EARTH: Paving the Way for Future Energy Efficient Broadband Wireless Networks

Luis Sanchez[1], Oliver Blume[2], Manuel Gonzalez[1], Gergely Biczók[3], Dieter Ferling[2], and István Gódor[4]

[1] TTI (Technologies of Telecommunication and Information). Albert Einstein 14, Santander, Spain
[2] Alcatel-Lucent Deutschland. Lorenzstraße 10, Stuttgart, Germany
[3] Budapest University of Technology and Economics. Műegyetm 3. Budapest, Hungary
[4] Ericsson Magyarország Kft., H-1097 Budapest, Könyves Kálmán krt. 11., Hungary
lsanchez@tlmat.unican.es, mjgonzalez@ttinorte.es, {oliver.blume,dieter.ferling}@alcatel-lucent.com, biczok@tmit.bme.hu,istvan.godor@ericsson.com

Abstract. Currently, the vast majority of mobile subscribers rely on second-generation mobile technologies, but service providers are investing into aggressive rollouts of mobile broadband networks to deliver a fully-featured wireless Internet. While the main focus in research has been put on enhancing the capacity of this kind of networks, very little has been done regarding their energy efficiency. On the other hand, rising energy cost and growing awareness of climate issues require a shift of focus. The EARTH (Energy Aware Radio and neTworking tecHnologies) project addresses this by investigating and proposing effective mechanisms to drastically reduce energy wastage and improve energy efficiency of mobile broadband communication systems, without compromising system capacity and users' perceived quality of service. In this paper we sketch the main research approaches taken within the project. First, the methodologies to evaluate the energy efficiency of cellular networks, as well as the respective energy efficiency metrics are presented. Afterwards, the proposed solutions are described; within EARTH a holistic approach is being used so that advances in radio components, radio network technologies and advanced network management protocols are exploited jointly, resulting in combined gains that enable an expected power consumption reduction by 50%.

1 Introduction

The planet Earth is experiencing global warming mainly due to the rising emission of greenhouse gases requiring immediate action to reduce carbon dioxide (CO_2) emission of all human activities. Even though the United Nations Climate Change Conference COP15 in Dec 2009 has failed to yield legally binding reduction plans many countries have committed to reducing their CO_2 footprint by 20% by 2020, compared to 1990 [1]. It is believed that the Information and Communication Technology (ICT) industry can play an important role in such reduction plans. Scientific findings have indicated that the CO_2 emission of the ICT industry is

K. Pentikousis et al. (Eds.): MONAMI 2010, LNICST 68, pp. 326–339, 2011.

contributing a considerable percentage to the world energy consumption budget [2]. Within the ICT sector mobile communication is one of the fastest growing contributors with a CO_2 emission of 150 GTo in 2007 [3]. So, today and in the next 5-10 years there is a high demand for energy efficient improvements of ICT, driven by the socio-economic requirement of reducing climate change [4].

In the development of mobile systems, such as GSM and UMTS, operators and equipment manufacturers were focused on improving transmission capacity and spectral efficiency to offer higher data rates and better quality of service. Energy efficiency was not on the mainstream of research and it came as a side effect obtained by improved radio techniques and technological evolution. Now after it has become evident that these improvements do not compensate for the exponentially growing traffic and the related additional deployments, energy efficiency of networks becomes a research theme of its own. The cost of energy resources makes up for 20-30% of the OPEX cost, this has forced the major operators, such as Vodafone and Orange, to aim for reducing energy consumption by 20% to 50% [5] in order to counteract on their growing operational costs. Therefore, in future mobile systems, e.g. LTE and LTE-Advanced, energy consumption will also be a major issue from the point of cost of operation.

Recently, several research projects began to address energy efficiency improvements. For example, MobileVCE [6] and Opera-Net [7] are targeting aspects of energy efficiency. In order to tackle the associated research problems in an even more comprehensive manner and to achieve significant impact, the multi-disciplinary expertise of Europe's most successful and innovative companies, research and academic institutions is required. In January 2010 the highly ambitious 7th Framework Programme project EARTH (Energy Aware Radio and networking TecHnologies) [8] was launched, applying a holistic approach to investigate the energy efficiency of mobile communication systems. EARTH is committed to the development of a new generation of energy efficient equipment, components, deployment strategies and energy-aware network management solutions. EARTH is investigating the energy efficiency limit that is theoretically and practically achievable whilst providing high capacity and no unwanted QoS impact. The target of EARTH is to reduce the energy consumption of mobile systems by a factor of at least 50%. The project is primarily focused on mobile cellular systems of LTE, its evolution LTE-A, where potential impact on standardization is envisaged, but it will also consider 3G (UMTS/HSPA) technology for immediate impact. This paper sketches the technical approach of EARTH and results achieved in the first six month of the project duration.

