Exergy based analysis of radio access networks

Slavisa Aleksic and Mehdi Safaei

Exergy based analysis of radio access networks

(Invited Paper)

Slavisa Aleksic and Mehdi Safaei
Institute of Telecommunications, Vienna University of Technology
Favoritenstr. 9-11/E389, 1040 Vienna, Austria
slavisa.aleksic@tuwien.ac.at, safaei.mehdi@gmail.com

Abstract—**Currently, the total energy consumption of the information and communication technology (ICT) sector is continuously increasing due to the fast penetration of ICT into many areas of business and society. Particularly high growth rates have been observed in the area of technologies and applications for communication networks. Over the last decade, there has been an exponential increase of both data traffic and number of devices connected to the Internet, which has led to a fast increase of network capacity. In this context, the role of the network infrastructure is becoming increasingly important because satisfying the need for high capacity generally means higher energy consumption of the network equipment. Especially mobile networks have experienced constant evolutions that have led to new technology generations and advanced radio interfaces capable of providing data rates in the order of hundreds of Mbps or even Gbps. Additionally, the number of active mobile subscribers has grown continually and rapidly.**

Even through the use phase is very important because of the high energy consumption and related greenhouse emissions of telecom infrastructures, it is just a part of the story. The whole life cycle, i.e., also the production and disposal phases should be considered when determining sustainability of communication networks, especially because of the relatively short life-cycle of ICT devices. In this paper, we report results of a study that apply widely used thermodynamic tools in combination with network modeling to assess sustainability of radio access networks. In particular, we utilize the concept of available energy or exergy to determine the environmental impact of the whole life cycle of radio access network infrastructure and present results of a case study of radio access network for the city of Vienna.

I. INTRODUCTION

Already today, advanced radio interfaces are capable of providing data rates in the order of hundreds of Mbps or even Gbps [1]. Additionally, in recent years, there has been a constant increase of the number of active mobile subscribers worldwide [2]. The rapid evolution and penetration of radio network technologies has made possible a ubiquitous Internet access and broad use of Internet applications. Advanced Internet applications and services can, among others, be used to increase the efficiency of resource usage in many areas such as in transportation, smart buildings, water management, manufacturing as well as in production, distribution and consumption of energy (smart grids). Thus, the Internet and, more generally speaking, the information and communication technology (ICT) can be used to improve the global energy productivity.

Recently, there have been a number of studies concentrating on potential energy savings in communication networks [3-8]. It has been shown that significant savings in energy consumed by the network infrastructure can be achieved when optimizing both the network concept and the architecture of network elements with regard to energy consumption, together with using energy-efficient technologies and components as well as energy-aware algorithms and protocols. Additionally, a high-performance global network infrastructure that is optimized to efficiently support rapid development and broad use of applications and services for improved energy productivity can lead to very large indirect energy savings (second order effects). It has been recently estimated that the potential reduction of greenhouse gas (GHG) emissions through the use of advanced ICT applications and services is ten times higher than the ICT's own emissions [9]. Thus, complex interactions between the network and various advanced services and applications should be better understood in order to optimize both network infrastructure and applications for maximizing improvements in energy productivity in other branches of business and society [10]. Finally, the whole life cycle of ICT equipment should be considered to properly understand and assess the role of ICT in sustainable development.

Thermodynamic theory and, in particular, the second law of thermodynamics, is a universally applicable tool for analyzing energy and entropy flows in heterogeneous systems [11-13]. Communication processes and systems can be seen, similarly to many other processes and systems in the nature, as dissipative transformations that level differences in energy density between participating subsystems and their surroundings. Particularly, the concept of exergy is well suited to alanlyse communication networks from a holistic point of view. This paper describes the use of *exergy-based life-cycle analysis* (E-LCA) to assess sustainability of ICT systems and shows an example of applying the E-LCA on a model of radio access network infrastructure for the city of Vienna. The paper is structured as follows. The next section gives a brief introduction to E-LCA. An example of application of E-LCA to study exergy flows for radio access networks is shown in III. Finally, conclusions are drawn in Section IV.

