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Published in:
Wireless Personal Multimedia Communications

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

GREEN COMMUNICATION: WHERE CAN IT REALLY HELP AND HOW IT IS RELATED TO RFID

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ABSTRACT

In the recent years, the awareness about the harmful long-term effects of the greenhouse gases (GHG) has markedly increased. As information and communication technologies (ICT) have successfully and irreversibly pervaded everyday life, many technology leaders have started to look into the green ICT, i. e. ICT solutions that have reduced carbon emissions. A sobering report from WWF has indicated that only 2 % of the carbon emissions can be attributed to the ICT systems. Therefore, the real green impact of ICT can be made by using ICT to make the other systems more energy-efficient, such as the buildings, transportation, power grid, industry and production. In this paper we argue that the RFID technology can be one of the key drivers for implementing green ICT solutions in the systems that are not originally associated with ICT, e. g. transportation. In particular, the passive, battery-less RFID systems have potential to map the physical world to the virtual one and drive actions back from the virtual to the physical world with positive carbon balance, i. e. the carbon emissions saved by those actions are larger than the carbon emissions caused to operate the RFID systems. Motivated by that observation, we list several example green applications of the RFID systems.

I INTRODUCTION

The information and communication technologies (ICT) have brought profound improvements in all the areas of human activity and the quality of life. The latter relies mostly on impact that the ICT has had on the people through the immediate rewards provided by those systems. For example, the mobile phone brings reachability, which is almost ubiquitous, while the Internet provided unprecedented access to information and created countless opportunities for novel social interactions. Nevertheless, ICT has yet to unleash its potential in solving the global problems that will have long-term effects, such as the reversal of the trends in global warming, reduction of greenhouse gasses (GHG), dealing with the scarce resources (energy, water), protection of the environment, and sustainable global growth. These objectives are significantly interdependent, while the reduction of carbon emissions will have the largest effects.

Carbon dioxide (CO2) is the most important anthropogenic greenhouse gas (GHG) accounting for almost 80 % of the overall GHG emissions in the atmosphere [1]. The usage of ICT for reducing carbon emissions has been a subject of many recent analyses, see [2] and the references therein. It is also seen as one of the areas that can direct the research and innovation within ICT in the coming years. The understanding of the interaction between ICT and GHG is still in its infancy, although some indicators are already emerging. For example, the WWF report [2] has indicated that only 2 % of the current carbon emissions can be attributed to the ICT systems. This is a strong message that the benefits obtained from making, for example "green wireless networks" or "green server farms", can be almost negligible as compared to the benefits obtained if the ICT actions are targeted to ameliorate the activities that are responsible for the dominant part of the carbon emissions, such as the power production sector, buildings, industry and production, transport, etc.

The overall task of putting ICT to work towards making the world greener is enormously complex and includes several subtasks. The first is data collection and analysis, in order to make assessment of the GHG production in relation to all the human activities, and thus make projections about the quantitative impact that the ICT will have on the GHG emissions rooted at those activities. Another subtask is development of the technology that will enable low-carbon operation in the targeted activity areas, as well as innovation of applications that can replace some of the present activities with low-carbon counterparts. The "usual suspect" related to the latter is the replacement of the travels by video-conferencing, but many more applications and examples are needed to drive the environmental impact. A proper milieu for green ICTs to be put to work can be created by suitable policies and strategies. Such policies should be created by accounting for the opportunities and capabilities of the technology. For example, the system of incentives that can be introduced regarding the GHG activities can be built around rules for monitoring/acting that are assuming certain level of technology sophistication.

In this paper we advocate the Radio Frequency Identification (RFID) technology as one of the key components of the green ICT. Before summarizing the arguments behind such a claim, we need to briefly introduce the RFID technology. A RFID system provides automated identification and information gathering from objects and people. The two key components of an RFID system are tags and readers. A tag is a small microchip equipped with antenna which is attached to the physical object or the person. The most interesting types of tags are the passive, batteryless tags, as they can have low cost and thus be deployed in large volumes. The readers (or interrogators) are devices, usually deployed at strategic locations in order to efficiently collect information from the tags in their radio range. The tags attached to the objects or humans and thus make the physical world perceptible for the computers. That is why the passive tags are enablers of the "Internet of things". Particularly important developments related to the RFID technology can be seen in RFID sensors and energy harvesting. With RFID sensors, the tag is integrated with a sensor or multiple sensors and the radio link to the reader is used to convey the sensed data. Furthermore, energy harvesting will augment the computation/communication capabilities of the passive tags.

