner when changing the network. For this, horizontal and vertical handover techniques are used to switch between networks of the same technology and of different access technologies. Various algorithms have been proposed and evaluated for the latter in the past decade to ensure an interrupt-free communication. Current approaches for vertical handovers prefer mechanisms that select those networks that optimally meet their demands, as rule networks with the highest data rate, the strongest signal strength, or the best energy efficiency, combined with possibly low cost.

There is an increasing interest in mobile collaborative applications, such as joint editing, audio and video conferences, remote diagnoses, patient supervision, and others, in which users interact and collaborate in groups. In the group context, however, singular vertical handover decisions may lead to an uncoordinated network selection and as consequence to increased energy consumption from the application point of view. Every mobile system independently makes its own decision which network it switches to and at which time it changes. This "egoistical" behavior and the lack of any coordination among the mobile devices may cause that the network selection will be inefficient. The local decisions can indeed reduce the energy consumption of the individual mobile systems, but the overall energy consumption of the entire collaborative application may increase. For example, when one mobile system in a group switches to a network with a lower data rate, the other mobile devices need more time to transfer their data to this system due to the reduced data rate. Thus, the energy consumption of the group increases because more time is needed for transmission of the same amount of data. In addition, the device interfaces may also work non-efficiently for this data rate, since network interfaces in mobile devices work only energy-efficient for certain data rates [5]. Moreover, the users may hold different roles within the collaborative application, e.g., recording secretary or conference moderator. An uncoordinated network change does not take such special requirements into account to maximize the application lifetime. Consequently, it lacks a common awareness of the handover situation of the group. A coordinated handover decision in which the group members communicate their local preferences may help to select the optimal network.

There is no agreed definition for cooperative vertical handovers in the literature. In different papers [1], [2], [4] it is referred to as *Group Vertical Handover* (GVHO). It means that a group of mobile systems performs a vertical handover at the same time or almost simultaneously. Such scenarios may, for instance, occur in urban areas where a large number of users sit in cars, buses, or trains. On speaks of a cooperative handover when both the mobile system and the network side are responsible for the collection of connection and network data, but also process the collected information. They

© This work was supported by the Brandenburg Ministry of Science, Research and Culture (MWFK) as part of the International Graduate School at the Brandenburg University of Technology (BTU).

MOBILWARE 2013, November 11-12, Bologna, Italy

DOI 10.4108/icst.mobilware.2013.254265

cooperate with each other by exchanging information and decisions taken. In this paper, we present a distributed vertical handover decision algorithm to coordinate the selection of the most appropriate network among the mobile devices. The aim of this group decision is to ensure an optimal quality of service for the collaborative application and a low energy consumption of the respective mobile devices. The proposed algorithm calculates a group benefit for each alternative network which provides a group awareness of the quality of the available target networks. This allows the devices to coordinate their local handover decisions and to select those access networks which are the most suitable in the application context. The primary objective of the approach is to maximize the lifetime of the collaborative application. The remainder of the paper is organized as follows. In Section 2 we give a brief overview of previous work in the area of vertical handover. Section 3 describes the proposed distributed cooperative vertical handover decision algorithm. Section 4 analyzes the functional capability of the algorithm using an empirical analysis. Some final remarks conclude the paper.

II. VERTICAL HANDOVER DECISIONS

The area of vertical handovers has been deeply investigated in the recent years. Various methods have been proposed. Most of them are limited to a certain range of mobile systems. These approaches usually only consider when and to which network a handover is to be performed. There are only a few approaches in which several mobile systems cooperate when deciding on a handover [1-2]. These approaches primarily focus on the network selection. They pursue the aim to avoid network congestions. Therefore, they mainly consider urban areas and highways, where a large number of users are using the same access point from their vehicles. User and application demands for the network selection are largely ignored. When the users leave the coverage of a wireless network, they have to select an alternative network. If all users select the same network, it can, according to Cai and Liu [4], drastically reduce the available data rate of the network. Our approach, in contrast, focuses more on the consequences for the mobile collaborative application rather than on the network characteristics. Our objective is to maximize the lifetime of the application by selecting the most energy-efficient network for the group.