As it is shown in Figure 1, the EARTH consortium involves 15 partners from 10 European countries in a European large scale Integrated Project (IP). The partners represent industry, operators, research institutions and universities, complementing the full range of knowledge and experience. The resources mobilised by the 15 participants of the EARTH consortium represent a total budget of 14.8 M€ with a total requested EC contribution of 9.5 M€ for the duration of 30 months. The especially strong industrial commitment in the project is expected to facilitate real-world results and fast commercialisation of the project's efforts. A strong contribution by academia assures a high level of innovation and bases the project on cutting edge research know-how.

Next to the environmental improvements, the substantial reduction of network energy consumption will yield large cost savings for mobile operators, substantially reducing the economical barrier to offer ubiquitous mobile broadband coverage. Hence, EARTH also enables the provisioning of high speed mobile services to citizens in countryside areas which are not yet reached by mobile broadband services.

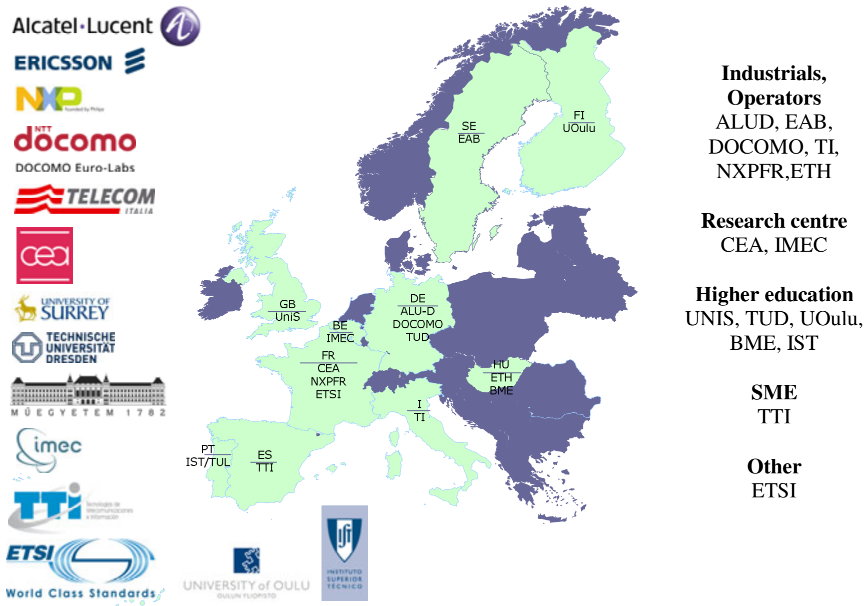

Fig. 1. EARTH Consortium

2 Research Strategy and Expected Impact

Instead of improving single components, the EARTH project [8] addresses the whole system with a holistic approach, from component level to network deployment and network management.

2.1 S&T Methodology

The technical work is organized around a structure with four groups of tracks as can be seen in Figure 2. In the first group of tracks, EARTH studies the global carbon footprint of wireless communications today and provides a forecast for the years 2010 to 2020. Furthermore, reference scenarios and an evaluation framework are being developed. These include the specification of meaningful "green" metrics and optional system extension scenarios in order to enable the proper assessment of energy efficiency for the project's technical solutions. Based on these metrics and scenarios, the following three groups of tracks investigate theoretical limits, technology potentials and practical targets on different levels of Radio Communication networks.

In a second group of tracks, EARTH identifies and investigates mechanisms and solutions by reconsidering the mobile cellular networks architecture and deployment. The work places special emphasis on cooperative base stations, multi-hop extensions and heterogeneous deployments including relays and small cells.

The third group of tracks studies how network management and radio resource management can be enhanced for energy aware operation and dynamic adaptivity to variable traffic loads. The behaviour of networks and network components in low loaded situation, e.g. during night times, has been neglected in the past. Therefore high potential for large saving is expected in these situations.

The fourth group of tracks is devoted to energy efficient components of radio base stations and to enhancements of transmission techniques.

