QoS based access network selection algorithm for energy efficient mobile nodes

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Abstract—Mobile terminals in fourth generation cellular heterogeneous access networks often undergo horizontal and vertical handovers. To choose the optimal network considering required Quality of Service and efficient energy consumption, network selection process is a primary issue for mobile clients. This paper delivers a handover decision algorithm that selects the optimal network from the available ones while considering the tradeoff between performance and energy consumption. The proposed method is suitable for deciding amongst networks while running our everyday mobile services as the most important QoS criteria are weighted according to user preferences using fuzzy logic. Energy cost is defined by aggregating multiple parameters including battery level or the energy component of the service being used and connecting to a certain network. A practical simulation environment demonstrates how the proposed method work in our everyday life and verifies the expectations and the efficiency of the algorithm.

Keywords—cellular mobile network; energy efficiency; handover; heterogeneous network; network selection; Quality of Servie (QoS)

I. INTRODUCTION

Mobile communications became an everyday way of communication during the last twenty years. First, improving performance and decreasing cost were the main factors when spreading cellular systems. When performance reached a level which was required by users, vendors and service providers began to develop efficient energy schemes. Research on green networks has an ever growing interest in the academic and industrial sectors. The main focus is on rising energy cost and carbon-dioxide emission [1].

Cellular networks consumed 0.5% of the world's electrical energy with end-user terminals and the network consuming 1% and 99% of the total cellular energy consumption respectively before the third generation technologies became widespread. An enormous change occurred when multimedia applications requiring high bandwidth appeared. The total energy consumption of cellular network became three times more as before and the previous ratio changed to 20% and 80%. This is due to the growth of Internet users, mobile service subscribers and the change in the trend of using our mobile phones.

As energy efficiency from the user point of view previously was only a concern to enable end-devices to operate longer with their finite capacity batteries, nowadays it is desired to reduce energy consumption of various end-devices to make a huge impact on the consumption of the whole ICT sector. Obviously, this ambition shall not endanger former demands, for example providing high bandwidth and low latency.

Different technologies appear in four generation mobile networks because former technologies also exist in today's cellular networks. A network including many different technologies is called a heterogeneous network. Newer technologies have such advantages that older ones cannot cope with but they often have larger geographical coverage which provides their reason for existence. The main challenge of heterogeneous networks is to provide seamless communication and mobility at the same time. Seamless communication is supported as busy geographical areas are covered with more than one cell, also cells of different technologies but still, network selection must be executed in a reasonable way.

The mobile end-device can roam among different cells during the lifetime of a connection [2]. This means the migration of a connection from one base station to another, which is also called a handover. A handover is the process where the mobile node changes radio transmitter or access media used to provide the bearer services, while maintaining a defined bearer QoS. Handovers can be classified into a wide range of categories based on the decision factors that result in their execution. A horizontal handover takes place when the mobile node changes its point of attachment from one base station to another one belonging to the same technology, and at the same level of network hierarchy. A vertical handover happens when the mobile node switches connection to a new base station belonging to a different access technology higher or lower than the current network in the hierarchy. During a vertical handover if the connection with the old network's base station is broken before being established with a new network's base station, the mobile node is said to perform a hard handover. In a soft handover the connection with a new network is established before the connection with the old network is lost.

Categorization based on the entity that decides to perform a handover results in client-controlled and network controlled handovers. In a network-controlled approach, the network maintains an up to date knowledge of context information at the mobile node and decides when and how it should perform a vertical handover. This task can be very complex in the case of multi-interfaced devices where the mobile node is connected simultaneously to several base stations of different networks and experiences largely varying QoS at each interface. The network-controlled approach requires a high level of interactivity among base stations belonging to different network domains, controlled by independent service providers. This will result in increased complexity due to the resolution of a large number of technical and administrative issues arising from the sharing of confidential network and customer information, something service providers may not be willing to do. In the client-controlled approach, as the multi-interfaced client is directly connected to different networks it possesses up-to-date context knowledge of the medium access, network and transport conditions for each active network interface. Hence it is in a more superior position to take decisions on important issues such as handovers, QoS management, and network selection. The mobile node in this case must possess the ability to negotiate QoS and switch to an appropriate network at the right time to get the best utilization of network resources. In fourth generation heterogeneous clients, the crucial role of handover related decision-making has to a large extent shifted from the network side towards the client side and an increasing number of studies have adopted the client-controlled approach for vertical handovers.