The basis for performing handovers between heterogeneous networks is the IEEE 802.21 standard [10]. It defines the mechanisms and the semantic information needed for network detection and selection, and for performing the handover. In addition, it specifies a *Media Independent Handover Protocol* (MIHP) for the communication between the mobile system and the supporting network components, but it does not define algorithms for deciding a network change in handover situations. For the latter, different mathematical models are used, such as simple attribute decision making algorithms, multi-criteria decisions, methods of the artificial intelligence, and fuzzy-based approaches. Simple attribute decision making algorithms compare single parameters of different networks [12]. *Multiple Attribute Decision Making* algorithms (MADM), such as *Simple Additive Weighting* (SAW), *Technique for Order Preference by Similarity to Ideal Solution* (TOPSIS), *Grey Relational Analysis* (GRA), and *Analytical Hierarchy Process* (AHP) [12], [13], use several criteria. They enable a more fine-grained evaluation and prioritization of the available networks. When using neural networks [15], it is also possible to describe the network dynamics and to adapt the decision to changing circumstances [17], [18]. Fuzzy logic-based decision procedures, in contrast, convert the fuzzy non-linear network characteristics into linguistic terms and evaluate the benefit with classical multi-criteria decision methods based on a defined fuzzy rule set [14], [16]. The advantage of these methods is the analysis of imprecise data and the modeling of nonlinear behavior. Their disadvantage is the required expert knowledge and the lack of a learning capability.

III. COORDINATED GROUP DECISIONS

Nowadays, usually several alternative networks are available in a handover situation. Hence, users of mobile collaborative applications may communicate with each other via different (heterogeneous) networks (see Fig. 1). During a handover process the selection of the new network is usually decided locally [8], [9]. The local network selection considers the available networks and chooses the most appropriate one on the basis of a classical network selection algorithm. As argued above, this uncoordinated network selection may be not optimal for the collaborative application.

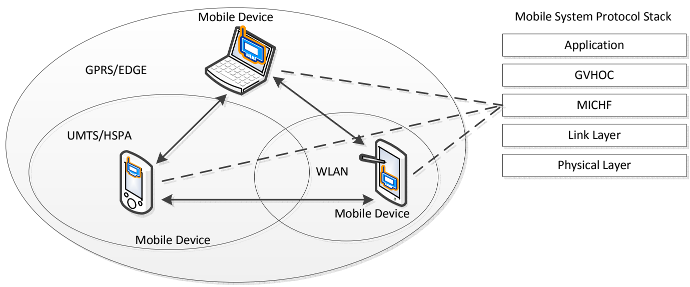

Fig. 1. Collaborative application using different mobile networks

A coordinated network selection aims at choosing a network which is optimal for the application or parts of the application based on the information provided by all or a subset of partners involved in a handover situation. It does not matter whether the whole group or only some of the participants are in a handover situation. The resulting network proposed by the coordinated handover decision algorithm is only a recommendation for the mobile devices. It is not binding for them. This gives the mobile devices the opportunity to take local preferences for the network selection into account because a mobile system may not support the selected network or the preferences of the user are contrary to that of the group decision because other running applications prefer the current network.

A. Criteria for a Coordinated Handover Decision

The selection of criteria for a coordinated handover decision is complicated by the different operating systems and hardware of the mobile devices involved. Possible indicators are quality of service, bandwidth throttling, energy budget and consumption, (monetary) cost, user preferences, and user prioritization. The concrete selection depends on the respective decision procedure.

- ***Quality of Service***: The quality of service (QoS) of the networks describes the available data rate and parameters, such as latency, jitter, radio signal strength (RSS), and bit error rate (BER), of the network connection. With a low QoS, data can only be received with a lower throughput and a high delay. Depending of the connection, retransmissions may be needed because the communication partner cannot determine whether the problem is caused by the network access connection or the Internet. Thus, a network change at the partner's side would improve the quality of the communication.
- ***Bandwidth throttling***: Bandwidth throttling relates the maximum data rate of the network interface to that of the application. It can be used to detect mobile systems that have only a limited throughput. Otherwise the communication partners would assume an overload situation in the network or a bad network connection. A possibly triggered handover would not improve the communication quality in this situation.
- ***Energy Budget***: The energy budget and its consumption by the network connection should enable a trade-off between energy efficiency and data throughput in order to maximize the lifetime of the application with an acceptable QoS.
- ***Monetary Cost***: The communication costs should be minimized, whenever possible.
- ***Device Prioritization***: The mobile systems may have different priorities within a collaborative application depending of the role their users have overtaken in the application (e.g., moderator in a conference). Depending of this, they have a higher or lower impact on the network selection.

