AN OVERVIEW OF EARTH - ENERGY AWARE RADIO AND NETWORK TECHNOLOGIES FOR EFFICIENT ENERGY

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Abstract:Wireless mobile communications are increasingly contributing to overall energy consumption. The EARTH (Energy Aware Radio and neTworking tecHnologies) project tackles the major issue of reducing CO2 emissions by developing the energy efficiency of cellular mobile networks. EARTH is a holistic approach to develop a new generation of energy efficient products, components, deployment methods and energy-aware network management solutions. In this paper the holistic EARTH approach to energy efficient mobile communication systems is initiated. EARTH is an important new European research project starting in 2010 with 15 partners from 10 countries. Its main technical objective is to achieve a reduction of the entire energy consumption of mobile broadband networks by 50%. EARTH will develop corresponding deployment methods as well as management algorithms and set of rules on the network level. On the component level, the project focuses on base station optimizations as power amplifiers absorb the most energy in the system. A large potential for energy savings lies in the process of radio base stations. In particular, base stations absorb a considerable amount of the available power budget even when processing at low load. Energy efficient radio resource management (RRM) methods need to take into account slowly conveying daily load patterns, as well as highly dynamic traffic fluctuations.

Keyterms:- Energy efficiency, Mobile communication networks, Radio access, Radio Resource Management(RRM), Energy aware management, load adaptivity, EARTH.

I. INTRODUCTION

The global wireless mobile communications industry is growing very rapidly. Nowadays there are more than four billion mobile phone subscribers worldwide, more than half the overall population of the world. Obviously, this develop is accompanied by increased energy consumption of mobile communications[1]. The work of the EARTH project is to address the global environmental challenge by finding effective strategy to substantially reduce energy wastage and to improve energy efficiency of mobile network systems, without satisfying network coverage and customer perceived quality of service. While the performance of radio access technologies is typically featured by metrics like spectral efficiency, throughput or coverage, these metrics are unable to quantify the energy efficiency of a network system. Thus, an essential prerequisite for efforts to develop the energy efficiency of cellular networks is to produce a framework to quantify the energy saving mobile communications. Today's mobile networks systems have a large potential for energy savings. A power efficient transceiver will be enhanced that adapts to changing traffic load for an energy consume operation in mobile radio systems. With these results EARTH will rectify energy costs and carbon dioxide emissions and will thus enable a sustainable increase of mobile data rates. While the energy efficiency of mobile systems is highly optimized because of the stringent constraints on the available power supply, until recently energy power consumption of base stations has been largely ignored. This has led to a situation where terminal energy consumption is only a fraction of the energy consumption of the mobile network, while base stations are the major source of CO2 emissions . Depending on the SMART 2020 study [2] the overall data and communications technology (ICT) industry accounted for 530 Megatons of CO2 in 2002 and 830 Megatons in 2007. This is approximately 2% of the global carbon dioxide (CO2) emissions and about equivalent to those of global aviation. Consequently, the EARTH approach has put its focus on enhancing the energy efficiency of radio base stations.

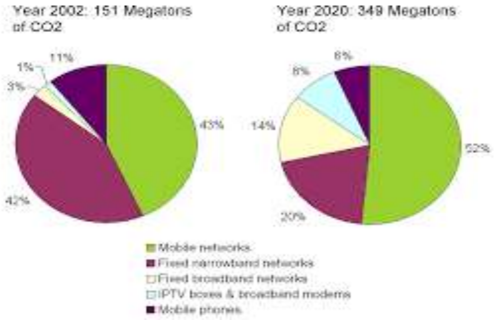

Figure 1:Contribution of mobile network to the CO2 footprint of telecommunication

The biggest fraction of CO2 emission from mobile communications occurs in the radio access network, i.e. in the base stations. When we compared to this, the energy consumption (and the according CO2 emissions)In particular, even at low load base stations consume a considerable quantity of the available power budget. EARTH will contribute with concepts and algorithms to significantly rectify the energy power consumption even at low load situations. One further source of energy wastage is the layout of wireless cellular networks. Obviously, a network layout optimized for coverage does not necessarily maximize energy efficiency of cellular networks. EARTH aims at developing a basic principles of energy efficient network layouts. It includes heterogeneous networks with a sophisticated mix of various cell sizes, optimized for minimal energy consumption. Ultimately, this leads to novel energy efficient network architectures.

