Energy-Availability-QoS Trade-off for Future Converged Fixed-Mobile Networks

T. Cinkler Á. Ladányi R. Béres A. Mitcsenkov G. Paksy B. Molnár R. Andó
High-Speed Networks Laboratory (HSN*Lab*), Department of Telecommunications and Media Informatics
Budapest University of Technology and Economics, Budapest, Hungary, E-mail: cinkler@tmit.bme.hu

***Abstract*—In the access part of the Future Internet the fixed and mobile access is expected to converge not only to better utilize the resources, but also to decrease the power consumption, to increase the availability and also to improve the QoS/QoE of uesrs.**

We present architectures and algorithms to show what Energy-Availability-QoS tradeoffs can be reached. We support our approach by intensive simulations.

The electric energy consumption [kWh] grows from year to year. The share of InfoCommunications Technologies (ICT) grows even faster. In this paper we focus primarily onto reducing energy consumption of the access part of modern heterogeneous mobile networks that leads to "greening" of this part of the network. The idea of our "greening" algorithm is based on selective switch-off and on consolidation of resources, employed *jointly* with both, the vertical and the horisontal handover (handoff). We show by simulations the energy saving benefits of our approach.

I. Introduction

In this section we give a motivation why it is so important to reduce power consumption (Section I-A), how the handover works today and how it is supported (Section I-B) without going into the details of protocols, and we also give an overview of heterogeneous (multi-technology or multi-radio) mobile access networks (Section I-C).

A. Electric Energy Consumption

The emergent growth of the electric energy consumption has attracted significant attention in last years, not only because of environmental aspects but rather for the reason of increased share of electricity bills in the OPEX of mobile operators. The problem is that the steady traffic growth induces a much faster growth in electric energy consumption. For an excellent overview of the problem as well as for the classification of the alternative solutions see [1].

B. Handover (HO) in Mobile Networks

Handover (or handoff) is the action when a mobile station (user) having connection or active session to a base station (cell) connects or is connected to another base station. For different technologies there are different handovers and even more different terms for it. For a comprahensive overview see [2].

There are multiple types / variants of the handover:

- Hard handover: Break-before-Make: It loads a single cell at time.
- Soft handover: Make-before-Break. It loads two or even more cells in the moment of the handover.
- Horizontal Handover: Handover between from one cell to another, both using the same radio access technology (RAT). It is also sometimes referred to as homogeneous handover.
- Vertical Handover: Handover between different RAT technologies [3]. It is also sometimes referred to as heterogeneous handover.
- Terminal (MS) Controlled: The terminal initiates and handles the handover. Typically based on signal quality measurements.
- Terminal (MS) Initiated, Network Assisted: Although the terminal initiates the handover, the network handles it.
- Network Initiated, Network Controlled: The handover is initiated by th enetwork as well as it is handeled by the network.

Since seemless handover is preferred we assume soft handover, both horizontal (HHO) and vertical handover (VHO) and mostly the Network Initiated and Network Controlled (NINC) handover. However, in certain cases the terminal (MS) will initiate the HO.

We do not go into the details of the protocols, however we would like to emphasise that some of the most promising solutions for vertical handover (VHO) are (Media Independent Handover) [4] [5] and IP v6 mobility based one.

C. Heterogeneous Mobile Networks

In a heterogeneous wireless mobile network we assume parallel coexistence of multiple technologies at both sides, at mobile stations as well as at the base stations.

We can consider e.g. the following 9 different technologies: GSM - GPRS - EDGE - WiFi(802.11) - UMTS/CDMA2000 - HSPA (HSDPA/HSUPA) - HSPA+ - LTE - WiMAX(802.16). For simplicity reasons, we choose only 3 of them, namely, GSM (2G), UMTS (3G) and LTE (4G). This heterogeneous access part is often referred to as MRAN: Multi-Radio Access Network.

Vertical handover is an automatic fallover from one technology to another in order to maintain communication while, in our case, the objective is to reduce energy consumption. Of course such handover can be performed only, when the mobile station (MS) and the base station (BS) are compatible. Typically all new devices (both, BS and MS) are backward compatible, i.e., they support the older technologies as well. However, since the density of the LTE cells is much higher than that of UMTS or GSM it is not justified to use LTE

		Base station compatibility		
		GSM	UMTS	LTE
Mobile station compatibility	GSM	+		
	UMTS	+	+	
	LTE	+	+	+

TABLE I
OVERVIEW OF THE COMPATIBILITY OF MOBILE STATIONS AND BASE STATIONS. '+' MARKS THE COMPATIBILITY CASE.

	energy [kVAh]	reach [km]	cell / GSMcell	total cells	total [kVAh]
2G: GSM	1	3	1	78	78
3G: UMTS	2	1.3	7	220	440
4G: LTE	3	0.6	24	2176	6528

TABLE II
OVERVIEW OF OUR SIMULATION ASSUMPTIONS.

base stations to support older technologies. Therefore the fall-back opportunity, i.e. the compatibility between the mobile station and the base station (in more general the network) will primarily depend on the mobile station as illustrated in Table I.