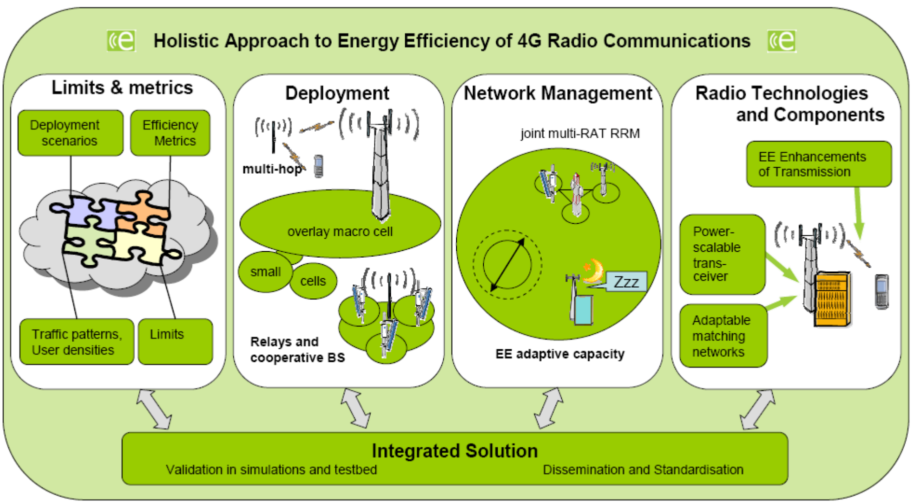

Fig. 2. EARTH holistic approach to Energy Efficiency of 4G Radio Communications

Developing early proof of concepts of sub-systems will be a key factor for the success of the proposed solutions. EARTH validates the investigated concepts by implementing selected solutions in a test platform provided by Telecom Italia's testlab. Other approaches are verified in system simulations. With the experiences gained, the individual solutions of the different tracks will be consolidated and aligned into an integrated solution. The evaluation framework and the defined metrics will be applied to calculate the energy efficiency improvement achieved by EARTH.

The scientific results of the innovative energy efficiency solutions will be widely disseminated. Large parts of the solution will require submission of amendments to standards or of new standards in order to ensure multi-vendor interoperability and wide applicability.

2.2 Estimation of the Ecological Impact of Mobile Communications

Several estimations of the energy consumption and the corresponding CO_2 footprint of ICT have been published [9] [3], the SMART 2020 report probably being the most prominent one. The EARTH project has undertaken to revisit the ecological footprint of mobile communications to predict the impact on the global scale and what mitigation the EARTH project can provide for reducing this footprint.

The study within EARTH is based on comprehensive data of the consortium on deployed base station sites of cellular networks, broadband subscriptions, types of mobile devices and the amount of traffic they generate. The study takes into account the radio access network, core network data centres and mobile devices. For each of these, energy consumed during manufacture and operation is studied separately in a full life cycle analysis. These data are extrapolated to the year 2020, regarding several scenarios: (i) efficiency improvements are leveraged for capacity gains rather than energy savings, (ii) business-as-usual with an observed annual 8% reduction of energy consumption mainly based on Moore's law, and (iii) improvements foreseen from EARTH. Finally (iv), also the usage of renewable energy is studied for a reduction of CO_2 emissions.

The study yields an overall carbon footprint for 2007, that is significantly below the one estimated in SMART 2020 study of 150 Mto CO_2-e. The difference is mostly due to updated electricity consumption data of base stations. The projection to 2020 [10] suggests that the overall carbon footprint of mobile communications will almost triple between 2007 and 2020 if no additional means for reduction are taken. By 2020 the contribution of mobile device manufacturing will catch up with the CO_2 footprint of network operation, driven by the increasing use of smartphones and laptops for mobile access. This prediction is slightly higher than that given by the SMART 2020 study, which did not consider smartphones and laptops. Extrapolations of the Cisco Visual Networking Index suggest that mobile traffic volume might rise by a factor of 100 to 150. In spite of that, the overall RAN energy consumption can be kept flat by realizing both component and system-level energy efficiency improvements that the project EARTH strives to provide [11].

3 Technical Approaches Undertaken

The EARTH project is committed to study the energy saving potential of a broad range of solutions. Following all of them would risk diluting resources and missing the maximum impact on power consumption of future LTE and LTE-advanced systems. Therefore EARTH is devoting the first year of the project to analyse the theoretical gains and limits of all tracks. Leveraging the metrics and the evaluation framework EARTH that are being defined in parallel to that, EARTH will then select the most promising tracks to pursue in more detail in the remainder of the project. At the time of writing this position paper, the project is on half way to the selection process, and this paper can just give a first status of the modelling of the different tracks.