The remainder of the paper is organized as follows. Section 2 summarizes related work to network selection and vertical handovers. Section 3 describes our network selection algorithm which is validated in Section 4. The derived conclusions are summarized in Section 5.

II. RELATED WORK

Due to the presence of heterogeneous networks vertical handovers became a popular research area during the previous years. Initially only received signal strength determined the preference amongst different networks, mobile nodes connected to the base station offering the strongest signal. The task turned into a more sophisticated process which takes more and more factors into consideration such as network connection time, available bandwidth, power consumption, monetary cost, security and user preferences [3]. Network interfaces in mobile nodes have to be in active state to be able to monitor network parameters facilitating vertical handovers. As it consumes a huge amount of energy between, network interfaces can be set into long periods of inactivity (during which no signal is transmitted and saves energy) and short periods of activity during which a signal is transmitted to refresh the receiver state [1]. At least 50% energy saving is made over the traditional approach of using an idle signal.

Another sensible approach is to consider energy consumption besides many important parameters when selecting network, resulting in a choice not wasting energy unnecessarily and extending the use of the mobile node. There is an example in [4] delivering a handover decision process considering energy consumption besides QoS performance, however, it does not deal with determining QoS parameters in a real-time network environment. The algorithm decides among CDMA, WiBro and WLAN networks.

Further works, such as [5] proposed a network selection method considering only QoS parameters. This is a useful example for the application of multiple-criteria decision analysis. Other papers concentrated more on energy efficient operation. The aim of the proposed method in [6] is to offload cells and in [7] to select an optimal network with decent signal strength out of third generation mobile networks, WLAN and WiMax networks while considering energy efficiency. A popular way of executing a multiple-criteria vertical handover decision algorithm is to apply fuzzy logic. An example for this is presented in [8].

A more complex method is published in [9] which uses QoS performance and energy consumption to find the best network to connect but unfortunately simulation parameters are not included besides the mathematical model. [10] summarizes the main aspects of the works listed above: it takes context (QoS) and energy into consideration. The selection is executed by using fuzzy logic and the decision process is client-controlled. Other advantage of the paper is that it provides simulation results.

Our delivered algorithm approaches the challenge exclusively from the user’s point of view because an everyday user is interested in the performance and user experience of his mobile node instead of the network concept. It provides extra comfort if energy can be saved with conscious handover decisions in our everyday smartphones resulting in an extended usage with a single battery charge.

III. HANDOVER OPTIMIZATION ALGORITHM

The section is built up to enable the reader to understand the way how the algorithm is executed. Som tools need for this are introduced in the first part such as QoS parameters, mobile applications, energy consumption of mobile nodes and the mathematic apparatus. Following these subsections a detailed description of the algorithm is presented.

A. *QoS parameters*

As cellular networks provide finite resources Quality of Service has to be considered to provide satisfactory service for the users while traffic in the networks is ever growing. QoS in packet switched networks can be described with many parameters [11]. The most important ones regarding our work are listed below:

- Bit rate of transferring user data available for the service or target throughput that may be achieved.
- Delay experienced by packets while passing through the network. It may be considered either in an end-to-end relation or with regard to a particular network element.
- Packet loss rate, usually defined as the ratio of the number of undelivered packets to sent ones.
- Jitter variations in the IP packet transfer delay. Again, it can be applied to an end-to-end relation or a single network element.

QoS criteria can be divided into two broad categories: downward criteria and upward criteria [10]. Upward criteria are those whose utility rises monotonically as their value gets higher, like bit rate. Conversely, the utility of downward criteria rises monotonically when their value gets lower, like delay, packet loss rate or jitter.