The various criteria applied in a coordinated group decision may differently be weighted by the users regarding to their preferences (see below). Furthermore, some parameters have to be normalized to ensure their comparability. In order to distribute the indicators of the applied criteria among the mobile devices for the subsequent common decision the cooperative media-independent handover function (*Cooperative Media Independent Handover Function*, MICHF) is used (cp. Figure 1) which is based on the IEEE 802.21 standard [10]. MICHF enables a unified communication, coordination, and cooperation among mobile systems involved in the application using the *Media Independent Handover Protocol* (MIHP). It allows one to compare the various group-specific strategies of the used networks, e.g., for maximizing the application lifetime. For this purpose, we have enhanced the IEEE 802.21 standard by appropriate features for exchanging application-specific information. The enhanced MICHF allows us to exchange network information in a consistent manner and to deliver it to the *Group Vertical Handover Coordination* (GVHOC) layer of each mobile device (cp. Figure 1) that is responsible for the cooperative handover decision. There are two options for the decision making: centrally by a group leader and distributed by each group member. They will be discussed further below.

B. Decision Model

The decision model applied in the coordinated handover decision procedure determines a group benefit for each alternative network available in a handover situation. This benefit is derived from selected parameters of the available networks and involved mobile devices. The group benefit recommends whether or not the current network should be leaved. Let $N=(N_1,N_2,...,N_m)$ the set of networks available in the collaborative application, e.g., WLAN, GSM, etc., and $P=(P_1,P_2,...,P_k)$ the set of mobile systems participating in the cooperative handover decision. In addition, a priority λ_l can be assigned to each mobile system P_l which reflects its significance within the collaborative application. In many applications the group members have an equal priority, but this can be handled differently. So a group may prioritize, for instance, mobile systems with a critical energy level. The energy level of a mobile system P_l is derived from the energy budget of the system taking its battery capacity C and the remaining energy budget into account:

$$Rel.Energy\ Budget_l = \frac{C_l}{\sum_{l=1}^{k} C_l} * EnergyBudget_l \quad (1)$$

The priority of the mobile system is then calculated as follows:

$$\lambda_l = \frac{Rel.\ Energy\ Budget_l^{-1}}{\sum_{l=1}^{k} Rel.EnergyBudget_l^{-1}} \quad (2)$$

The vector $\lambda=(\lambda_1, \lambda_2, ... \lambda_k)$ represents the weights of all mobile systems of the group:

$$\sum_{l=1}^{k} \lambda_l = 1 \wedge 0 \leq \lambda_l \leq 1. \quad (3)$$

As explained in the precedent section, various criteria, e.g., QoS, energy budget, may be used to decide the need of a handover. Let $C=(C_1,C_2,...,C_n)$ the set of criteria applied for the cooperative handover decision. The mobile systems may assign a weight w_i to each criteria to express their own preferences. Accordingly, $w_l= (w_1,w_2,...,w_n)$ represents the weights for all criteria:

$$\sum_{j=1}^{n} w_j = 1 \wedge 0 \leq w_j \leq 1. \quad (4)$$

The decision basis for a handover is a matrix consisting of the alternative networks N and the decision criteria C (see equation (5). Each value x_{ij} indicates the local importance of the criteria C_j, with j=1 … n, for the available alternative networks N_i, with i=1 … m.

The decision of a mobile system P_l is represented by the matrix X_l.

$$X_l = \begin{array}{c} \\ N_1 \\ N_2 \\ \vdots \\ N_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} x_{11}^l & x_{12}^l & \cdots & x_{1n}^l \\ x_{21}^l & x_{22}^l & \cdots & x_{2n}^l \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^l & x_{m2}^l & \dots & x_{mn}^l \end{bmatrix} \end{array} \quad (5)$$

In order to decide the handover for the application the matrix $X=[x'_{ij}]_{m\times n}$ is derived based on the individual matrices X_l by aggregating every local importance x_{ij} with the priority λ_l of the respective mobile system P_l to a group rating x'_{ij}:

$$x'_{ij} = \sum_{p=1}^{k} \lambda_p x_{ij}^p \cdot$$

In addition, the weights w_j for each criteria C_j of all mobile systems P are aggregated to the group weight vector W=[$\acute{w}_1$, $\acute{w}_2$, ..., $\acute{w}_n$] with

$$w'_j = \sum_{l=1}^{k} \lambda_l w_l^j \ .$$

***Group Decision**:* The most appropriate alternative network for the group is then selected using the SAW algorithm as follows (see equation (6)). The advantage of SAW, in contrast to TOPSIS, AHP, and GRA, is that it only slightly increases the computational complexity for mobile systems. The algorithm relates the group preferences x'_{ij} with the respective group weight w'_i to a group benefit $w'_i x'_i$ for each alternative network. Then the group benefits $w'_i x'_i$ are ordered and the network with the highest group benefit is recommended as the network to select N^*_{Sel}:

$$N^*_{\text{Sel}} = \arg(\max \sum_{i=1}^{n} w'_i x'_{ij}) \quad (6)$$

C. Normalization and Evaluation of the Decision Criteria

In order to assure a fair comparison of the networks we need to normalize the various parameters used as decision criteria. One of the problems that have to be solved when comparing the indicators is that some of them, such as the energy budget, are represented in different units on the various mobile systems. Therefore, an additional normalization is needed.