3.1 Reference System, Reference Scenarios and Evaluation Framework

For analysing the potential gains of the different technology tracks studied in EARTH, a baseline system (BLS) and reference scenarios (RSc) are an indispensible prerequisite. In the first months of the project such a common reference system has been defined, building a cornerstone for the EARTH project. To capture the state-of-the-art, the specified parameters and settings are based on 3GPP LTE standards and best-practice of system simulations. Further, the reference system definition will serve for the configuration of the testbed and for the final assessment of achieved gains at the end of the project. The Reference Scenarios (RSc) are technology agnostic use cases chosen to represent relevant cases for energy efficiency evaluation with certain deployment assumptions, channel models and geographical, temporal and service specific traffic models.

The Optional System Extensions (OSE) broadens the baseline system by innovations, spanning the energy efficiency solution space envisaged in the EARTH project, e.g.

- Traffic aware power amplifier concepts
- Remote radio heads
- Relaying concepts
- Heterogeneous networks and small cells
- Coordinated multipoint transmission
- Multiple combined radio access technologies (multi-RAT)

Figure 3 shows a graphical representation of the EARTH reference concept.

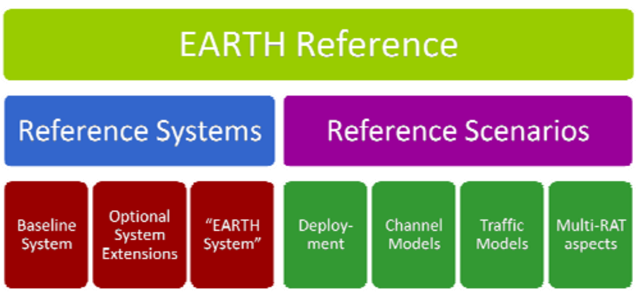

Fig. 3. Graphical representation of reference system and reference scenarios

The specification of the baseline system and of the system with optional extensions are organised in a hierarchical manner, from component level to system level, as shown in Figure 4. This provides a toolbox for studying single tracks or combined effects of the most promising tracks selected in EARTH.

3.2 Energy Efficiency Metrics and Evaluation Framework

Today, there exists no widely agreed methodology to evaluate the energy efficiency of cellular networks. Similarly, meaningful energy efficiency metrics are currently lacking. But both are a prerequisite to determine the energy saving potential of concepts or technologies as developed in EARTH.

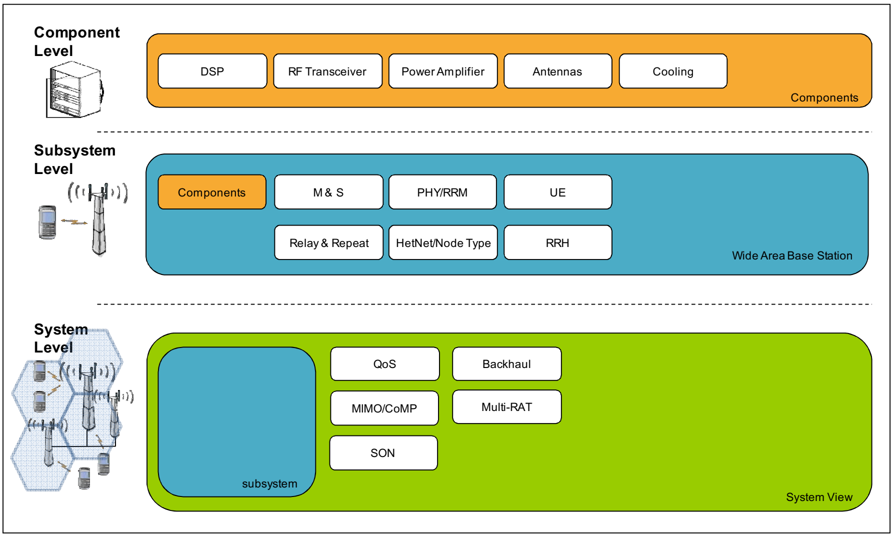

Fig. 4. Hierarchical structure of the Optional System Extensions

The evaluation of energy efficiency on the system level requires combining contributions and interaction of components, deployment, traffic scenarios and system management. This cannot be achieved in a complete system simulation, but requires detailed simulations on radio link level, modelling of energy consumption of radio components, stepwise abstraction of such models into a system level with weighted contributions according to the reference system or its extension.