When considering QoS from the users' point of view we are curious about the end-to-end network performance as this is primarily experienced by the users.

B. *Mobile applications*

Our mobile telephone usage completely changed when smartphones appeared on the market. While we used our mobile telephone primarily for voice calls and transmitting short text or multimedia messages before the smartphone revolution, nowadays we are connected to the Internet with it to download websites, send and receive e-mails, stream high definition videos or play real-time online games. The new generation of voice calls is represented by IP-based calls (VoIP) or even video conference calls when not only voice but also video image of the participants is transmitted.

These applications require different QoS criteria to provide satisfactory user experience. Although they can be served by older network technologies they (especially those which require high bit rate or low delay) seek some improved technologies with more beneficial parameters. We can divide the popular applications into two groups: for real-time applications the most important criterion is to provide low latency for the packets and for non real-time (best-effort or delay tolerant) applications bit rate is the important factor.

C. *Energy consumption of mobile nodes*

Different expectations directed the evolution of mobile telephones. First the main target was to decrease its size to fit in our pocket which was realized by the mid 1990s. Parallel to this there was a huge demand on performance development. A huge step was made when smartphones came true, but we soon recognized the excessive energy consumption of big screens and multimedia applications. Since vendors are limited by the size of a phone in respect of the battery size we cannot expect any huge improvement to provide more comfort for the user by longer lasting batteries unless there is revolutionary evolution in battery technology.

Measurements verify that different amount of energy is needed to connect to different network technologies. We can state that connecting to a later developed network technology require more energy from the client. The main difference between third and fourth generation networks is shown by the difference in transmission energy [12]. Choosing a third generation network instead a fourth generation one means around twenty to forty percent saving compared to the fourth generation network [13]. When a mobile terminal is connected to a second generation network it returns to IDLE state much faster than in a third generation network which provides forty to seventy percent saving. Connecting to a WLAN network differs from any classical mobile cellular networks. After connecting to an access point the client switches to Power Save Mode until it has to transmit data. This means a lot more efficient energy consumption and measurements show that it is one third of a two generation network on average. Considering the above statements, Table I shows the relative energy consumption of mobile phones when connecting to different network technologies.

Running applications with different characteristics of data transmission consume also different amount of energy as it was shown by measurements. Efficiency can be increased by modifying the timing of the transmitted packets. Delay tolerant applications, such as e-mailing, is a good example for this [14]. However, we cannot be such wasteful with other applications as they are less flexible and user experience has still to be provided. Videostreaming also can benefit from timing modification when using a cache but strictly real-time applications (VoIP, videoconference, online games) cannot save energy like this. Tendency shows that the amount of transmitted data will determine the energy needed in these cases: larger amount of data transmitted denser will require more and more energy for the mobile phone. Table II summarizes the energy consumption ratios of different applications.

Mobile phones nowadays use lithium ion batteries as they are lightweight and durable considering the available solutions. A special advantage is that its voltage decrease only slightly at a discharge which enables vendors to feed mobile phones with energy through a single cell. Experiments show that a discharge curve follows an exponential characteristic (Figure 1) which concludes that a battery will run out in a more quickly way when approaching the end of the discharge curve.

TABLE I. MOBILE PHONE ENERGY CONSUMPTION RATIOS WHEN CONNECTING TO DIFFERENT NETWORK TECHNOLOGIES

Network technology	**Energy ratio**
EDGE	0.3
UMTS	0.6
HSPA	0.8
LTE	1.0
WLAN	0.1

TABLE II. MOBILE PHONE ENERGY CONSUMPTION RATIOS WHEN RUNNING DIFFERENT APPLICATIONS

Application	**Energy ratio**
VoIP	0.8
videoconference	1.0
videostreaming	0.8
webbrowsing	0.6
online games	0.5
e-mail	0.3