II.CARBON FOOTPRINT OF GLOBAL AND LIFE CYCLE ANALYSIS

Today, Information and Communication Technology (ICT)systems including data networks, fixed and wireless networks,as well as overall end-user equipment such as PCs, home network equipment and mobile systmes, are responsible for about 2% of global CO2 emissions and about 1.5% of global CO2-eq emissions

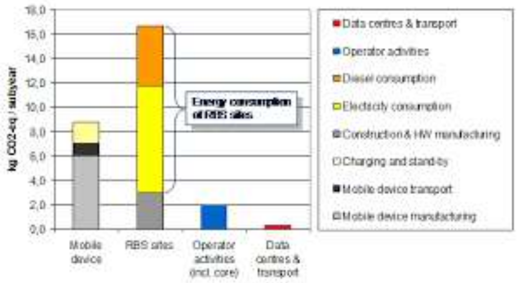

Figure 2:The carbon footprint (CO2-eq emissions)

In order to sacrifice climate change the EU Commission recently issued a call on ICT industry for intensified efforts to minimize its carbon footprint by 20% as early as 2015 for [3]. This report has identified lot of opportunities for the ICT industry, to change goods and services with virtual equivalents and to provide technology to enable energy efficiency. The ICT sector must work quickly to demonstrate what is possible, get clear messages from policy makers about targets and continue to innovate radically to reduce carbon co2 emissions. The scale of carbon emissions reductions that could be activated by the smart integration of ICT into new method of operating, living, working, learning and travelling makes the sector a key player in the fight against climate change, despite its own growing carbon footprint The mobile part of ICT is responsible for about 0.2% of global CO2-eq emissions but the lot of radio base station (RBS) sites and mobile system subscribers are steadily increasing (4 billion subscribers right now) and data-intensive methods are proliferating. Obviously, this develop is surely accompanied by an increased energy consumption of mobile networks, with a corresponding increase in the carbon footprint [4].On the other hand, rising energy costs, especially for networks where a large share of the RBS sites runs on diesel generators, have led to a situation where such sites contribute significantly to the network operation costs.

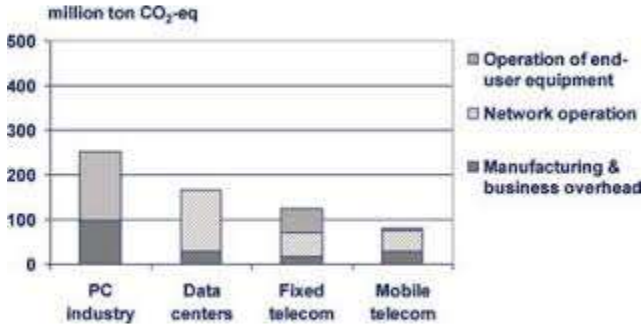

Figure 3:CO2-eq emissions for the different ICT subsectors

It is based on data for the full year 2007. The carbon footprint is based on extensive LCA studies covering the global life cycle of the various components that are part of a mobile network.It can be clearly seen that the energy consumption of RBS sites is responsible for the biggest part of the total life cycle carbon footprint, followed by the mobile phone manufacturing.As a majority of sites has low traffic most of the time, this "stand-by" behavior of the network has a vast potential for energy power consumption in the future.A major part in an LCA of mobile networks is to assess the emissions from the electricity production sources.The carbon footprint for an average mobile subscriber has minimised over time from more than 100 kg CO2 per subscriber per year in the early 90's to approx. 25 kg in the mid 00's.However, the increased number of RBS sites operated on diesel, "growing" mobile devices, and the rapid growth of new mobile networks has reversed this positive method.

III.EARTH AND THEIR WORK

There has been a significant interest in energy efficiency in ad hoc networks and multihop mesh network planning due to the limited battery life of the communicating nodes [5,6,7].radio applications in sensor networks where the nodes operate on batteries so that energy consumption must be reduced while solving given throughput and delay requirements. In this context, we analyze the best modulation and transmission strategy to reduce the total energy consumption required to send a given number of bits.A distributed, ad-hoc wireless micro sensor network consists of hundreds to several thousands of small sensor nodes scattered throughout an area of interest.