II. THE PROPOSED METHOD

In [6] the authors aim to maximise user throughput and maintain the QoS while performing vertical handover between WiFi and WiMAX. In [7] the authors optimize the handover decision between WiFi and WiMAX to reduce terminal energy consumption. In [8] the authors propose energy efficient vertical handover between CDMA2000 and WiFi networks, and try to minimise the number of discarded verticel handovers via a penalty function.

In contrast to these papers our aim is to reduce the energy consumption of the whole network, primarily that of base stations, secondary, that of the mobile stations. Furthermore, we have assunmed three technologies, namely GSM (2G), UMTS (3G) and LTE (4G), without limiting the generality.

We propose here using the technology and location selective switch off. Whenever there is a choise of multiple technologies, i.e., both the BS and the MS support the same technologies, they will fall back to that technology that has lowest power consumption while it still satisfies the traffic and quality requirements for that service. I.e., instead of using LTE they fall back to either UMTS or GSM depending on the requirements of the service used. E.g., in case of voice traffic GSM should be sufficient.

Whenever a cell of a certain technology is not used it is switched off to a sleep mode. Similarly, it wakes up eaither in a periodical or in our case rather in a triggered way whenever it is necessary for either horizontal or vertical handover and when it cannot be substituted by a technology with lower power consumption or by any neighbouring cell of that or another technology. When chosing either horizontally or vertically the measured signal level must be always satisfactory, i.e., reducing energy requirement is not allowed if the signal quality is deteriorated below a certain level.

III. THE SIMULATION

A. Asumptions on the Networks

In this subsection we give an overview of our assumptions used during simulations on the diameter, density and location of cells as well as on the electric energy consumption of the base stations of these cells.

[9] gives an excellent overview of the energy consumption of different technologies. Accordingly, in our simulations we assume that the average energy consumption is 0.5-1 kVAh for a single base station in GSM, roughly double (1-2 kVAh) for 3G (UMTS/HSPA) and roughly tripple (1.5-3 kVAh) for LTE.

Furthermore, the number of cells required to cover a certain area grows as the bit rate grows and therefore, due to the spectrum imposed radio interface bottleneck, the cell size drops. We have assumed, that while a GSM cell covers a roughly circle-shaped area of a radius of roughly $\sim$ 3 km, the 3G has reach of $\sim$ 1.3 km that can rapidly change depending on the total load of that cell due to the phenomenon known as breathing cell, while the radius of an LTE cell is assumed to be $\sim$ 0.6 km, that can even more vary, and not only in diameter but in shape as well, through the beem forming feature of MIMO. Therefore, we have asumed for simplicity reasons, that an area of a single GSM cell can be served by 7 UMTS cells or by 24 LTE cells. Columns 3 and 4 of Table II shows these asumptions.

In our simulations we have assumed a city of a diameter of roughly 10 kilometers, with uniform cell distributions. We assumed that wherever we have a GSM antena its tower will be used for UMTS and LTE as well, however, not all LTE or UMTS base stations support e.g., GSM.

B. User Mobility and Traffic Model

A very simple user mobility model has been implemented. The given number of users appears randomly with uniform distribution anywhere in the network, then it moves forward with constant velocity with 95% probability. 2.5% is the likelihood that it turns left (90°) as well as 2.5% is the likelihood of turning right.

We assume that the technology (GSM, UMTS or LTE) used by certain mobile stations has equal probability. Whatever technology is used by the mobile station it must be served by a base station using that technology. If the mobile station changes to a technology that has lower energy consumption, vertical handover will be performed and it will be served by that technology. The probability that a user changes the service and therefore it can be served by a different technology has probability of 0.25% at each step as it moves through the network.

C. Load Dependent Energy Consumption Results

For simulations we have used the network as explained in Section III-A and number of cells as listed in Column 5 of Table II with the user model as explained in Section III-B.

The software for simulations was developed under Windows Vista, in C++, using the OpenGL library for the graphical interface of the simulator. The computer had an Intel Core2Duo 2 GHz processor and 2 GByte of RAM. The simulation has taken roughly 1 minute per thousend users. I.e. as we incresed the number of users that are simultaneously present in the network the simulation time has grown, however, its time requirement is still moderate.