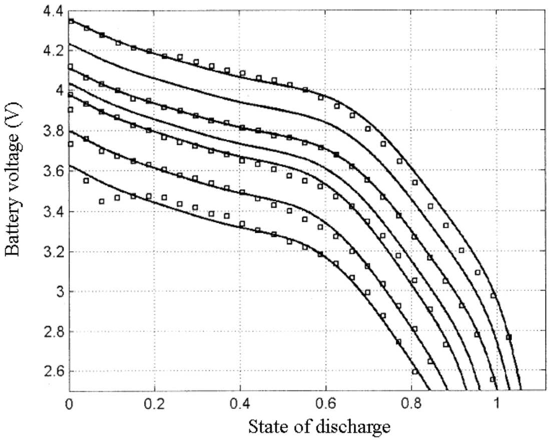

Fig. 1. A discharge curve of a lithium ion battery shows its voltage vs. state of discharge

D. *Mathematical apparatus*

It often happens in our everyday life that a decision has to be made by assessing many factors. An efficient decision making mechanism consists of the following steps:

1. identification of the problem,
2. determining the goals,
3. making a decision after assessing the factors.

The first step in this particular case is the task itself: network selection in a heterogeneous network. The goal is to make an optimal choice considering performance and energy consumption. The decision is made after determining the optimal one after the assessment.

Multiple-criteria decision analysis, a sub-disciple of operations research is a right tool to a make decision when multiple factors need to be taken into account. Instead of comparing the options pair wise the weighted sum model provides an appropriate method to start the evaluation.

In general, suppose that a problem is defined on *m* alternatives and *n* decision criteria. Furthermore, let us assume that all the criteria are benefit criteria, that is, the higher the values are, the better it is. Next suppose that w_i denotes the relative weight of importance of the criterion C_j and a_{ij} is the performance value of alternative A_i when it is evaluated in terms of criterion C_j. Then, the total (i.e., when all the criteria are considered simultaneously) importance of alternative A_i, is defined as follows:

$$A_i = \sum_{j=1}^{n} w_j a_{ij}\, , i = 1,2,3 \ldots m \qquad (1)$$

For the maximization case, the best alternative is the one that yields the maximum total performance value.

When looking for a practical solution for a problem it is often difficult to determine exactly the importance of the criteria. Fuzzy logic is a form of many-valued logic which deals with reasoning that is approximate rather than fixed and exact and which is an appropriate tool to find weights for the QoS criteria. The importance is assessed on the following five-point scale: very low, low, fair, high, very high. Table III summarizes the fuzzy numbers assigned to these levels as it is provided in [10].

TABLE III. FUZZY WIEGHTS OF QOS PARAMETERS

Level of importance	**Fuzzy weight**
very low (VL)	0.1167
low (L)	0.3000
fair (F)	0.5000
high (H)	0.7000
very high (VH)	0.8333

E. *The algorithm*

The assessment process in the algorithm consists of two steps:

1. determining the weighted QoS utility numbers (A_i), and
2. deducting the energy cost (C_i).

Figure 2 summarizes how the algorithm operates.