II. EXERGY-BASED LIFE CYCLE ANALYSIS (E-LCA) OF ICT EQUIPMENT

Exergy analysis is well suited to investigate the sustainability of heterogenous systems. There are a number of studies that apply E-LCA) to assess sustainability of complex systems and technologies [14-18]. Since recently, E-LCA has also been

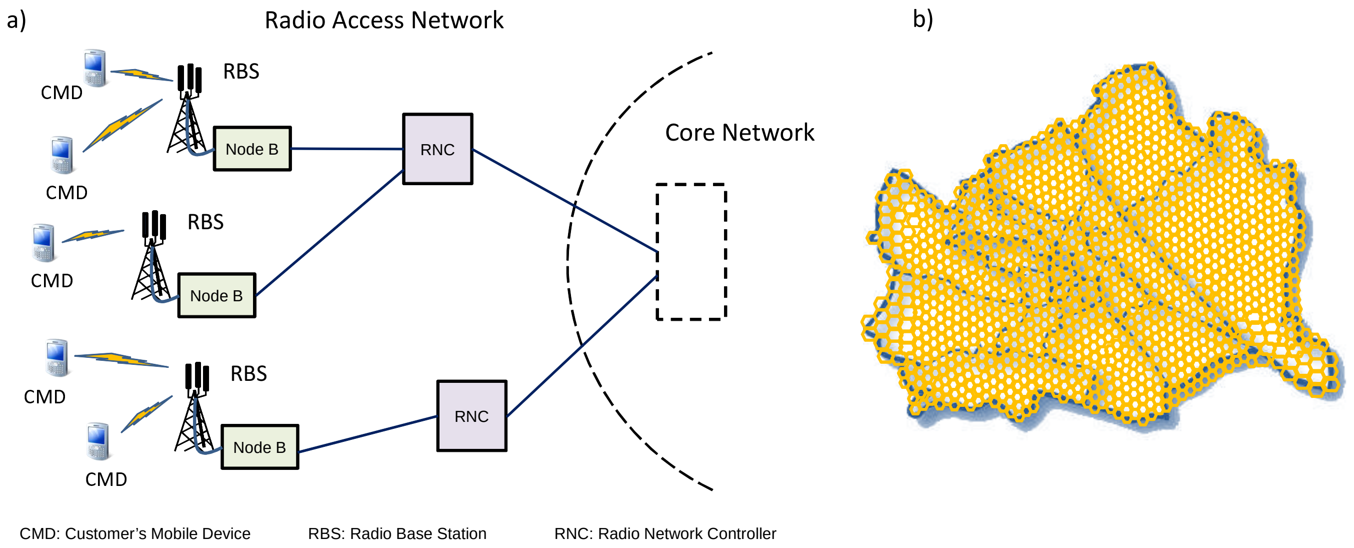


Fig. 1. a) Generic architecture of a UMTS radio access network (RAN) and b) exemplary coverage of the city of Vienna by a UMTS macrocell RAN.

used by several research groups to assess the sustainability of ICT infrastructure and applications [17,18].

In E-LCA, the flow of exergy is determined for each phase of a device life cycle. First, the embodied exergy of materials used to manufacture the device is determined. This embodied material exergy acts as the exergy input into the system. Then, the amounts of exergy consumed and destructed during various LCA phases including transportation, manufacturing, use and disposal are calculated. Also exergy content and conversion efficiencies of various energy sources can be considered. As a result of E-LCA one can determine exergy-based sustainability indicators that can be used to easily compare the sustainability of different concepts, technologies and approaches.

III. E-LCA OF RADIO ACCESS NETWORKS

In order to illustrate the use of E-LCA for evaluating sustainability of communication networks we consider an exemplary radio access network (RAN). Here we assume a system as shown in Fig. 1a), which represents a generic architecture of a UMTS RAN. The main components of such a network are the base transceiver station (Node B), the radio network controller (RNC) and the connection to the core network that is referred to as backhaul. The backhaul can be realized in different ways and using different technologies based on either microwave links, copper cables or optical fibers. Customers use mobile devices (CMD) to connect to radio base stations in order to use various services and applications such as telephony, classical Internet services or new services such as videoconferencing, video on demand, file sharing or any kind of cloud services.

As an example, we model a radio access network for the city of Vienna. According to the statistical data on areas and population densities [19] and using typical network configuration and coverage parameters for the city of Vienna we estimate the required number of base station sites (see Fig. 1b) and, consequently, the number of network elements such as Node B, RNC and backhaul equipment using the tool for evaluation of energy efficiency of access networks presented in [20,21]. We also estimate the required total length of copper and fiber cables as well as the time-of-the-day dependent traffic profiles of active users. A result of the radio access network model is the overall energy consumption. Hence, knowing the operational energy consumption, the required number of network elements and their life cycles it is possible to obtain exergy consumptions of different life cycle phases of the network.