We argue that the role of RFID in enabling green ICT is multilateral. In the data collection process, it enables gathering of information to a very detailed level, which is an important step to relate different activities to the GHG. The usage of RFID tags can have direct impact on the environment by enabling more efficient waste management and recycling. Being the bond between the physical and the cyber world, the tags can be the key drivers in attacking the 98 % opportunity of the carbon emissions, by enabling real time planning in the virtual domain and sensing/acting in the physical domain. Finally, the passive tags can enable enforcement of policies and strategies and be instrumental to introduce incentive systems in GHG emission and the carbon trading schemes.

The paper is organized as follows. The next section provides some facts and figures related to emission of greenhouse gases. Section III introduces the basics of RFID and some related technologies. In Section IV we discuss several promising applications that can have tangible impact on the carbon emissions. This section is followed by the concluding section.

II Carbon Emissions: Fact and Figures

Carbon dioxide (CO2) is the most important anthropogenic greenhouse gas (GHG) accounting for almost 80 % of the overall GHG emissions in the atmosphere. According to statistics by the International Panel on Climate Change (IPCC) the global atmospheric concentration of CO2 has increased to 379 ppm in 2005, which exceeds by far the natural range over the last 650,000 years (180 to 300 ppm). The concentration of CO2 has grown with increased intensity during the last decade. Thus, while from 1960 to 2005 CO2 concentration had an average growth rate of 1.4 ppm per year, only from 1995 to 2005 the average growth rate has been 1.9 ppm per year [3]. This is a direct consequence of the fact that annual fossil CO2 emissions increased from an average of 23.5 billion tons per year in the 1990s, to 26.4 billion tons of CO2 per year in 2000-2005, see Fig. 1.

II.A Sector Approach

Statistical data shows that largest CO2 emitter is the power production sector with 28 % of total emissions [1]. Another 32 % of the global CO2 emissions coming from industry, transport, and residential services and agriculture, are emitted by power consumption when energy is processed into final products. Nevertheless, attention should not be concentrated only on CO2 emission but also on other GHG gasses such as CH4, N20, SF6, HFC, and PFC as they account for almost one fourth, or 23 % of the total GHG emissions. Sector- emission percentages are as listed in Table 1.

Figure 1: Historical development of the carbon emission volumes. From: *http://cait.wri.org/figures.php?page=ntn/1-2*

Power production:	28 %
Industry:	12 %
Transport:	13 %
Residential services and agriculture:	7 %
Land Use Change:	17 %
Non-CO2 GHG Emissions:	23 %

Table 1: Sectoral emission in percentage [1]

II.B Intervention

By 2050 global emissions of CO2 need to be reduced by 85 % in order to keep the temperature increase below 2C degrees. To achieve this, interventions in each of the GHG emitting sectors is needed by improvement of energy efficiency; increase in the share of renewables in the energy-mix; as well as "cleaning" of the fossil- fuel energy generation sector. Increase in efficiency is mostly relevant in the sectors such as industry, buildings, transport and power generation where energy and materials are being transformed into products and services [1]. The power production sector has on average very low efficiency. Old coal power plants have an average efficiency of 30 %. Yet, with new components and optimized process integration, their efficiency could improve up to 50 %, which would mean a reduction of 1.4 million tons of CO2 annually [1].

Electric grids, also, contribute to the loss of efficiency. During the transportation of electricity to consumers certain percentage is lost due to electrical resistance in the cables in the grid. Future development of Smart Grid power network will provide sustainable development, efficiency and cost benefits [4]. The Smart Grid leverages on ICT concepts in order to provide information flow and control over the electric grid in order to make the grid more efficient.

A very important and promising sector, where energy efficiency can be increased while CO2 emissions can be significantly reduced is the building sector which is accountable for one third of the global energy related CO2 emissions [5]. Energy efficiency in both commercial and residential buildings can be improved by using variety of technologies, designs and materials. Some technologies and concepts for improvement of energy efficiency are through efficient lightning, for example Light-Emitting Diode (LED). Other interventions that can contribute to energy efficiency include introduction of equipment with lowest stand-by power, reduction of energy outside office hours, efficient cooling/heating. A good example for such an energy efficient building is the passive house which can save up to 75 % energy consumption and thus decrease its carbon footprint [6].

Improvement in energy efficiency requires investments in R&D in new low carbon, and energy efficient technologies. Since 20 % of the world's population that is mostly located in the developed countries consumes 80 % of the world's natural resources including energy, they should be accountable for investment in energy efficiency. Yet, according to predictions by the US Department of Energy, world's energy consumption will grow by 50 % from 2005 to 2050 [7], mostly due to increased demand in emerging economies such as China and India. China and India for instance perceive the western developed countries historically accountable for the concentration of GHG in the atmosphere. They would not agree to cut GHG emissions and invest in energy efficiency if developed countries do not commit to higher GHG emission reduction, share of low carbon technologies as well as investment in energy efficiency in developing countries. Developed countries will have to commit to invest in improvement of their energy efficiency, yet will also have to invest in improvement in the energy efficiency in the developing world without affecting their path to development. According to Greenpeace, G8 countries will only put the Post-Kyoto negotiation on a path towards success if they commit to contribute USD 106 billion every year by 2020 to help developing countries face the climate change challenges [8].