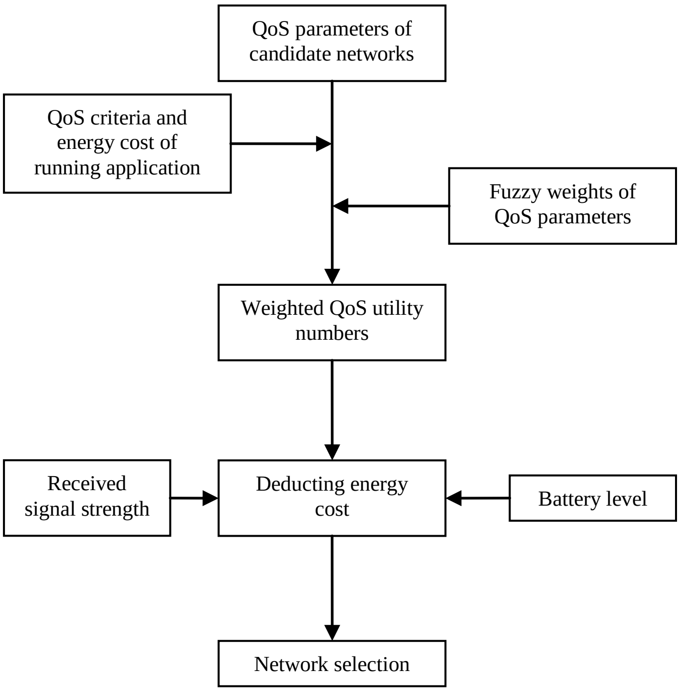

Fig. 2. Network selection process via our algorithm

The parameters of the candidate network alternatives and the application being run on the mobile client need to be known to determine the weighted QoS utility numbers. The algorithm is based on the applications listed in the paper before and their QoS criteria need to be quantified. We assign two values (a minimum and a maximum) to each QoS parameter of each application. If at an upward criterion the application does not perform at least at the minimum QoS level, the user experience does not reach a satisfactory level. If an upward QoS parameter is greater than the maximum at an application the user experience cannot be any better. Downward criteria shall be considered the opposite way. The QoS criteria of the applications are summarized as an extension of [10] in Tables IV and V.

All QoS criteria have to be benefit criteria so that the formula for the multiple-criteria decision analysis can be applied. The benefit criteria come from the [0,1] interval. We assign zero to an upward QoS criteria if the application perform below the minimum level and one if above the maximum level. The benefit criteria follow a uniform distribution between these two edges. The process for downward criteria is the opposite; this guarantees that all QoS criteria are benefit criteria. Figure 3 illustrates how benefit criteria are determined.

TABLE IV. QOS PARAMETERS OF APPLICATIONS (PART 1)

	Bit rate (kbps)		**Delay (ms)**	
	min	***max***	***min***	***max***
VoIP	32	64	75	150
Videoconference	512	5000	75	150
Videostreaming	128	2000	2000	4000
Webbrowsing	128	1500	250	500
Online games	32	256	20	150
E-mail	32	128	2000	4000

TABLE V. QOS PARAMETERS OF APPLICATIONS (PART 2)

	Packet loss (%)		**Jitter (ms)**	
	min	***max***	***min***	***max***
VoIP	0.1	2	0	30
Videoconference	0.1	2	0	30
Videostreaming	0.1	2	0	30
Webbrowsing	0.1	0.5	0	40
Online games	0.1	0.3	0	20
E-mail	0.1	0.5	0	50

TABLE VI. IMPORTANCE OF QOS PARAMETERS FOR EACH APPLICATION

	Bit rate	**Delay**	**Packet loss**	**Jitter**
VoIP	L	VH	F	VH
Videoconference	H	VH	F	VH
Videostreaming	H	L	F	H
Webbrowsing	L	L	VH	F
Online games	F	VH	H	VH
E-mail	L	L	VH	L

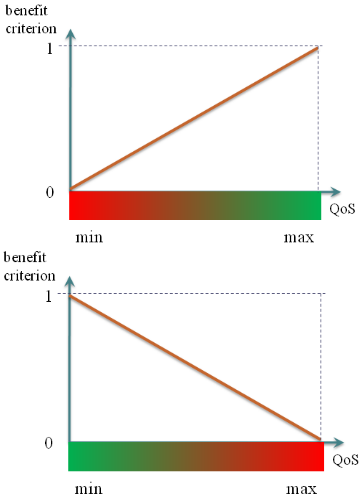

Fig. 3. Determining benefit criteria for upward QoS criteria (up) and downward QoS criteria (bottom)

Looking back on Equation (1) all a_{ij} values are produced now. Next we list the importance level for each QoS parameter at each application and prepare Table VI as an extension of [10]. Of course, these importance levels shall be replaced with the values in Table III when running the algorithm.

Now all QoS utility numbers can be determined for each candidate network when running either of the applications using all the above listed parameters. The second main step of the assessment is deducting the energy cost from the QoS utility number of each candidate network. Energy cost is determined by considering four components:

1. network connection ($C_{network}$),
2. running application (C_{app}),
3. battery level ($P_{battery}$),
4. received signal strength (P_{RSSI}).