The life cycle of a radio access network for the city of Vienna including the customer's mobile devices is presented in Fig. 2 a). Here we assume a case where all row materials are available within a radius of 1000 km from the manufacturing location, while the recycling is taking place 750 km away from the location of use. The raw material reutilization is 40 %. All other assumptions regarding network dimensioning and the number of mobile customers are made according to data we obtained from the Statistics Austria, the Austrian Regulatory Authority for Broadcasting and Telecommunications (RTR), Austrian network operators and the Forum Mobilkommunikation (FMK); particularly, data on technology penetration, market shares and population statistics. The main assumptions are listed in Table I. For a more detailed information about the modeling method for radio access networks the reader is referred to [20-22].

The total life-cycle exergy consumption of the radio access network inclusive user mobile devices over eight years of service is estimated to be about 10.6 PJ (see Fig. 2a). Customer's mobile devices contribute by about 6.5 PJ, which is approximately 60 % of the total exergy consumption. Hence, although a mobile device (e.g., a smartphone) consumes much less electricity than a network device such as Node B or RNC, the high number of customer's mobile devices and their relatively short service time lead to a significant contribution of mobile devices to the total system's exergy consumption. The effect of mobile devices on the sustainability of the entire

TABLE I
MAIN ASSUMPTIONS MADE FOR THE E-LCA STUDY.

E-LCA MODEL	**Case 1:** **w/o Material Reutilization**	**Case 2:** **40% Material Reutilization**	**Case 3:** **60% Material Reutilization**
Raw Material Extraction	• Spatial context: southeast Asia/China • No material reuse • Material supply: within a radius of 1000 km	• Spatial context: southeast Asia/China • 40% of material flows from the recycling phase • Material supply: within a radius of 1000 km	• Spatial context: southeast Asia/China • 60% of material flows from the recycling phase • Material supply: within a radius of 1000 km
Material Transportation	• Spatial context: within a radius of 1000 km • Mode of transportation: rail/truck	• Spatial context: within a radius of 1000 km • Mode of transportation: rail/truck	• Spatial context: within a radius of 1000 km • Mode of transportation: rail/truck
Manufacturing and Assembly	• Spatial context: southeast Asia/China	• Spatial context: southeast Asia/China	• Spatial context: southeast Asia/China
Product Transportation	• From southeast Asia/China to Austria/Vienna • Mode of transportation: rail/truck/ship	• From southeast Asia/China to Austria/Vienna • Mode of transportation: rail/truck/ship	• From southeast Asia/China to Austria/Vienna • Mode of transportation: rail/truck/ship
End-of-Life Transportation	• From northeast Austria/Vienna to Germany • Mode of transportation: rail/truck	• From northeast Austria/Vienna to Germany • Mode of transportation: rail/truck	• From northeast Austria/Vienna to Germany • Mode of transportation: rail/truck
Recycling	• Based on the mass of equipment • Approximately 520 kJ/kg exergy consumption [17]	• Based on the mass of equipment • Approximately 520 kJ/kg exergy consumption [17]	• Based on the mass of equipment • Approximately 520 kJ/kg exergy consumption [17]

system becomes evident from Fig. 2b) that shows the relation between the embodied and the operational exergy for the considered radio access network with (the diagram on the right hand side) and without (on the left hand side) mobile devices. Without mobile devices the operational exergy of the network is 13 times higher than the embodied exergy. When considering mobile devices the operational exergy becomes lower than the embodied exergy. This result emphasizes the importance of using a holistic approach and considering the entire life cycle.

In order to assess potential exergy savings through row material reutilization we define three cases as described in Table I. Case 1 refers to a UMTS RAN inclusive mobile devices without any material reutilization (see Table I). For cases 2 and 3 we assume that 40% and 60% of the recycled materials are reutilized, respectively. Case 2 with 40% material reutilization is presented in Fig. 2a). The estimated exergy savings are summarized in Fig. 2c). As can be seen from this figure, savings of about 92 TJ could be possible when 40% of recycled materials are be used for manufacturing new devices, while savings as high as 138 TJ are achievable in case of 60% material reutilization. Even though these values are large, they represent only a few percent of the total exergy degradation through the life cycle of the entire system (see the diagram on the right hand side of Fig. 2c). Hence, these results show that an increase in service time of mobile devices can potentially lead to much higher exergy savings than material reutilization.

IV. CONCLUSIONS

In this paper, we assessed sustainability of radio access networks using a holistic approach that combines network modeling and exergy-based life-cycle analysis. The analysis was performed on an example of UMTS radio access network for the city of Vienna. The obtained results underlined the importance of using a holistic approach and considering the entire life cycle of network elements and user devices. A short service time of user mobile devices has a strong impact on the exergy destruction. Even though row material reutilization can help to improve the suistanability of the entire system, an increase in service time of devices and equipment would have much stronger effect.

