material for the computer results in 500 kg of mining waste while with recycling this is 93 kg. This means that when considering green technologies the entire life cycle has to be taken into account. A life cycle analysis considers material extraction, production, use, transport and end-of-life as the five phases in the life cycle of a product and all phases should be considered in order to have a complete view of the environmental impact of a product. Next to the concerns about material use in ICT there is the subject of energy consumption. Energy consumption is closely related to carbon emissions. More accurately, when discussing carbon emissions one should consider the anthropogenic greenhouse gas (GHG) emissions. The Kyoto protocol stated 6 major GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), HFCs, and PFCs. These GHGs all have a different global warming potential (GWP) considered for a hundred years horizon. These GWPs are expressed relative to the GWP of carbon dioxide in CO_2e (CO_2 equivalent). For example, for methane, which has a GWP of 25, an emission with 1 ppmv (parts per million by volume) of methane is equivalent to an emission with 25 ppmv of carbon dioxide. When regarding the energy consumption of ICT equipment this energy consumption is exclusively in electricity consumption (in the use phase of the life cycle). Based on global electricity production statistics, an average of 500 g CO_2e/kWh is emitted. However, in reality the CO_2e emissions per kWh vary depending on the country or region where the electricity is produced. For example, in Australia the emissions are approximately 875 g CO_2e/kWh while in Iceland the emissions are virtually 0. This is due to the technologies used for energy production. Coal and gas installations emit typically between 800 and 950 g CO_2e/kWh while renewables do not emit greenhouse gasses. The greenhouse gas emissions for nuclear power are also very low, but this energy source has other environmental issues related to it such as the treatment of nuclear waste.

B. Direct and Indirect Impacts

When analysing environmentally friendly solutions there are both the direct and indirect impacts to consider. Direct impacts are directly related to the implementation of the considered solution. For example, implementing a solution which reduces the energy consumption of a service results in a direct impact. Indirect impacts of solutions are related to the broader consequences of the adoption of the solution. For example, adoption of email may lead to a higher environmental impact of ICT but at the same time reduce the number of letters being sent which in turn leads to less impact of transport, paper usage, etc. Indirect impact reduction typically has a higher potential in limiting environmental issues. However, these reductions are harder to predict as they are dependent on political, financial, informational and behavioural factors. Related to this we wish to point out the rebound effect. A very common strategy in limiting environmental impacts is increasing efficiency. For example, increasing the distance travelled per unit of fuel for a car. The rebound effect states that this increased efficiency decreases the associated cost as well. This will lead to a higher usage of the solution and in turn an increased impact. If we again consider the adoption of email, one could state that by replacing every letter sent by an email we are largely reducing the impact of those letters. There is however not a one-on-one relation between the number of emails sent and the number of letters written before email was adopted. This case demonstrates that predicating the indirect environmental impacts of solutions is a difficult exercise which has to be carried out with great care.

Carbon Footprint Models and Assumptions: To quantify the impending mobile footprint, we consider all generations of cellular mobile networks including all end-user equipment accessing the networks, all business activities of the operators running the networks, and the use of fixed network resources as a result of data traffic generated by mobile network users. An overall carbon footprint model for mobile communications can conveniently be broken down into six categories:

1) Manufacturing of mobile devices refers to the manufacturing of mobile terminals including low-end phones, Smartphone’s, and laptops, based on actual sales in the same year and covering all equipment newly deployed that year.
2) Mobile devices operation refers to charging of batteries and standby consumption of chargers left plugged in for all mobile phones and Smartphone. Here, charging and grid operation for laptops (excluding docking stations), extra monitors, and other peripherals are included.
3) RAN sites manufacturing and construction means manufacturing of all electronic equipment as well as site equipment like diesel generators and batteries, as well as construction of site infrastructure such as antenna towers and site housings covering all equipment newly deployed each year.
4) RAN sites operation refers to the total electricity consumption of base station sites — control sites as well as core sites. A total site view that includes transmission, cooling, rectifiers, backup power, and so on is used. Diesel consumption for off-grid site operation and backup power is also included.
5) Operator activities cover operation of offices, stores, vehicle fleet, and business travel related to all operators’ business activities.
6) Data centers and data transport refers to the use or allocation of other network resources based on the data traffic generated by mobile network users.