QoS evaluation: To evaluate the QoS of each available alternative network N_i we use the QoS function of Chen and Shu [18]) (see equation (7)). The parameters taken into account are the data rate (D), the latency (L), the jitter (J), the radio signal strength (RSS), and the bit error rate (BER), which are normalized (see equations (8) and (9)), and weighted according to their influence using w_n.

$$QoS_i = f_{Di} * w_D + f_{Li} * w_L + f_{RSSi} * w_{RSS} + f_{BERi} * w_{BER} \quad (7)$$

First the parameters f_n of each applied criteria n have to be normalized with their respective lower value limit Lf_n and upper limit Uf_n regarding the network QoS and with the lower and upper limits $LR_{m,n}$ and $UR_{m,n}$ of the application QoS requirements [17]. The QoS parameters to be maximized are normalized with

$$f_{i,n} = \begin{cases} 0, & \frac{UR_{i,n} + LR_{i,n}}{2} \geq Lf_n \\ 1, & \frac{UR_{i,n} + LR_{i,n}}{2} \leq Uf_n \\ \frac{\frac{UR_{i,n} + LR_{i,n}}{2} - Lf_n}{Uf_n - Lf_n}, & Lf_n < \frac{UR_{i,n} + LR_{i,n}}{2} < Uf_n \end{cases} \quad (8)$$

and the ones to be minimized with

$$f_{i,n} = \begin{cases} 0, & \frac{UR_{i,n} + LR_{i,n}}{2} \geq Lf_n \\ 1, & \frac{UR_{i,n} + LR_{i,n}}{2} \leq Uf_n \\ \frac{\frac{UR_{i,n} + LR_{i,n}}{2} - Lf_n}{Uf_n - Lf_n}, & Lf_n > \frac{UR_{i,n} + LR_{i,n}}{2} > Uf_n \end{cases} \quad (9)$$

Monetary cost: To compare the monetary cost MK of the networks we normalize their cost in cents paid per minute with a weight a between [0,1]. According to the formulae of Chen et al. [3], the weighted costs are

$$MK_i = \frac{1}{e^{a_i}} \qquad \alpha_i = cost_i / a \quad cost_i : cents \ / \min \quad (10)$$

When using a flat rate, the cost for network $cost_i$= 0 and a=1.

Energy budget and consumption: A variety of studies have examined the energy consumption and its management for various wireless technologies [5], [11]. The energy consumption depends not only on the data rate, but also on the configuration of the network interface by the network provider. This state-controlled energy management of 2G and 3G networks allows the network operator to adapt the transmission timers, the data rate, and in result the latency and the energy consumption of the data transmission (see Fig. 2). Therefore, to recognize it we transmit consecutive UDP Datagrams between two peers one of them connected via Ethernet and the other one successively via GPRS/EDGE, UMTS, HSPA and at least WLAN on a Nokia N900. During the transmission we performed some energy measurements to analyze the energy behavior as well as the energy state machine and the energy consumption in a more detailed manner. So the UMTS/HSPA interface, for instance, remains in a high energy state (tail energy) for a few seconds after sending a message in expectation of further transmissions.

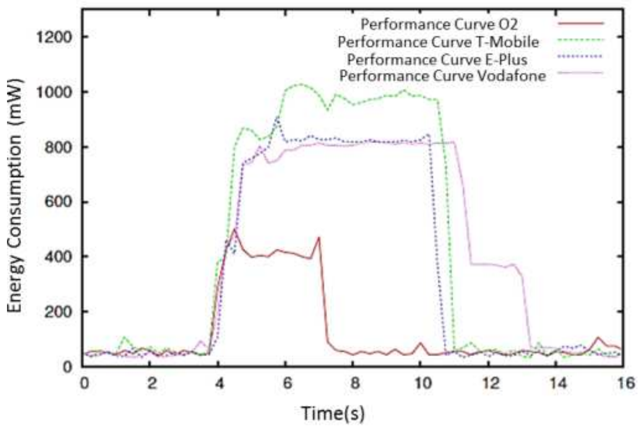

Fig. 2. UMTS keep-alive energy consumption

In addition, the energy level for these data rates is lower in EDGE than in UMTS (see Fig. 3). The energy consumption of EDGE though increases with larger data rates. UMTS/HSPA and WLAN are more energy-efficient for large data volumes. Therefore, periodically keep-alive messages or sporadically transmitted text messages from chat programs have a significant impact on the energy consumption of a mobile system in cellular networks (see arrow in Fig 3.)