During the simulations we have compared three scenarios (cases) from the energy consumption point of view.

- **Technology** and location selective switch off:
  when only the technology with the lowest consumption is switched on out of those technologies that are compatible with the instant requirements of the end user in a certain geographic location. This means that a mobile station in a certain location can be served by any of available technologies, or by any of the neighbouring cells if they are switched on and their signal quality is satisfactory. Whenever there is no such user being served by a cell that cannot be served by another cell that technology in that location can be switched off. Then the user will be handed over to another active cell. This is our proposed method that we compared to the next two.
- **Location** selective switch off:
  when all technologies are switched on in a cell, whenever at least a single user is present and active. This is justified in cases when a single unit serves all the technologies and parts of it can not be switched on or off. This method still has good performance, comparable to that of the proposed method.
- **Full** power:
  is the reference method, where all the tehnologies are switched on all the time. This is a very wasteful approach. However we did not take load proportionality of energy consumption into acount at this point.

We refer to these three networks in Figures 1 - 5 as 'full', 'location' and 'technology', respectively.

In Figure 1 it can be well seen that the energy consumption of 'technology' and 'location' grows, while for the 'full' it can be considered constant. The 'technology' curve is closer to the load proportional (linear) energy consumption. In Table II we can see, that from the three technologies the power consumption of the LTE is the absolutely most significant. It covers almost 93% of the total power in the case of full power state!

Figures 2 - 4 show the share of the three technologies at different loads. In Figure 2 it can be seen that due to the few and large cells they have to be switched always all the time, since practically in case of a few hundered users the total of 78 GSM cells will be almost always in use. However, the total power requirement for this technology is quite low, negligible when compared to that of LTE.

In Figure 3 somewhat longer transient can be seen as the number of users grows in the network. This is proportional to the ratio of the number of cells to the number of active users. The total power share of this technology is still small compared to that of the LTE.

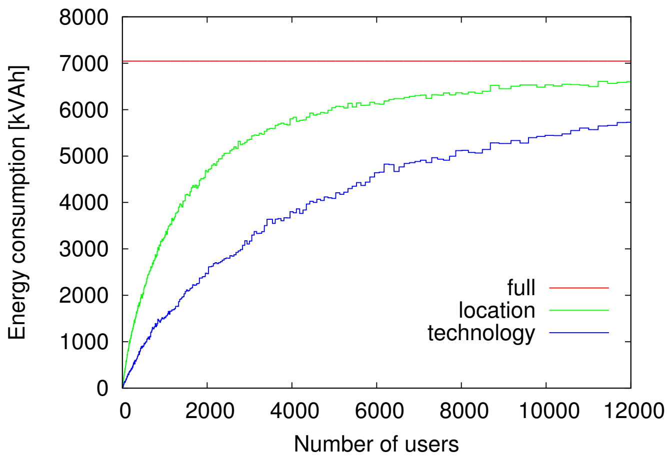

Fig. 1. Total energy consumption of the three technologies used in parallel: GSM + UMTS + LTE

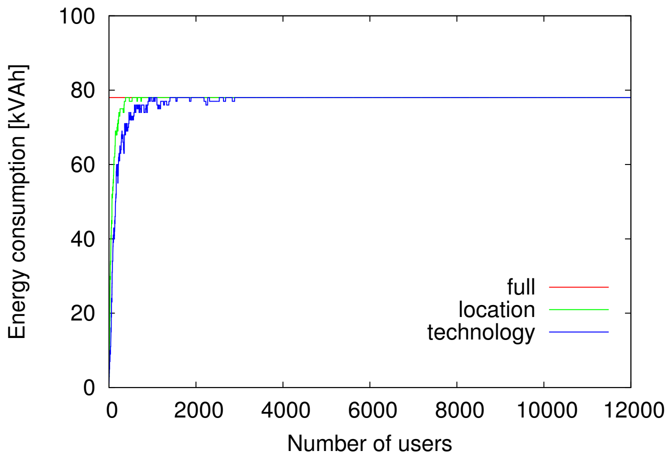

Fig. 2. Energy consumption of the GSM only

In Figure 4 we can see a smooth growth of the energy consumption as the number of users grow. LTE absolutely dominates the power consumption figures, however, for low or moderate loads it enables very significant energy savings! Due to the small size of LTE cells in periods of lower or moderate load it often happens that a cell can be switched off.