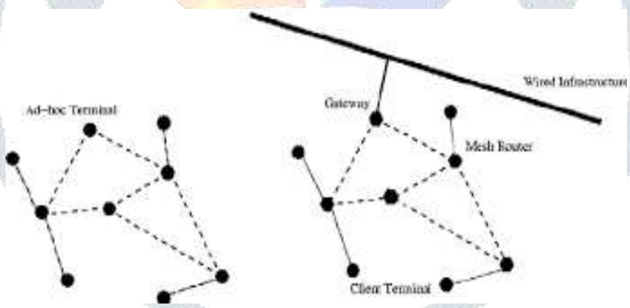

Figure 4:Ad-hoc and Mesh network

Each individual sensor contains both processing methods and communication elements and is created to monitor the environment for events specified by the deployer of the wireless network.The global energy consumption includes both the transmission energy and also the circuit energy consumption. In conventional cellular communication systems work on the energy efficiency has rather been limited to the mobile wireless system with their limited battery power [8], and the energy efficiency of the infrastructure end has been largely deleted. A literature survey for the energy efficiency method corresponding to different protocol layers of both infrastructure and ad hoc wireless networks, is available in [9].There are several recent research projects that assumes the problem of energy efficiency of communication systems and their components. OPERA-Net [10] investigates the opportunities to enhance the energy efficiency of broadband wireless cellular networks by assuming the optimised cooling and energy recovery from the base stations and the optimisation of the components used in communication systems. PANAMA [11],ELBA [12] and Class-S [13] projects focus on techniques of saving energy by more efficient design of the power amplifiers in the communication systems as the important source of energy consumption and typically run at still quite low efficiency.

Cool Silicon [14] aims at creating recommendations for high performance communication systems with low energy consumption by focusing in three main areas: micro/nano technology, broadband wireless access and wireless sensor networks. Cool Silicon project focuses on the optimisation of individual aspects of the communication systems like the architecture of the system, communication algorithms and protocols and physical components. Mobile VCE Green Radio[15] aims at expanding the efficiency studies to the energy metric for cellular system and end to end communication system. However, a unified approach to target the overall system from energy efficiency perspective is still missing. Also little effort is devoted to the efficency of next generation wireless access systems (4G systems).The new EU FP7 project EARTH is mainly focussing on mobile broadband networks with the future key based technologies LTE (3GPP Long Term Evolution) and LTE-Advanced. Its objective is to deliver tangible results such as new network architectures and deployment strategies, e.g. with small indoor and outdoor cells, energy aware management mechanisms, and innovative component designs, all with respect to optimised energy efficiency. A major part of the reduction work will be reached during low load situations, by ensuring that the energy consumption of access networks is proportional to the traffic load.

IV. ENERGY EFFICIENCY SCHEME

The classical optimization for wireless network is the areal spectral efficiency(SE), measured in [bit/s/Hz/m2].This implies enlarging the data rate per unit area for a given transmit power budget.To this end, an appropriate energy efficiency metric should take into account the following components:

• The input power required to create a specific output power at the antennas. This input power accounts for the desired power in analogue front-end, the power amplifier losses, air conditioning power consumption within base stations and the power loss of the feeder cables.

•The energy that is consumed by executing the digital signal processing equipment (e.g. powerful channel coding with the associated complex decoders).

• The impact of the RRM scheme on the energy efficiency such as subcarrier and transmit power allocation and base station cooperation (energy required for the exchange of message signals as well as additional control signaling).

• The energy to deliver data to the base station (backhaul energy power consumption).

A system level view requires a total energy efficiency metric, which is composed of specific metrics on the component level.

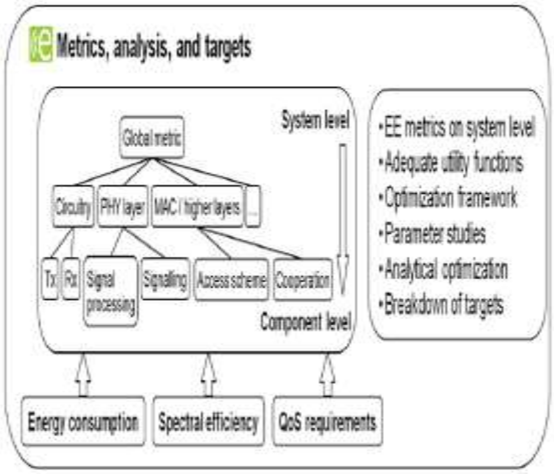

Figure 5:EARTH approach towards a global energy efficiency metric.

The challenge in finding a suitable energy efficiency metric lies not only in the dimension of the problem space, but also in the fact that the energy power consumption of the relevant components is interdependent.Standardization of energy efficiency metrics has already commenced. For example the ETSI Technical Committee on Environmental Engineering (ETSI-TC-EE) [16] has introduced work on a specification of energy efficiency metrics for wireless cellular system.However, these specifications only focus energy efficiency metrics on component level (e.g. power efficiency for high power amplifiers) rather than the overall system (end-to-end connectivity including backhaul). Furthermore, criteria related to the quality-of-service are ignored.For analysing the efficiency of the communication link, several metrics are used in the literature. The most commonly used metric for the energy efficiency of a communication link is bit per joule [17], which is an information theoretic measure of the energy efficiency of delay insensitive communication. To account for the data rate as well the communication distance, a modified metric of bit meter per joule may be utilized.This metric explains the efficiency of reliably transporting the bits over a distance towards the destination per unit of energy consumed [18]. For a cellular area of coverage, this metric is to be changed to bits per joule per unit area, so to capture the extent of the coverage area. The system level method energy efficiency of a single cell was studied in [19], where the energy efficiency of communicating over a frequency selective cellular uplink channel was optimized.The authors conclude that both the circuit energy (energy required to keep nodes active) and transmission energy need to be designed, so to calculate the overall energy efficiency in terms of bit per joule.