Such a methodology will be provided by EARTH for a fair comparison of different concepts and technologies. Figure 5 shows a sketch of the evaluation framework that is currently under construction in EARTH. Each step is fed by parameterized models, from component level up to system level. For example, a simplified energy aware scheduler model defines the resource utilisation pattern of the LTE radio frames. Combined with the DC power consumption model of the transceivers (TRX) this yields the TRX power consumption. For a given base station and deployment model the system power can be computed from this for the covered area of the system.

Now, the final step of assessing energy efficiency is the application of a metric to the energy consumption. Simple metrics just sum the power consumption of all components. But obviously the lowest energy consumption is not the best mode of operation, when the quality of service is jeopardized or the coverage is patchy. Proper energy efficiency metric has to capture the amount of service provided by the energy spent, i.e. rating the consumed energy in relation to the transported data, to the covered area or to QoS parameters like call drops or data delay.

Another aspect of the metric is whether it regards the instantaneous power P (i.e. energy consumption on a microsecond scale) or the power averaged over longer times (e.g. a radio frame of 10msec, an hour or a week), and the instantaneous or averaged data rate R served by this power. Note that mathematically it is not the same to compute the average of the ratio of power and data rate compared to the ratio of the average values (Eq. 1). Usually a network operator will not care about instantaneous

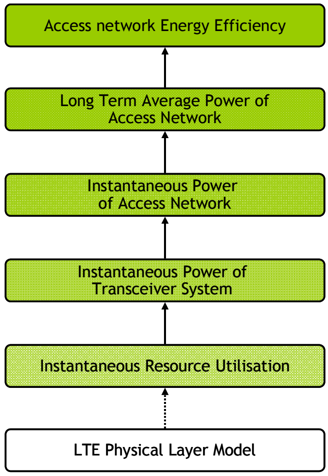

Fig. 5. Stepwise abstraction of system power consumption in the evaluation framework

values, but about the monthly energy bill and the user data throughput per month. Also it may be very difficult to record the instantaneous values in a real-world system.

$$\varepsilon = \text{Average}(R) \,/\, \text{Average}(P) <> \text{Average}(R/P) \tag{1}$$

In EARTH the requirements for a suitable metric are being collected and a set of metrics have been identified as candidates for a meaningful system metric. Different key performance indicators (KPI) like data throughput or coverage can be regarded or additional boundary conditions (e.g. delay or acceptable blocking rate of services) are applied. One example metric is given below (Eq. 2)., aggregating the system data rate R(t) as key performance parameter and relates it to the aggregated consumed system power P(t) over a time interval T.

$$\varepsilon_T = \frac{\int_0^T R(t)dt}{\int_0^T P(t)dt} \quad \left[\frac{bit}{J}\right] \tag{2}$$

4 Potentials of EARTH Technical Solutions

The technology potential of some key technical approaches of the EARTH project will be briefly described in the following, grouped according to the work packages named “Green networks” and “Green Radios”. Detailed studies to quantise the achievable energy savings have been started and are ongoing at the time of writing.

4.1 Green Networks Technological Potential

Temporal and spatial traffic variations greatly influence the achievable energy savings. A method which allows extracting traffic variations from cell-specific measurements in the form of spatial distributions will be used to transform operator’s measurements into a surface map of spatial densities, so that the information can be treated separately from the underlying network layout. Then, network scenarios with different layouts of cells can be compared. An energy-aware network management should match the number and locations of active radio resources to the temporal and spatial variations of traffic demand.

Within the EARTH project several solutions have been studied to enable the reduction of energy consumption at the network level of mobile cellular networks by adapting the resources offered to the users' demands. They are grouped in the following three main areas that encompass the three different time scales used when reasoning over radio networks: network deployment strategies, network management algorithms and radio resource management (RRM). While network deployment is designed for long-term measured in years, network management acts on day-to-hour-basis and radio resource management is almost real-time.

For each of these areas, different solutions have been proposed, and their theoretical potentials have been analysed. An important aspect that will be analysed is the possible combination of solutions from different areas, for example, designing a deployment strategy taking into account the possible management mechanisms that could be implemented on top of it.