REFERENCES

[1] Akyildiz, I. F.; Gutierrez-Estevez, D. M.; Reyes, E. C. The evolution to 4G cellular systems: LTE-Advance. Elesevier Physical Communication **2010**, 3, no. 4, DOI: 10.1016/j.phycom.2010.08.001, 217 - 244.

[2] International Telecommunication Union Telecommunication Standardization Sector (ITU-T) Statistics. **2012**, http://www.itu.int/ITU-D/ict/statistics/at_glance/KeyTelecom.html

[3] Aleksic, S. Energy Efficiency of Electronic and Optical Network Elements. (invited) IEEE JSTQE **2011**, 17, no. 2-3, 296 - 308.

[4] Tzanakaki, A.; Katrinis, K.; Politi, T.; Stavdas, A.; Pikavet, M.; Van Daele, P.; Simeonidou, D.; O' Mahony, M. J.; Aleksic, S.; Wosinska, L.; Monti, P. Dimensioning the Future Pan-European Optical Network with Energy Efficiency Considerations. IEEE/OSA JOCN **2011**, 3, no. 4, 272 - 280.

[5] Aleksic S. Power Consumption Issues in Future High-Performance Switches and Routers (invited). in Proceedings of ICTON **2008**, 194 - 198.

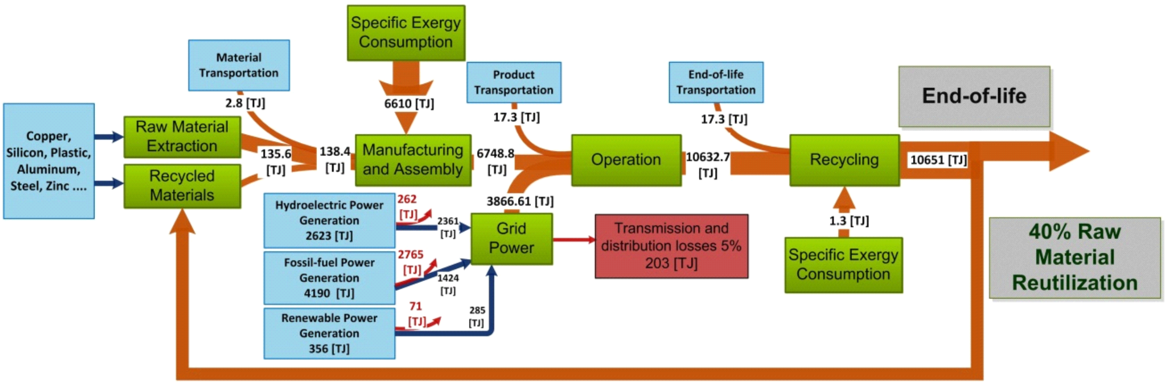
[6] Van Heddeghem, W.; Deruyck, M.; Puype, B.; Lannoo, B.; Joseph, W.; Colle, D.; Martens, L.; Demeester, P.; Power Consumption in Telecommunication Networks: Overview and Reduction Strategies. IEEE Comm. Mag. **2011**, 49, no. 6, 62 - 69.

[7] Fiorani, M.; Casoni, M.; Aleksic, S.; Performance and Power Consumption Analysis of a Hybrid Optical Core Node. IEEE/OSA JOCN **2011**, 3, no. 6, 502 - 513.

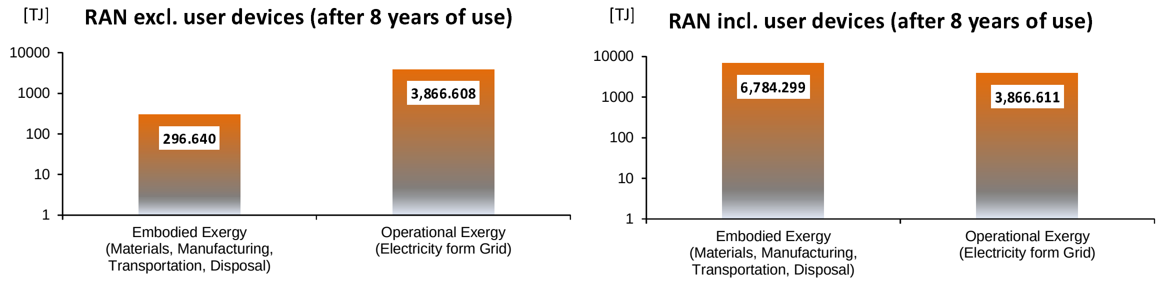
[8] Aleksic, S. Power Consumption of Hybrid Optical Switches. Proc. of OFC 2010 **2010**, OThP6.