V.NETWORK LEVEL

Energy efficiency optimisation at the network level has been explained in some studies [20,21]. However a context in which these studies fit in the overall picture is still missing. Network level oriented system methods which the EARTH project targets on. EARTH targets significant energy savings by using new deployment methods of radio access networks. Because of the strong minimise in signal strength with respect to the distance of the base station the energy efficiency generally increases with decreasing cell size. This is limited by the fact that each base station must support some basic functionality and that the effort to deploy very large numbers of small base stations may be uneconomical.

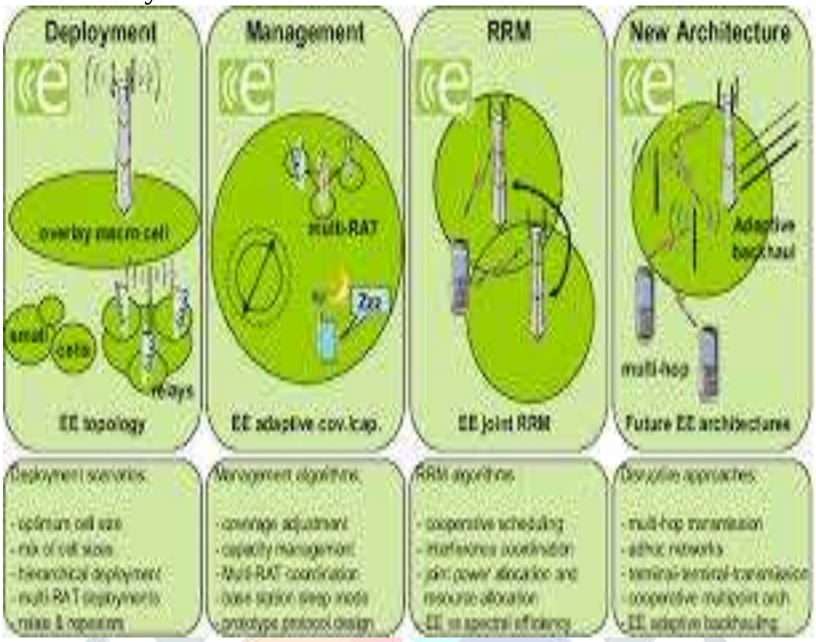

Figure 6:Green network management tasks in EARTH

A crucial task of EARTH will be to identify the ideal cell size that is expected to be significantly smaller than in conventional macro cell deployments. Depending on the reference scenarios analyzed before there may even be various ideal cell sizes for different constraints. Further, the role of repeaters and relays will be analyzed in detail, because these techniques have the inherent advantage that they virtually bring the transmitters closer to the receivers and therefore advantage from the small cell effect discussed above. An unavoidable consequence of minimising the cell-size or of using repeaters is the stronger inter-cell interference, when the spectrum re-use ratio is kept fixed. Reducing the re-use ratio to control the interference will result in lower spectral efficiency. Alternatives are either to coordinate the interference or to manage it at the receiver end by deploying multiuser detection methods. These cell cooperation strategies are well analyzed for their spectral efficiency ([22] and references therein) and can deliver starting points to evaluate the energy efficiency of these deployments. As already focused, this comes with an associated cost of higher computation energy at the receiver end and in terms of increased energy consumption for control message signalling. A delicate balance should be hold to ensure that the adopted strategy is energy efficient on the overall scale.

VI.COMPONENT LEVEL

EARTH will analyze energy saving potentials also on the component level, with respect to the system level methods of interfaces and network management Specifically, adaptation efforts include power, transmission mode, and load. In any case the important focus of EARTH is to follow an integrated optimization from a holistic point of view and to enable rapid dynamic changes, for example by delivering suitable protocols and signaling means to send components to a standby state.