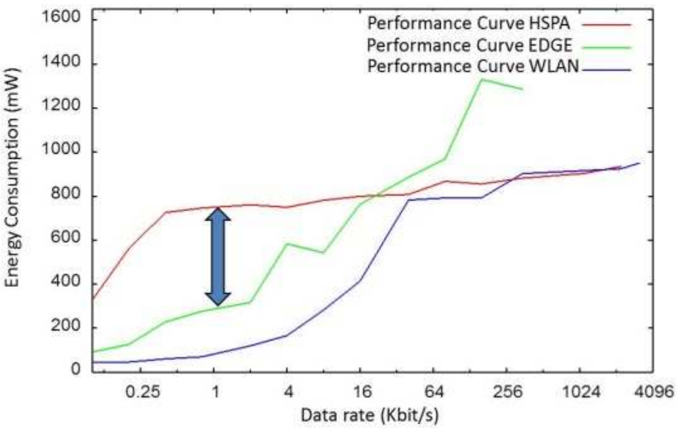

Fig. 3. Energy consumption of different mobile networks

For the handover decision process, the energy consumption of each network interface *i* has to be determined and compared with the most energy-efficient network. The energy consumption of a network interface *i* is assessed as follows. Based on the data rate of the collaborative application, the energy consumption of a network interface is determined (see Fig. 3). Then the differences to the most energy efficient network for this data rate are determined and weighted by the user for each network *i* with a user defined factor b_i. This energy ratio β_N is then normalized by an exponential function $f_{i,E}$ for network *i*

$$E_N = \frac{1}{e^{\beta i}}; \qquad \beta i = \frac{f_{i,E} - \min(f_{1,E},...f_{m,E})}{b_i} \qquad (11)$$

Rating of preferred networks: The users may prefer or prevent the use of a network for various reasons. For this, the rating of a network N_i by user P_l is determined by N_{il} with $0 \leq N_{il} \leq 1$, where $N_{il} = 1$ represents a high preference, $N_{il} = 0$ correspondingly a refusal.

D. Collaborative Decision-Making Procedure

A coordinated group decision is performed if one, several, or all systems are in a handover situation, i.e., there is a need for them to change the network. The decision-making procedure is executed in the *Group Vertical Handover Coordination* (GVHOC) layer (cp. Figure 1). It consists of the following stages (see Figure 4):

- ***Publication phase***: The identities of all mobile systems and their role within the group are published to all involved mobile devices.

- ***Initialization phase***: The group decision can be made in two ways: either decentralized by each mobile device or centralized by only one device. The centralized approach reduces the communication among the group members and accelerates the decision process. In addition, less performing systems are relieved, since the necessary calculations are displaced. This requires that the mobile devices first select a *group leader* which coordinates the decision-making process. For example, the device with the highest energy budget or the highest data rate of the group may be chosen for this. Figure 4 presents the decision procedure with a group leader.

- ***Information phase***: The mobile systems in a handover situation scan for alternative networks, weight them, and exchange this information either with the group leader or the other mobile devices of the collaborative application.

*Decision phase***:** Each system determines its decision matrix and sends it to the group leader or the other group members, respectively. Afterwards, the group benefit of all alternative networks is determined. The ranked list of alternative networks is announced to the group as a proposal. Each system then selects the network with the greatest group benefit. However, if this network is not available in the neighborhood the proposal is ignored and the next best network with similar properties to the proposed network is selected. The goal is to achieve a homogeneous distribution of networks in the group to ensure an acceptable quality of service. If the mobile systems have the same or similar conditions they least influence each other and can collaborate optimally.

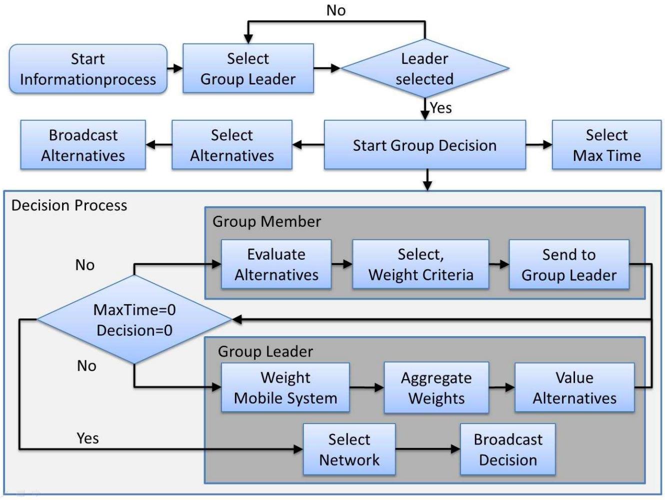

Fig 4. Coordinated handover decision procedure with group leader

IV. EVALUATION

The vertical handover decision algorithm has been evaluated using an audio/video conference application between mobile devices and a stationary computer. The application runs over the TCP/IP stack. We considered the data transmission in idle state, i.e., only signalization messages were exchanged, for audio transmission, and for video transmission. As mobile test devices, we used HTC Touch Pro 2 with Windows Mobile 6.5, Li-ion battery with 1500 mAh, and following network interfaces GPRS/EDGE/HSPA/IEEE-802.11b/g) and a Windows 7 desktop computer with WLAN (IEEE 802.11b/g/n).