The following equation provides the link among these components:

$$C_i = P_{battery} \cdot (P_{RSSI} \cdot C_{network} + C_{app}) \qquad (2)$$

The goal is to assess the candidate networks relative to each other which means that it is enough to characterize $C_{network}$ and C_{app} as described in Tables I and II, i.e. knowing the ratio of the different networks and applications. Furthermore, energy component of network connection depends on received signal strength (RSSI) which varies typically between -40 and -110 dBm [15]. Table VII summarizes P_{RSSI} values according to our three-level quantization.

TABLE VII. P_{RSSI} VALUES ACCORDING TO RSSI

Linguistic value for RSSI	**RSSI interval (dBm)**	**P_{RSSI}**
strong	-70…	1.0
fair	-90…-70	1.5
low	…-90	2.0

As it was presented before deceasing battery charge leads to a more critical mobile phone usage in respect of energy. Let B denote the current battery charge percentage. Knowing that the discharge curve follows an exponential nature let us define $P_{battery}$ the following way:

$$P_{battery} = 2^{\frac{100-B}{100}} \tag{3}$$

Figure 4 illustrates $P_{battery}$ values when battery charge is changing.

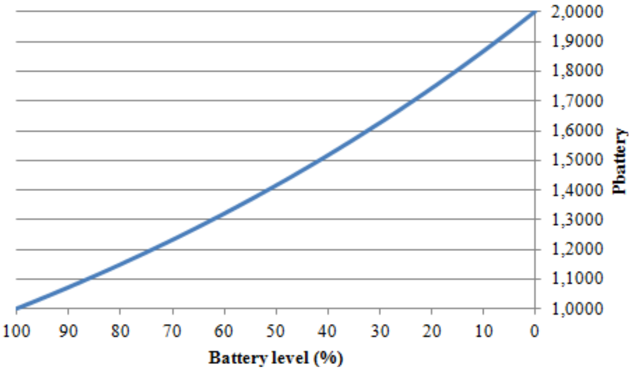

Fig. 4. $P_{battery}$ values vs. battery charge

The assessment process concludes with deducting battery cost values from the QoS utility numbers of each candidate network which determines the cumulative network performance values. The algorithm will choose the candidate network with the highest cumulative performance value.

IV. VALIDATION OF THE ALGORITHM

The validation of the algorithm will show some desirable scenarios to prove its usefulness. Almost all the parameters are given to provide simulation results except the main input values: the QoS parameters of the candidate networks. We examined different use-cases including office environment (where wireless LAN connection is also available besides the cellular mobile networks) and mobile environment where only mobile cellular networks are available. We modeled different availability patterns which mean combinations of EDGE, UMTS, HSPA, LTE and WLAN (802.11b and 802.11g) networks available with different received signal strength in a heterogeneous network.

The basic, usual QoS parameters of the networks that are used to execute the simulation are shown in Table VIII. To model the dynamics of the network we modified these QoS parameters according to the received signal strength quantized similarly as we did to determine P_{RSSI} values [15]. These modification coefficients are shown in Table IX.

A. *Office environment*

Let us assume wireless LAN with strong received signal strength inside the office or at home. In these cases WLAN networks will dominate mobile cellular networks due to their high QoS performance and extremely low energy cost.

Figure 5 presents two cases showing diagrams with the cumulative performance value of different candidate networks. The titles of the diagrams show the application being run by the mobile node, adding the battery level to be complete for the algorithm.

When there is a bigger distance between us and the WLAN access point the received signal strength will be lower. The difference is already much slighter in these cases between WLAN and mobile cellular networks but still, the algorithm prefers mostly WLAN networks as shown in Figure 6 due to their low energy costs.