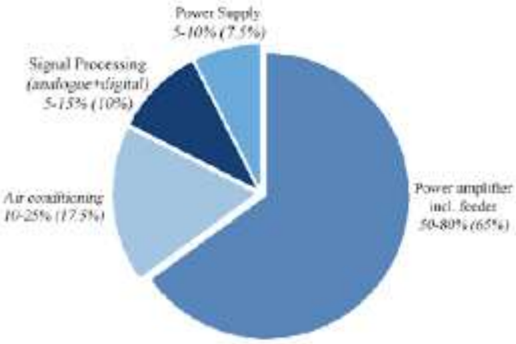

Figure 7:Breakdown of power consumption in radio base stations

A huge potential for energy saving is similar to the power amplifiers, which consume the largest part of power in the base station. The undistorted transmission of signals with significant peak-to-average power ratios (PAPR) requires to operate the power amplifiers on average levels way below their maximum signal amplitude. This minimizes the power efficiency, since a simple power amplifier is optimized for maximum output power. The recent evolution of mobile communication systems from GSM to the Long Term Evolution of 3GPP leads to a continuous rise of the PAPR, which will be further increased by using multicarrier and multi-standard solutions.

VII.MANAGEMENT OF MULTI-RAT NETWORKS

Currently base stations of multiple radio access technologies (RAT) are usually located and several RATs may cover the same area, but they deliver various levels of services (GSM, 3G, WLAN). With the projected roll-out of the 3GPP long term evolution (LTE) network, the number of available radio interface technologies further increases.

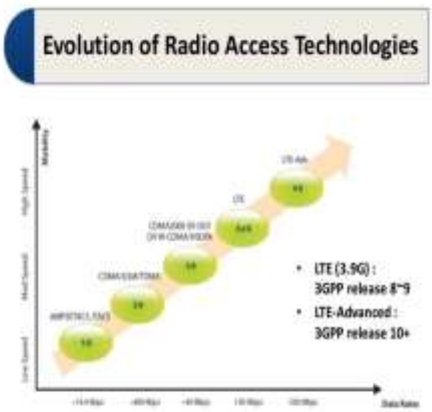

Figure 8. Evolution of Radio Access Technologies

Multi-RAT terminals may take advantage of coexistence of various RATs. Unfortunately, the present practice is that each RAT has its own network outlining, operations & maintenance and resource management methodologies. Recent efforts from operators and vendors, e.g. carried out within the EU project Ambient Networks [23], aim at joint management of multi-RAT technologies, performing on capacity and coverage optimization. In order to yield energy savings from different multi-RAT technologies new network functions are needed, to facilitate the dynamic distribution of load among interfaces (without any user intervention), to support the parallel use of multiple interfaces for the same data transfer (e.g. large file download),and to facilitate smooth switching of user traffic between interfaces. Specifically, radio resource management (RRM) is to be enabled to use multiple air interfaces as a common resource. EARTH will develop deployment and operating methods on how the network of different RATs can be deployed and operated in a coordinated fashion. In order to rectify the energy consumption in multi-RAT deployments, as rule of thumb, the RAT with the lowest carrier frequency should be selected to maintain coverage at minimal power dissipation, due to the favorable propagation conditions at lower frequencies. Along this line, very low power and low coverage RATs (e.g. LTE femto cells) that typically achieve in higher frequency bands should cover higher traffic demand areas. In this latter case, the minimum distance between transmitter and receiver over compensates the energy efficiency loss of the high carrier frequency. Naturally, the aims of EARTH go beyond the above examples and try to identify the best network management solutions, which provide a joint optimization of multi-RAT networks.

VIII.CONCLUSION

Future wireless telecommunication systems have to contribute to reduce in energy consumption and greenhouse gas emissions of ICT. Quite some progress has already been completed on the energy efficiency of wireless communication networks, but there is a need for a holistic approach and research on system level innovations. EARTH is a European research project that has set itself the focus to deliver a holistic analysis of state-of-the-art systems and to develop improvements in order to come up with integrated deployment recommendations for future wireless communication networks. A two-fold approach is pursued in the project: On the network level, architectures, protocols, and algorithms are focused, whereas on the component level methods to optimize individual elements and their dynamic adaptation to the actual needs are regarded. The ambitious goal of EARTH is to cut the energy consumption of mobile broadband networks by 50%. The identifies will be evaluated using in simulations and in a large test bed operated by a major telecommunication operator. The innovations worked out in EARTH will be joined into an integrated solution. Tangible results will be initiated to standardization bodies and industry exploitation in order to confirm impact of the project to the technical community. This will enable a sustainable deployment of future broadband wireless communication sytems, with respect to carbon dioxide emissions as well as to operational costs. Leveraging these networks, further rectifications of the global CO_2 footprint are expected by intensive use of ICT services, e.g. for teleconferencing, telecommuting and dematerilisation.

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