A. Group decision

One of the objectives of the cooperative handover decision algorithm is the selection of networks w.r.t. their energy efficiency and quality of service. In the first experiment we proved the feasibility of the coordinated handover decisions in

Metrics		**Signalization**	**Audio conference**	**Video conference**
Data rate (KBit/s)	max	25	64	500
	min	3	9,6	50
Latency (ms)	max	10	10	10
	min	500	150	150

Table 1. Data rates of the different applications

respect thereof. Due to the multitude of handover decision criteria and ways of weighting, we used averaged values in the different experiments (see Table 1).

In the idle state the mobile devices sent only keep alive and chat messages via IEEE-802.11g and EDGE/UMTS/HSPA network interfaces (see Table 2). Despite the theoretical data rates of HSPA, most tariffs are limited to 7.2 Mbit/s. In practice, even these data rates are achieved rarely.

Table 2. Used networks and their properties

Metrics	**WLAN**	**EDGE**	**UMTS/HSPA**
Data rate (MBit/s)	6-54	0.64-0.368	1-7.2
Latency (ms)	5-20	60-200	50-150
Cost	Flat rate	Flat rate	Flat rate

In the next experiments we investigated the network selection. We only considered here two peers.

Table 3. Group decision with two peers

	Idle state	**Audio conference**	**Video conference**
Experiment 1	**W** > E > U	**W** > U > E	**W** >U > E
Experiment 2	**E** > U	**U** > E	**U** > E

The network ratings of the group decision for the different requirements of the application always prefer the WLAN if it is available because the WLAN is very energy-efficient regarding the quality of service (see Fig. 3). Exclusion criteria, however, are its low availability and coverage. Therefore, a fast-moving user should not prefer it. The WLAN has been excluded in the second experiment due to its high preference.
It shows that EDGE is preferred in the idle state in both experiments because EDGE is more energy-efficient than UMTS and meets the quality of service requirements at low data rates. In active audio and video conferences the group prefers UMTS, since it is more energy-efficient at high data rates. EDGE would have been the wrong decision here.
The next experiment analyzes how much time is required for the group decision in groups with different sizes. The decision time is determined by the transmission time of the used networks and the performance of the mobile devices. Figure 5 shows the results for the use of a WLAN with -49 dBm signal strength.

With a good connection quality, the decision time for a group of two group members is 194 ms on average. Eight participants already require a significantly higher decision time is with of 1250 ms on average. Since the decision time in mobile networks is noticeably worse than in WLAN due to the higher packet loss rate and the poorer signal strength, we further examined the time in a WLAN with interferences and very poor signal strength of -63 dBm (see Fig. 5). Starting with a group size of 4 members, the decision time increases significantly from 722 ms with four to 2129 ms with 8 participants.

The fast growing group decision time prevents seamless handovers with larger group sizes. When group members are in a handover situation due to a deteriorating connectivity they cannot wait for this decision. Therefore, the group decision should be executed in parallel to the local network selection during the handover process.