TABLE VIII. BASIC QOS PARAMETERS OF CANDIDATE NETWORKS

	Bit rate (kbps)	**Delay (ms)**	**Packet loss (%)**	**Jitter (ms)**
EDGE	200	150	2	30
UMTS	1000	150	0.5	30
HSPA	4000	100	0.3	25
LTE	15000	10	0.25	15
WLANb	5000	100	0.15	10
WLANg	25000	100	0.1	10

TABLE IX. MODIFICATION COEFFICIENTS FOR CANDIDATE NETWORKS IN RELATION WITH RSSI

Linguistic value for RSSI	**upward QoS criteria**	**downward QoS criteria**
strong	1	1
fair	0.75	1.5
low	0.5	2

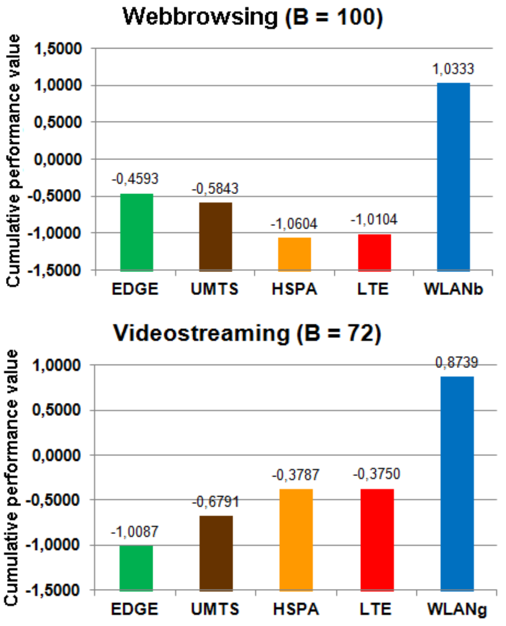

Fig. 5. Scenarios when WLAN networks are available with strong RSSI

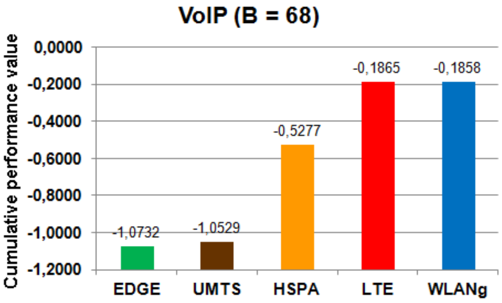

Fig. 6. An exmaple when a WLAN network is available with low RSSI

B. *Mobile environment*

In mobile environment we examined the difference between selection according to the QoS utility numbers and according to the cumulative performance values of candidate mobile cellular networks. We observed same choices when the battery level was high and different choice as it became lower. Same choices often resulted in an LTE or a HSPA network with strong RSSI (when available), as they have high QoS performance. When the choices were different the full algorithm which considered energy cost always preferred a candidate network with lower connection energy cost and of course, lower QoS performance. The reason is the exponentially rising coefficient of energy cost according to battery level. Figure 7 provides examples for same choices and different choices. Blue columns show QoS performance values, green columns mean cumulative performance values of candidate mobile cellular networks.

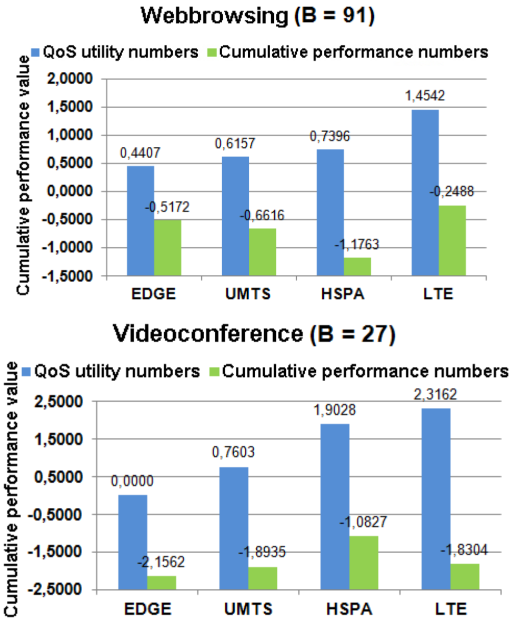

Fig. 7. Same decisions at higher battery level (top) and different choices at lower battery level (bottom)

C. *Energy efficient handovers*

In this scenario we fixed the combination of the available networks and also assumed that the user is not moving. We still experienced vertical handovers while running a particular application. The reason was again the battery level. The battery level is getting lower while an application is being run, and the exponential coefficient of the energy cost rises at the same time which implicates different effects on different network technologies.