Mobile Devices: We consider three categories of devices accessing the network: regular mobile phones, smartphones, and laptops. Modelling of the footprint of regular mobile phones is based on “cradle to gate” LCA studies of mobile phone manufacturing including the transport to the customers resulting in an average of 18 kg CO_2e/device. The operation is estimated to 2 kWh/year based on charging every 60th hour equal to 40 percent of battery capacity every day and a standby scenario of 50 percent of the remaining time. It must be noted that modern mobile phone chargers have low stand-by power consumption in the order of 0.1 W. According to recent trends, it is reasonable to assume that both the manufacturing and operation emissions remain constant; that is, technological improvements on the component level are used for provision of phones with better performance and more functions. Corresponding values for the category of smartphones are 30 kg CO2e for manufacturing and 7 kWh/year for operation. The same assumptions and principles used for regular mobile phones also apply to smartphones. Based on a comprehensive review of LCA studies of personal computers, the manufacturing related emissions of laptops can be estimated to 240 kg CO2e/average device. The electricity consumption of the average annual use can be estimated to be 40 kWh in 2007. Based on current trends, we project that manufacturing and operation emissions of laptops decrease by five percent per year.

Radio Access Networks: Concrete figures of the carbon footprint of site manufacturing and construction for the radio access network (RAN) are based on a complete LCA of network equipment. Figures on emissions and energy consumption due to RAN site operation, operator activities, data centre operation, and data transport are based on a broad operator investigation covering networks that service about 40 percent of global subscriptions. In 2007, the RAN electricity consumption per average subscription was about 17 kWh. The construction of new base station sites every year as well as the removal of old site equipment is taken into account throughout the period of study. Surveying existing network equipment reveals that annual electricity consumption of new base station sites decreases about 8 percent on average compared to equipment installed the year before due to technological advances. This average figure is an overall estimate inclusive of all developments in power amplifiers, digital remote and small outdoor RBSs as well as the growing share of 3G base stations. In this regard, the base station model must be seen as an average of the mix of installed product. For predictions until 2020, we assume that the 8 percent/year trend continues over the study period and refer to it as continuous improvements. Under these assumptions and taking into account installation of new and removal of old equipment each year, the global average of base station site power amounts to about 1.7 kW in 2007 and reduces to about 1.2 kW in 2020. The study further assumes a roll-out model assuming between 600,000 and 675,000 sites newly deployed, and up to 300,000 sites taken out of service each year.

Femto Cells: The power consumption of a femto cell today is around 10 W, it will be around 6 W in 2012, and it can be assumed that a femto cell in 2020 will still consume about 5 W (if the power consumption for the fixed line connection is also included). An estimated number of 100 million femto cells in 2020 will consume about 4.4 TWh/year, which is less than 5 percent than consumed by the global RAN. Given this rather small impact and high uncertainty of deployment estimates, we exclude femto cells in the RAN energy consumption model. While femto cells consume a rather small amount of energy, their positive impact on data traffic and capacity, resulting in an energy consumption decrease, could indeed be larger.

Three Key Factors – Power, Environment and Green Spur the Telecommunications Industry into "Green Action"

• Energy costs account for as much as half of a mobile operator's operating expenses, so radio network solutions that improve energy efficiency are not only good for the environment, they also make commercial sense for operators and support sustainable, profitable business. These costs are rising, in some cases dramatically, due to high-usage data centres and mobile network expansion, particularly into rural.

• Environmental and energy cost concerns give rise to a number of sizable business opportunities to service providers - video and audio-conferencing, international connectivity, Ethernet LAN/IP VPN(IP Virtual Private Network), storage, power line communications, storage, RFID tracking, and intelligent transport.

New Directions: To fundamentally improve energy efficiency of wireless systems, a holistic view is required. Fundamental research problems remain in this area. The first step to solve those problems is to develop a clear understanding on energy consumption in current wireless networks in a wide range of scenarios. Most likely any energy saving solution comes with certain cost. The energy saving achieved in some components of a network may cause additional energy consumption in other components. Solutions need to be carefully evaluated from a holistic view, with all impacts taken into account. Another challenge is to derive energy efficient metrics accurately and efficiently quantifying energy consumption. Those metrics are the key to evaluate energy saving solutions. The basic form of energy efficiency metrics is Bit/Joule or Joule/Bit. It is not always easy to get that figure when the measurement is not possible. Other metrics, for instance, km2/W or subscribers/W for cellular system, can be used. Note that measuring those metrics may cost additional energy.

One of the key research problems in energy saving is to make energy consumption scale with the traffic load, and further with services. It is a goal that can only be achieved using a holistic solution across all layers of protocol stack and heterogeneous networks. Novel architecture and methods are demanded, most likely cross the boundary of currently isolated systems.

3. Conclusion

This article provides an overview of energy consumption problems in wireless access networks and describes network energy saving techniques proposed for the LTE system. It is identified that the common energy consumption problem in an RBS of a wireless access system is the energy scaling traffic load problem. This problem can be tackled by solutions from the time, frequency, and spatial domains. As most solutions only focus on a single RBS, we believe the most promising solutions are those that apply hybrid techniques cross multiple systems/networks. The energy saving problem cross multiple systems/networks is less understood. More efforts are needed from the modelling to specific solutions. As wireless access networks experience exponential growth worldwide, it is important to make EE a high priority in the design and development of wireless access networks.

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