[9] WWTF Outline for the first global IT strategy for CO_2 reduction. WWTF report **2008**.

a) E-LCA for radio access network (RAN) incl. user mobile devices and 40% of material reutilization



b) Relation between embodied and operational exergy for RAN with and without user mobile devices



c) Potential exergy savings through material reutilization

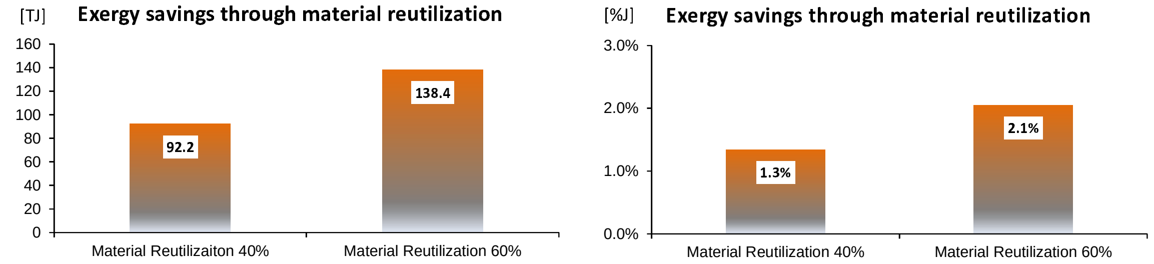


Fig. 2. Exergy-based life cycle assessment of the model UMTS radio access network for the city of Vienna: a) exergy flow inclusive user mobile devices and assuming 60% material reutilization b) relation between the embodied and the operational exergy for RAN with and without user mobile devices and c) potential exergy savings through material reutilization in TJ (left hand side) and in % (right hand side). The service life of network elements is assumed to be 10 years while that of smartphones 2 years.

[10] Aleksic, S. Energy-Efficient Communication Networks for Improved Global Energy Productivity (invited). Springer Telecommunication Systems **2013**, ISSN: 1018-4864, 1 - 18.

[11] Aleksic, S. Energy and Entropy Flow in Erbium Doped Fiber Amplifiers: A Thermodynamic Approach. Journal of Lightwave Technology **2012**, 30, no. 17, 2832 - 2838.

[12] Aleksic, S. Thermodynamic Aspects of Communication and Information Processing Systems (invited). in Proceedings of ICTON **2011**, Tu.B1.2.

[13] Aleksic S. Considerations Towards a Holistic Model of Energy Dynamics in Global Networks. in Proc. of the 11th International Conference on Telecommunications (ConTEL), **2011**, 237 - 242.

[14] Gutowski, T.; Dahmus, J.; Thiriez, A.; Branham, M.; Jones, A.; A Thermodynamic Characterization of Manufacturing Processes. IEEE Int Symp Electron Environ **2007**, 1 - 6.

[15] Masini, A.; Ayres, R. U. An Application of Exergy Accounting to Four Basic Metal Industries. CMER, INSEAD **1996**, 1 - 51.

[16] Rosen, M. A.; Bulucea, C. A.; Using Exergy to Understand and Improve the Efficiency of Electrical Power Technologies. Entropy **2009**, 11, doi:10.3390/e11040820, 820 - 835.

[17] Hannemann, C. R.; Carey, V. P.; Shah, A. J.; Patel, C. Lifetime Exergy Consumption as a Sustainability Metric for Enterprise Servers. Proceedings of Energy Sustainability **2008**, 1 - 8.

[18] Scharnhorst, W. Life Cycle Assessment of Mobile Telephone Networks with Focus on the End-of-Life Phase. PhD thesis, EPFL **2006**, 1 - 182.

[19] Statistics Austria Demographic indices. **2012**, http://www.statistik.at/web_en/statistics/population/demographic_indices/index.html

[20] Aleksic, S.; Deruyck, M.; Vereecken, W.; Joseph, W.; Pickavet, M.; Martens, L.; Energy Efficiency of Femtocell Deployment in Combined Wireless/Optical Access Networks. Elsevier Computer Networks **2013**, 57, no. 5, DOI:10.1016/j.comnet.2012.12.013, 1217 - 1233.

[21] Aleksic, S.; Franzl, G.; Bogner, T.; Mair am Tinkhof, O. Framework for Evaluating Energy Efficiency of Access Networks. Proc. Proceedings of IEEE ICC'13 - GBA **2013**, 1 - 6.

[22] Aleksic, S.; Deruyck, M.; Joseph, W. Energy efficiency of optically backhauled LTE: a case study. to be published in Proceedings of ICEAA - IEEE APWC - EMS 2013 **2013** 1 - 6.