We defined energy efficient vertical handovers to describe this phenomenon. The target network in these handovers has lower QoS performance but favorable connection energy cost values.

When observing energy efficient handovers we considered only cumulative performance values of candidate networks because QoS utility numbers do not include energy cost.

Figure 8 shows two examples for energy efficient handovers. The horizontal axis of the diagrams shows the decreasing battery level and the cumulative performance values are represented on the vertical axis. The upper diagram describes an online gaming scenario when the mobile node performs a vertical handover from an LTE network to an EDGE network at a 93% battery level. The lower example shows a mobile node used for e-mailing which performs a vertical handover from an LTE network to an UMTS network at a 34% battery level.

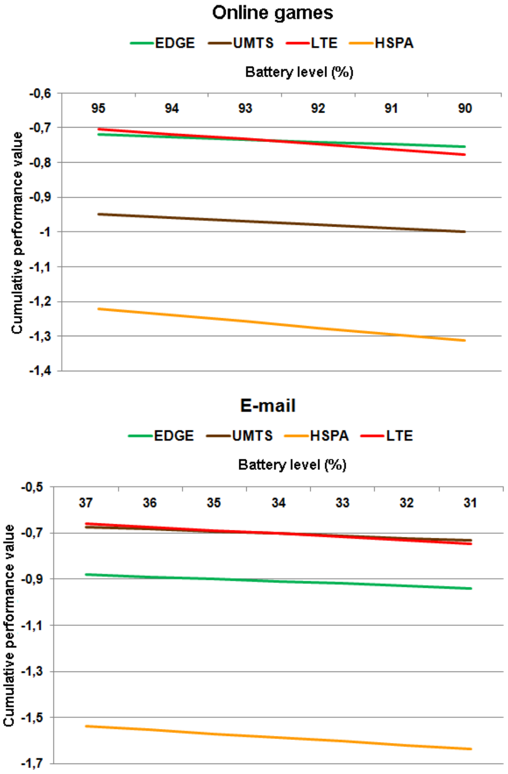

Fig. 8. Two examples for energy efficient handovers

V. CONCLUSION

Our everyday mobile phones often need to perform a vertical handover in the heterogeneous mobile and wireless networks. Conscious handover decisions play a huge role in supporting user experience and energy efficiency on the client side. In this paper we delivered a network selection algorithm which contributes to these intentions. Demands of users are often difficult to quantify that is why we applied fuzzy logic. The proposed algorithm fits in the everyday urban environment as it supposes the availability of EDGE, UMTS, HSPA, LTE and different wireless LAN networks. The introduced applications follow the trend of mobile phone usage, indicating the difference between real-time and delay tolerant applications. The algorithm approaches the problem strictly from the client side and from a practical point of view.

The simulation showed that mobile phones running applications requiring low bit rate or delay tolerant applications would be willing to choose a network with lower QoS performance if there is no WLAN networks available which would provide an energy efficient solution. Applications requiring high QoS performance obviously prefer LTE networks in mobile environment until they are available with strong received signal strength and the battery charge does not reach a critical value. At this point mobile phones would be willing to accept a tradeoff between network performance and energy consumption and they choose a network with lower QoS performance but effective energy parameters. If we stay at home or in an office, WLAN networks would be the optimal choice because of their specifically low energy parameters.

The simulation was suitable to prove the usefulness of the method, however, input parameters cannot be fixed like this in a practical environment. Mobile phones are capable of monitoring the available candidate networks and make real-time calculations to choose the optimal one.

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