Figure 5 shows somewhat different results. Here we assumed a realistic day-time change in the raffic pattern to demonstrate how much energy can be saved within a single 24 hour cycle. We changed the total number of active users according to the statistics presented in [10]. It can be seen that the savings are most significant in idle or low load periods while small or negligible in busy hours. The surfice between the curves is proportional to the savings achievable.

IV. Conclusion

In this paper we have demonstrated by simulations that even a simple selective switch-off combined with resource consolidation applied jointly with both, horizontal and vertical

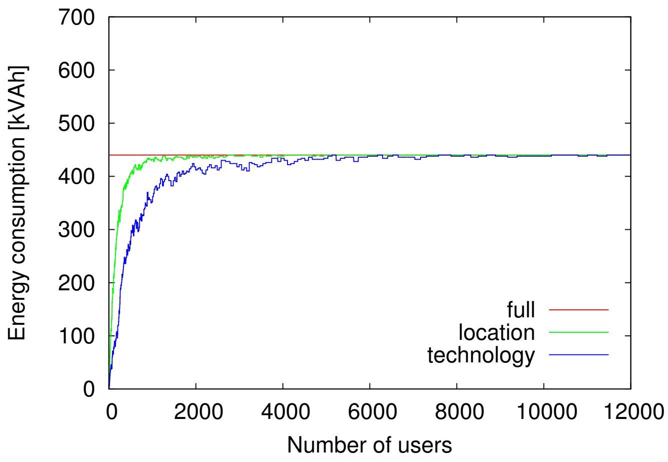

Fig. 3. Energy consumption of the UMTS only

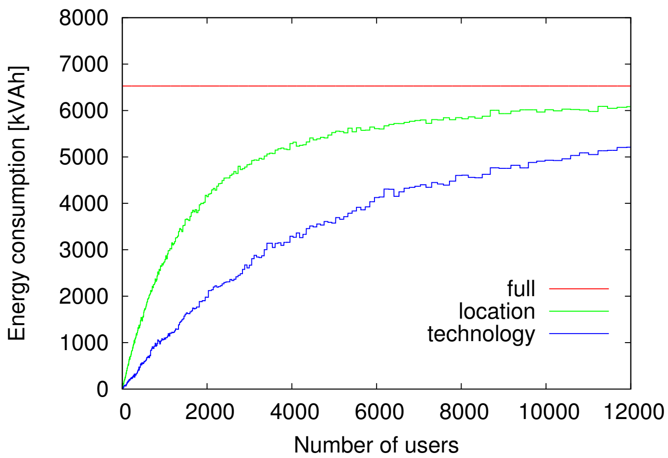

Fig. 4. Energy consumption of the LTE only

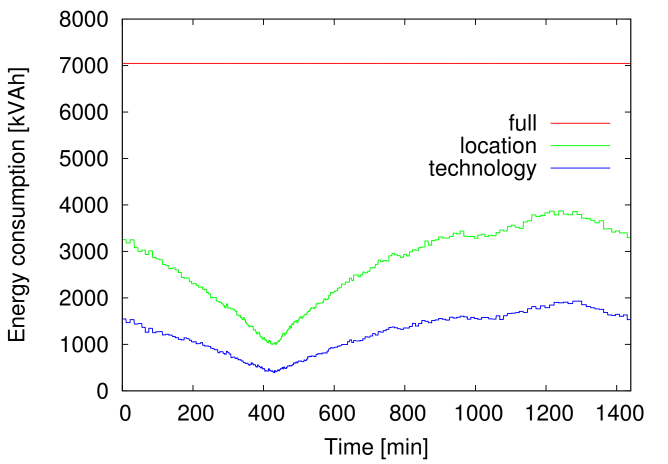

Fig. 5. Day-time energy consumption of the whole network in 24 hours (1440 minutes) as the traffic changes according to [10]. The minimum is in the early morning, while the maximum in the late evening.

handover can significantly reduce the power consumption of the heterogeneous mobile access. This holds particularly for the periods of the day with lower traffic. We have compared three scenarios. First, when only the technology with lowest consumption is switched on out of those technologies that are supported by the end users in that geographic location that can not be served by adjacent cells, i.e., if there are no users with higher requirement in that area that cannot be served by neighbour cells (referred to as 'location'). Second, when all technologies are switched on in a cell, whenever at least a single user is present and active (referred to as 'technology'). And third is the reference method, where all the technologies are switched on all the time (referred to as 'full').

The main message of our simulations is that LTE has the significantly largest energy consumption, however, due to its small cells, and great flexibility of the size and shape a very adaptive switch-off can be performed that leads to very significant energy savings.

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