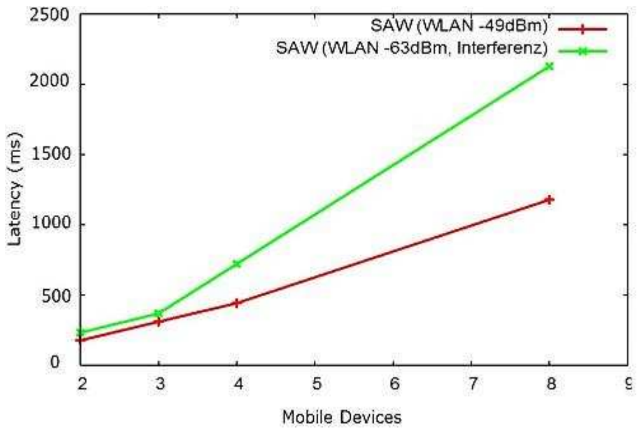

Fig. 5. Group decision time in 802.11g

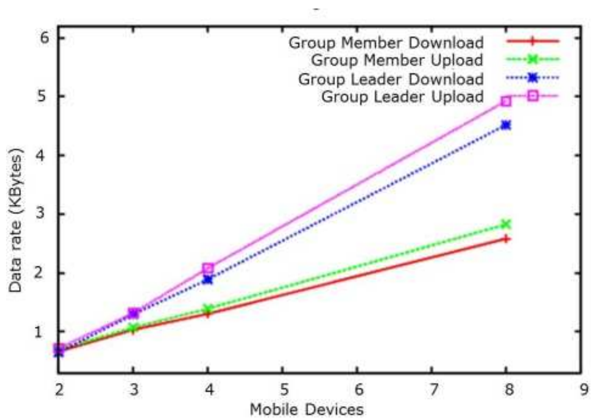

Fig. 6. Data load for handover decisions

B. Resource Consumption

The acceptance of the algorithm crucially depends on its ability to run on mobile systems with limited battery capacity. To demonstrate the influence of the algorithm's data transmission on the energy consumption we measured it for varying group sizes differentiating between the group leader and the normal members. In addition, we investigated how the energy consumption of the algorithm affects the life time the mobile device.

Fig. **6** shows the average load of the group members through sent and received data over a period of one hour with a group decision interval of 30 seconds. With two peers, the amount of data is approximately equally distributed. The group leader does not relieve the group. As it can be seen, the amount of exchanged data increases linearly with the number of peers. For groups of three members upwards, there is a significant advantage when using a group leader. So with a group size of 8, the members receive 35% and send 44% less data than the group leader, even with three 3 members, the saving is already 11% and 26%, respectively, i.e., the greater the group the more it is relieved by selecting a group leader. Unfortunately, this reduction in the communication of the group members increases the energy consumption of the group leader. Therefore, a group leader with permanent power supply should be preferred, if possible. On closer inspection, a significant difference in the data volumes exchanged only begins in groups with more than 8 members.

In order to analyze the energy consumption of the algorithm on a mobile device we activated the WLAN and 3G network interfaces and performed the group decision for two peers periodically each 30 seconds using pseudo-values for the network properties. The energy efficiency of the algorithm was derived from the battery life time of the mobile device (HTC Touch Pro 2). The measurements were repeated several times under the same conditions. Fig. **77** shows the energy consumption of the mobile device.

A clear difference between the lifetime with continuous group decisions and the idle state can be observed. With active group decisions every 30 seconds, the life time of the mobile device reduces about 20%. Investigations of the energy consumption of WLAN have shown that they have very low energy consumption for high data rates [19]. Thus, significant differences in energy consumption are only observed after a longer runtime of the algorithm. The constant retrieval of values and the permanently activated WLAN interface strongly affect the battery. Therefore, the execution intervals of the algorithm should not be too high, especially when the number of participating mobile devices increases.

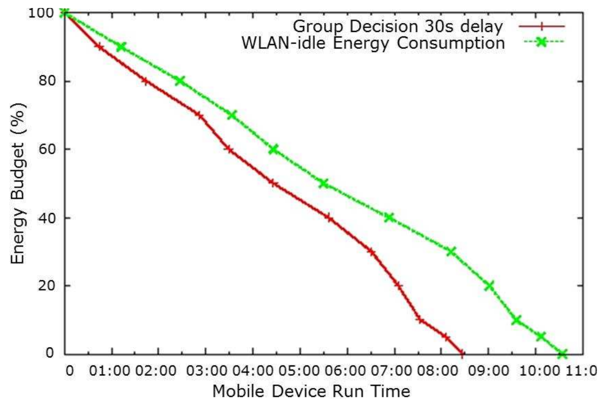

Fig. 7. Energy consumption of group decisions with two members in a WLAN

V. CONCLUSIONS

Current vertical handover decision approaches primarily relate to network changes of single users. In group applications, in which the group members may be in different networks, this may lead to an uncoordinated network selection because the algorithm does not take the different network environments into account. As a result, the energy consumption of the mobile devices involved in the mobile collaborative application may increase due to an inappropriate decision. In this paper, we have presented a distributed vertical handover decision algorithm that coordinates the selection of the networks among the mobile devices based on various decision criteria, thus trying to maximize the lifetime of the collaborative application. We have formulated a group decision model that determines a group benefit for each considered network taking the roles of the group members in the collaborative application and their preferences into account. The essential decision criteria are the QoS requirements of the application, monetary cost, energy consumption, and user preferences of the network connection. The decision process can be further accelerated by selecting a group leader which considerably reduces the communication effort.