4.1.1 Deployment Strategies

Energy efficiency of deployment strategies featuring the following techniques is being analysed:

- Variable cell size and cell mixing: The trade-off between required transmission power and the number of cells to cover an area is studied to derive the optimal strategy for the deployment of macro and micro sites in heterogeneous systems for different load conditions. Results from the studies performed so far indicate that significant gains (up to 70%) can be obtained in terms of area power consumption (W/Km^2) if micro-sites are combined with traditional macro deployment [12]. This solution has also been analysed under the condition of indoor-outdoor scenarios.
- Multi-hop relay: As part of the 3GPP study item LTE-Advanced relays are being studied as a technology to extend coverage and increase capacity [13]. By means of analytical studies, the energy efficiency fundamental limits for Decode and Forward, Amplify and Forward and Compress and Forward relaying schemes have been derived. Additionally, a relaying scenario has been modelled as a non-regenerative cooperative Multiple-Input and Multiple-Output (MIMO) communication system and its energy efficiency in bits-per-joule has been compared. Preliminary results show that for some relevant scenarios relaying strategies do not only enable higher spectral efficiency but also optimize the energy consumption per transmitted bit.
- Base station (BS) cooperation: Cooperative transmission of neighbouring BS like Network-MIMO and Coordinated Multi-Point Communication (CoMP) can enable interference mitigation and thus reduction of transmit power and of retransmissions, at the cost of higher traffic on the backhaul. An energy efficiency analysis of an idealized CoMP system have shown that it can be energy efficient in asymmetric propagation conditions and that the backhauling and cooperative processing power should be kept low for CoMP to provide any gain.

- Multi-RAT deployment: 3GPP networks comprise a range of radio access technologies (RATs), e.g. GSM, WCDMA and LTE. These RATs have different capacities and different ability to provide bearers with QoS profiles of certain services. A multi-RAT strategy can apply load balancing and separation of traffic types to maximise the overall energy efficiency.

4.1.2 Network Management

A first assessment of self-organizing networks (SON) mechanisms for autonomous selection of energy efficient network operation mode has also been carried out:

- Network management mechanisms with ON-OFF schemes are focusing on how to reduce the number of serving base stations according to the current needs of the network. A BSs can be switched off when the load condition is low and other BSs can serve the user demand. The viability of turning off BSs relates to the density of the BS that is required to cope with the capacity demands. In peak-traffic demand the cell sizes are deliberately reduced since the limiting factor is the BS capacity and not its power budget. Results have shown that simple management schemes might achieve, theoretically, significant energy savings (up to 20 %).
- Multi-RAT coordination and cooperation also aims to reduce the number of active BS adaptively to the actual traffic demands of the network. Assuming co-located sites equipped with multiple radio access technologies, the analysis performed in an urban macro environment has shown the real potential of multi-RAT management to enable more energy efficient operation through dynamic adaptation to the actual traffic demands of the network.
- Cooperative BSs can be used, e.g., to multicast traffic from a single source to a set of destinations through a set of BSs. Numerical results show the impact of average channel conditions on how to select the interim BSs between the source and destinations.

4.1.3 Radio Resource Management

Finally, RRM algorithms are being studied from an energy efficiency point of view.

- In order to investigate how the elasticity of the traffic and its characteristics can be utilized, the interaction of call admission control and RRM is being analyzed.
- In multi-RAT environment, it is interesting how to dimension the networks with system wide control of scheduling and call admission control in a more energy efficient manner.
- It is also an open question how neighbouring cells should cooperate with other to reduce their energy consumption. There are ongoing studies on joint scheduling and power control of multiple cells.

4.2 Green Radios Technology Potential

In today's mobile networks, the base stations are responsible for the major part of energy consumption in radio access networks, simply due to the large number of deployed BSs for guaranteeing the QoS and coverage. With the deployment of LTE, in coexistence with GSM and UMTS, the increasing number of BSs will cause an increase in energy consumption [8].

The EARTH project breaks down the consumption of base stations to its components and analyses the technology potential in energy savings, not only optimizing each block, but also providing a holistic approach. Three main fields of techniques and solutions have been identified to improve the energy efficiency of LTE with the low impact on overall performance:

- Energy Efficiency in Antenna Techniques
- Energy Efficiency in Radio Components
- Energy Efficiency in Radio Interface and Protocol Based Techniques

4.2.1 Energy Efficiency in Antenna Techniques

By using multi-antenna techniques such as spatial multiplexing and beamforming it should be possible to reduce the necessary transmit power while still maintaining QoS. The current activities are mainly focused on:

- New antenna topologies and the use of new materials are investigated from the energy efficiency perspective.
- Reconfigurable antennas and active antenna systems are considered for adapting to the traffic demand. On one hand, static parameters of an antenna, like beam width and pointing direction, can be tuned according to current traffic distribution, so that link budget is optimized. On the other hand, active antenna systems implement beamforming with maximum flexibility and energy savings related to space diversity and multiplexing techniques, as well as reduction of feeder losses (with Remote Radio Head, RRH).
- Smart antenna technologies, like MIMO, are also investigated. Multi-antenna operation and MIMO have been adopted by LTE to increase the coverage and capacity. However, the different operations in downlink (transmit diversity, spatial diversity with/without precoding, multiuser MIMO,…) [18] can strongly affect BS energy efficiency. Therefore, the best configuration of MIMO can be selected if an accurate model of performance and the impact on consumption of each MIMO mode is available.

4.2.2 Energy Efficiency in RF Components

The main BS blocks considered in the project are DSPs for baseband (BB) signal processing and control, Small Signal RF transceiver (SSTRX) and Power Amplifiers (PA). The energy consumption of each block presents different breakdowns in function of the cell size. For instance, in a macro cell BS, the power amplifier (including its cooling) consumes around 65% of the total consumption. However, in a pico cell BS, the BB/DSP and SSTRX dominate the energy consumption and use up to 70% of the BS power. Therefore, the investigations of the RF transceiver field puts special emphasis on the search of new solutions and approaches in the PA for macro BSs and in the BB/DSP and SSTRX for pico-BSs, with parallel research in the rest of the blocks.

- For PA, two concepts for Adaptive Energy Efficient Power Amplifiers are proposed to meet the required high energy efficiency performance [15]. Both are based on advanced amplifier design (transistor technologies and architectures) for allowing the adaptability to traffic statistics in LTE. Adaptive PAs leads to reduced

power consumption for low and medium signal levels by adjusting the operating point to the signal level. Fast component deactivation during time slots with no transmitted signals avoids further power wastage.
- For BB/DSP and SSTRX in pico-cell context, the challenge is to use the best suited components and to enable dynamic power management and voltage scaling, as well as to implement algorithms and signal processing in energy efficient ways by means of high performance processors (ASIC, ASIP, FPGA).

4.2.3 Energy Efficiency in Radio Interface and Protocol Based Techniques

The LTE standard unlike many other radio access technologies does not require continues transmission of reference signals (or pilots) allowing periods where the system does not need to transmit. These can efficiently be used for reduction of system energy consumption. Another key feature of LTE are multi-antenna techniques which also need to be addressed in terms or energy efficient network operation.

- The discontinuous transmission (DTX) and sleep mode techniques adapt the operation of PA to the required transmission periods. DTX and sleep modes can be classified depending on their time scales. *Micro DTX* is working on a fraction of a subframe (<1 ms), *short DTX* is designed to adapt to the radio frame structure (<10ms), and *long DTX* operates for longer than one radio frame. Finally more traditional *sleep modes* are designed for periods >10ms.
- The technique of adaptability to system dynamics takes in advantage all the flexibility of the LTE standard to use the best configuration in each moment. This means that Adaptive Modulation and Coding (AMC), MIMO pre-coding and rank adaptation algorithms are evaluated for the energy saving potential of re-assigning the transmission mode as a function of scenario.
- Retransmission schemes and HARQ protocols are considered to find optimal scheduler algorithms that enhance the usage of the PA, reducing the power consumption.

5 Conclusions and Future Developments

For the deployment of future high speed mobile communication networks the system power consumption and the CO_2 footprint are critical, both from environmental point of view and for the operational cost of mobile operators. In the framework of EC FP7, the EARTH project is set to study energy saving measures, to assess their limits and potentials and to provide an integrated solution with at least 50% of energy savings compared to today's baseline system.

The project was started in January 2010 and has already delivered a consistent estimation of the global power consumption of mobile networks up to 2020. It has achieved the definition of a baseline system and scenarios for the evaluation of energy efficiency improvements. Currently EARTH is working on the specification of meaningful metrics and an evaluation framework.

EARTH aims for improvements beyond current development trends. Those improvements will be yielded by energy efficient deployment strategies including heterogeneous networks, relays and cooperative base stations; energy aware network re-configuration and resource management; and transceivers or base station equipment with high adaptability to the traffic situation. Further improvements will be realized by employing advanced radio transmission techniques for energy efficiency instead of purely for spectral efficiency improvements and by energy efficiency enabling enhancements of radio interfaces. This position paper describes the main tracks and first results of the project.