The dichotomy related to the issue in which countries the investment in energy efficient technologies should be dominant, can be mapped into a dichotomy of two radically different technology approaches. In the developing countries many of the the systems (which are major sources of carbon emissions in the developed countries) have not yet been deployed. This gives opportunity for a *clean slate system design*, which starts to build the powersystem, transportation, industry, etc. based on the level of technological sophistication that is available today or in the near future and, most importantly, not being strongly bound by backward compatibility. Such a clean slate design can, for example, result in a transportation system that is as flexible and personalized as the car, but far more friendly to the environment. In such newly developed systems, ICT will have a decisive role, as the systems will rely on rich information flow and control among the system components.

Contrary to the clean slate approach, in the developed countries there are systems that are widely deployed and cannot be completely and instantaneously replaced, but they need to be gradually evolved, accounting for the backward compatibility. Hence in this case we need *wean slate system design*, where the existing systems should be upgraded to be weaned on the requirements for low carbon emissions.

III RFID and Some Related Technologies

There exist several opportunities for using ICT to reduce carbon emissions. Some of these are listed in [2]. One example is to use ICT to optimize scheduling and resource allocation in

Figure 2: The RFID tag and reader comprising a simple RFID system.

the physical world. In order to do this the physical world must be made perceptible in the digital world. As an example consider Smart Grid, where measuring devices are sampling the current power usage of a building and maybe estimates near-future power requirements, e.g. by knowing which devices that are currently using power [9]. Using communication systems this information is fed back to the supplier, who can then determine how to distribute the power to the customers most efficiently. A promising technology for coupling the physical world with the digital world is Radio Frequency IDentification, RFID.

III.A Basics of RFID Systems

RFID technology has been around for quite some time now, but recently this area has received immense attention due to reduced costs of implementation and production. An RFID system has two basic parts: Readers and Tags, as illustrated in Fig. 2. The reader is a transceiver that can activate the tag and reads its content. A tag is a device small enough to be embedded into an object, and it consists basically of a microchip with modest storage capacity connected to an antenna. When activated on demand by an external reader the tag backscatters its unique identifier and the information saved in its memory.

There exist different types of tags: Active tags, where an internal power source allows it to transmit its information at any time. However, having its own power source puts a limit to the lifetime of the tag, but it increases the communication range of the tag. The tags that have large potential for wide deployment and usage are the passive tags, which are powered by inductively coupled power from the signal transmitted by the reader. In other words, the passive tags harvest the required energy from the over-the-air transmission by the reader. By omitting the internal power source decreases the production cost and increases the lifetime of the tag.

III.B RFID Sensor Systems

Wireless sensor networks consist of a large number of small sensing, self-powered nodes that gather information and ultimately transmit this information to a base station in a wireless fashion. [10] Recently battery free wireless sensors based on RFID has been considered. RFID sensors is basically a passive RFID tag paired with a small sensing device. In this way the resulting device is a uniquely identifiable sensor with a wireless interface, as illustrated with a block diagram in Fig. 3. An example of such a device has been presented in [11].

Figure 3: The blocks of an RFID sensor device.

This means that the advantages of RFID is brought to wireless sensor networks creating devices with a small form factor and a long lifetime. Similar to the RFID system described in section III.A the RFID sensor is powered from inductively coupling when it is in the range of a transmitting reader, and the RFID sensor then backscatters its unique identifier and the state of the sensor. Since readers are not transmitting continuously, the power source for an RFID sensor is intermittent and unpredictable. This type of communication provides sufficient power for standard RFID systems, where a tag only backscatters the identifier. However, RFID sensors requires more power to operate the sensing device compared to standard tags. Hence it is difficult for the RFID sensor to assure that its tasks are completed based on the power received from the reader. It can therefore be beneficial to consider harvesting energy from other sources than the transmitted power from the reader [12].

III.C Energy Harvesting

Recently energy harvesting has been considered in order to prolong battery life of mobile phones [13], but in the context of small wireless devices, e.g. RFID sensors, it has the potential to make batteries in small wireless devices obsolete. The concept of energy harvesting can therefore decrease production costs as well as the required level of maintenance, while increasing the lifetime of the wireless sensor networks.