Our evaluation has proven the applicability of the algorithm. For larger groups, however, the group decision may take longer, so that it should be performed in parallel to other handover activities. The algorithm may also shorten the battery life time if applied intensively, but this will less occur in practice. For the evaluation of the reliability of the algorithm, further tests with a greater number of users and diversity of the parameters are planned.

References

[1] L. Sun, H. Tian, and P. Zhang: Decision-making models for group vertical handover in vehicular communications. *Telecommunication Systems*, 50(2012)4:257-266.

[2] G. Zhang and F. Liu: Optimization Network Selection for Group Handover in Heterogeneous Vehicular Network. *Journal of Computational Information Systems* 8(2012)1:379–386.

[3] L. J. Chen, T. Sun, B. Chen, V. Rajendran, and M. Gerla: A Smart Decision Model for Vertical Handoff. In: Proc. of the 4th International Workshop on Wireless Internet and Reconfigurability, Athens, Greece, 2004

[4] X. Cai and F. Liu: Network Selection for Group Handover in Multi-Access Networks. In: Proc. of the International Conference of Communications (ICC'08), Beijing, P.R. China, pp. 2164–2168, 2008.

[5] G. P. Perrucci, F. Fitzek, G. Sasso, W. Kellerer, and J. Widmer: On the Impact of 2G and 3G Network Usage for Mobile Phones' Battery Life. In: Proc. of the *European Wireless Conference 2009*, 255–259, 2009.

[6] J. McNair, and F. Zhu: Vertical handoffs in fourth-generation multi-network environments. IEEE *Wireless Communications* 11(2004)3:8–15.

[7] D. Lee, Y. Han, J. Hwang: QoS-Based Vertical Handoff Decision Algorithm in Heterogeneous Systems. In: Proc. of the International Symposium on *Personal, Indoor and Mobile Radio Communications*, Helsinki, Finland, 2006, pp. 1–5, 2006.

[8] M. Pink, T. Pietsch, and H. Koenig ; Towards a seamless mobility solution for the real world: Handover decision. In: Proc. of the 9th International Symposium on Wireless Communication Systems (ISWCS) Paris, France, 2012, pp.651-655, 2012.

[9] M. Pink, T. Pietsch, H. Koenig: An Adaptive Handover Decision Algorithm for Heterogenous Wireless Networks. In: Proc. of MOBILWARE 2012, Berlin, Germany, pp. 136-149, 2012.

[10] IEEE 802.21 - IEEE Standard for Local and Metropolitan Area Networks: Media Independent Handover Services, 2008.

[11] L. Wang and J. Manner: Energy Consumption Analysis of WLAN, 2G and 3G interfaces. In Proc. of the IEEE/ACM International Conference on Green Computing and Communications (GreenCom 2010) Hangshou, P.R. China, pp. 300–307, 2010.

[12] J. Márquez-Barja, C. T. Calafate, J.-C. Cano, and P. Manzoni: An overview of vertical handover techniques: Algorithms, protocols and tools. *Computer Communications* 34(2011)8:985-997.

[13] E. Stevens-Navarro and V. W. S. Wong: Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks. In: Proc. of the in *IEEE VTC 2006-Spring*, Melbourne, Australia, pp. 947–951, 2006.

[14] P.M.L. Chan, R.E. Sheriff; Y.F. Hu, P. Conforto, C. Tocci; Mobility Management Incorporating Fuzzy Logic for Heterogeneous a IP Environment; *IEEE Communications Magazine* 39(2001)12: 42–51.

[15] N. Nasser, S. Guizani, and E. Al-Masri: Middleware Vertical Handoff Manager: A Neural Network-Based Solution. In: Proc. of the International Conference of Communications (ICC'07), Glasgow, Scotland, pp. 5671–5676, 2007.

[16] M. Alkhawlani, and A. Ayesh: Access network selection based on fuzzy logic and genetic algorithms. *Advances in Artificial Intelligence* 8 (2008) 1: 1-12.

[17] A. Tudzarov and T. Janevski: Efficient Radio Access Technology Selection for the Next Generation Wireless Networks. International Journal of Research and Reviews in Next Generation Networks 1(2011)1: 14–25.

[18] W.-T. Chen and Y.-Y. Shu: Active application oriented vertical handoff in next-generation wireless networks. In: Proc. of the IEEE Wireless Communications and Networking Conference (WCNC 200), New Orleans, LA, USA, pp. 1383–1388, 2005.

[19] N. Balasubramanian, A. Balasubramanian and A. Venkataramani: Energy consumption in mobile phones: a measurement study and implications for network applications. In: Proc. of the 9th conference on Internet measurement conference (IMC '09), Chicago, Illinois, USA, pp. 280-293, 2009