Such techniques for improved energy efficiency of mobile broadband communications will only be deployed if they do not unduly impact on the system performance and the user's perceived "quality of service". The challenge of EARTH is thus to analyse the trade-offs between performance and energy efficiency. In this sense, metrics and figures of merit that account for both the energy efficiency and the capacity are studied during this first phase of the project. An evaluation framework that combines contributions and interactions from component to system level is being developed to enable a fair comparison of different concepts and technologies and to judge the gains of each standalone solution on the integrated system.

The results of EARTH will be widely disseminated and (where required) taken to the appropriate standardisation bodies. Several papers have already been presented [11][12][15] or accepted for publication [16][17]. Due to the industry driven consortium it is expected that the results will be quickly leveraged for efficient products, providing operators with sustainable equipment and operation of their future mobile broadband networks.

Acknowledgements

The authors gratefully acknowledge the contribution of the EARTH consortium.

The work leading to this paper has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 247733 – project EARTH. This publication made by participants of the EARTH project reflects only the author's views and the European Union is not liable for any use that may be made of the information.

References

1. Climate change: Commission welcomes final adoption of Europe's climate and energy package. Press release IP/08/1998 of the European Commission (December 2008), http://europa.eu/rapid/pressReleasesAction.do?reference=IP/08/1998
2. Long Term Evolution (LTE): an introduction, Ericsson White Paper (October 2007)
3. SMART 2020: Enabling the low carbon economy in the information age, The Climate Group, GeSI, http://www.smart2020.org/
4. EU Commissioner Calls on ICT Industry to Reduce Its Carbon Footprint by 20% as Early as 2015, Press release of the European Commission, MEMO/09/140 (March 2009)
5. Vodafone Corporate Responsibility Report (2008)
6. Green Radio – Sustainable Wireless Networks, Mobile VCE (February 2009), http://www.mobilevce.com/dloads-publ/mtg284Item_1503.ppt

7. Optimising Power Efficiency in mobile RAdio Networks (OPERA-Net), EUREKA CELTIC project, http://opera-net.org/default.aspx
8. Energy Aware Radio and neTwork tecHnology (EARTH), EC FP7 project INFSO-ICT-247733 (January 2010-June 2012), http://www.ict-earth.eu
9. Fettweis, G., Zimmermann, E.: ICT Energy Consumption – Trends and Challenges. In: Proc. of WPMC 2008 (2008)
10. Biczók, G., Malmodin, J., Fehske, A.: Economical and Ecological Impact of ICT. Public Deliverable D2.1 of EARTH (June 2010), To be released on http://www.ict-earth.eu in Q4 2010
11. Auer, G., Gódor, I., Hévizi, L., Imran, M., Malmodin, J., Fazekas, P., Biczók, G., Zeller, D., Blume, O., Tafazolli, R.: The EARTH Project: Towards Energy Efficient Wireless Networks. In: Future Networks & Mobile Summit 2010, Florence (June 2010)
12. Arnold, O., Richter, F., Fettweis, G., Blume, O.: Power Consumption Modeling of Different Base Station Types in Heterogeneous Cellular Networks. In: Future Networks & Mobile Summit 2010, Florence (June 2010)
13. Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Further advancements for E-UTRA physical layer aspects (Release 9), 3GPP TR 36.814 V9.0.0 (2010-03) (March 2010)
14. Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 9), 3GPP TR 36.211 V9.1.0 (March 2010)
15. Ferling, D., Bohn, T., Zeller, D., Frenger, P., Gódor, I., Jading, Y., Tomaselli, W.: Energy Efficiency Approaches for Radio Nodes. In: Future Networks & Mobile Summit 2010, Florence (June 2010)
16. Fehske, A., Malmodin, J., Biczók, G., Fettweis, G.: The Global Footprint of Mobile Communications – The Ecological and Economic Perspective. To appear in IEEE Communications Magazine, issue on Green Communications (November 2010)
17. Correia, L.M., Zeller, D., Blume, O., Jading, Y., Auer, G., Van der Perre, L., Ferling, D., Gódor, I.: Challenges and Enabling Technologies for Energy Aware Mobile Radio Networks. To appear in IEEE Communications Magazine, issue on Green Communications (November 2010)
18. LTE and the Evolution to 4G Wireless: Desing and Measurements Challenges, Agilent Technologies