There exist several options for harvesting energy from the surroundings [14]. For example energy from light, which requires a large surface, or vibrations which requires mechanical apparatus. However, for wireless sensors a small form factor is desired, hence light and vibrations are not suited as energy sources for this application. Instead, inductive coupling may be an interesting option. In today's RFID system the tag uses such power to backscatter its identifier to the reader, but this might evolve towards tags that store such energy for later usage. Considering the ubiquity and abundance of various wireless transmitters, a wireless device is not confined to harvest energy from the communication with its own base station, but has the possibility of continuously harvesting energy from ambient transmitters.

IV GREEN APPLICATIONS INVOLVING PASSIVE WIRELESS DEVICES

We have already stated that the potential of RFID regarding green operation of various systems is seen in the fact that RFID provides the link between the physical and the virtual world. In this section we will concretize this, rather abstract, claim through three example green applications of the RFID system or, more general, systems with passive wireless devices.

IV.A Supply Chain Management

Today RFID technology is currently used to automate supply chain management. Using RFID tags allows for each item to be uniquely identified providing a complete overview of the supply chain. This knowledge can be utilized in order to cluster items for more efficient transportation and distribution, which would help reduce carbon emissions. Moreover, complete control of the supply chain decrease the requirement of stock, hence each retailer can do with a smaller and more accurate stock. RFID can be used to closely monitor the carbon emissions associated with each product in all the phases (production, distribution, retail) and thus contribute to the price of the product or the carbon tax of the product. Clearly, such carbon-monitoring RFID records should be readable only by authorities. It is easy to see that such a monitoring can be a strong incentive for all involved parties to introduce low-carbon practices for each product.

Moreover, with respect to food products complete control over the supply chain and production line will help reduce waste in case of accidents. As an example consider the case where a number of cartons with milk are damaged due to detergent in the milk. If RFID is utilized it is possible to uniquely identify and destroy only the inflicted cartons which reduce waste in the production line. This does not have a direct impact on carbon emission, but it reduces the average carbon footprint for each successfully produced item and it provides more security for the consumers. Furthermore, it is "green" in a sense that it has environmental impact.

IV.B Smart Buildings

Implementing RFID technology in buildings and combine the information gathered by the RFID readers with the installed appliances can realize what is referred to as Smart Buildings. As an example consider an office building equipped with an RFID sensor network. In addition each employee is equipped with an RFID tag, e.g. in their name tag or access card. Using these tags the sensor network installed in the building can adjust the utilized resources in order to minimize carbon emission. As an example the air condition could be controlled by temperature sensors and the light installations could sense if any tagged employees were in its proximity. If not, the light should be dimmed, or completely turned off.

Current implementations of wireless sensor networks in buildings show a decrease of approximately 20 % in energy consumption [15]. Comprehensive control of utilized resources in buildings therefore possess a large potential when a reduction in carbon emissions is desired. Moreover, in addition to reduced energy consumption, wireless sensor networks also enable low cost monitoring of occupants, e. g. elder citizens living at home, in order to alert care givers in the event of accidents or illness [16], which indirectly has green effect, by sparing the transportation for regular personal visits.

IV.C Intelligent Transportation

Sensor networks can be used to make transportation intelligent in order to reduce carbon emission. For example a sensor network distributed throughout the infrastructure makes it possible to gather information on for example roadwork and traffic load. This data can then be used by the navigation systems in each vehicle to plan the most energy efficient route, e. g. by avoiding traffic jams. Moreover, implementing systems for communication between cars and traffic lights makes it possible to automatically turn off the engine in the cars waiting at a red light. This will reduce the time engines are running idle, which reduces carbon emission. This would also enable traffic lights to sense the traffic density and adjust the lights to the actual traffic load. These approaches are transparent to the users, as the energy consumption is taken into account automatically.

However, in order to really make a change towards green transportation we need to change the mind set of the users. One approach could be road pricing, where the tax is based on driven distance, number of people in the car and driving style. In order to keep the tax to be payed at a minimum people are encouraged to drive green, i.e. energy efficient, and take the environment into account. Here RFID again plays a role, since it can enhance the precision of the road pricing - e. g. the distances driven when the car has three passengers can be priced less than the distances driven when the car has a single passenger. RFID can be used to closely and securely log transportation data and thus be a key technology for introducing incentives towards achieving low-carbon transport.

V CONCLUSION

In this paper we have addressed the issue of using ICT systems to decrease emissions of greenhouse gases and thus reverse the global warming trend. The real green role of ICT can be seen if it is applied to the systems that bear the chief responsibility for increased carbon emissions, such as the power distribution grid, transportation, buildings, production processes, etc. We have identified RFID and, more general, the technologies based on passive wireless devices, as the ones holding large potential to facilitate low-carbon operation of the future systems. We have exemplified such usage of RFID through several applications. We believe that the observations in this paper will motivate further studies on the green potential of RFID as well as innovative thinking regarding other green applications that rely on passive wireless devices.

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