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Special issue on green radio

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Society has grown increasingly aware of the need to reduce CO_2 emissions in order to mitigate consequential environmental effects. The primary contributors to CO_2 emissions are electric power generation, transport, and manufacturing. Information and Communications Technology (ICT) at present contributes a non-negligible 3% of world-wide energy consumption, which in turn causes about 2% of the world-wide CO_2 emissions. The dramatic growth in Internet traffics and the growing pervasive use of mobile and wireless technologies to support this are likely to increase CO_2 emissions in the future unless greater energy efficiency can be achieved in networking technologies. Thus, the development of wireless networks that require lower energy consumption is desirable. In addition to this key driver of reducing CO_2 emissions, the cost of energy has increased substantially and this is a significant proportion of the costs of any wireless access infrastructure company. These issues have resulted in an increased interest in "green radio" networks that reduce the energy requirements for wireless communications, and can thus contribute not only to goals for sustainable development, but also to the profitability of the telecommunication industry.

Although green radio can be justified in the context of energy consumption as noted above, it also can be viewed in a wider sense, such as in the optimization of spectrum usage to reduce electromagnetic radiation levels in order to enable coexistence of multiple wireless systems (i.e., less interference) as well as to reduce human exposure to radiation, in the recycling and reuse of ICT equipment, and in many other related contexts. There are 17 papers in this special issue. It is difficult to classify these papers into distinct categories, as many of them deal with several aspects of green radio. Nevertheless, the classification proposed by Luis Suarez, Loutfi Nuaymi, and Jean-Marie Bonnin in their overview paper (see below) seems very appropriate for classifying these papers and, referring to Figure 1, we can make use of this classification as follows. In particular, this special issue has assembled papers

dealing with network considerations at large (both indoor and outdoor networks), with the cell layout adaptation (CLA) level (six papers), and with efficient techniques for the radio resource management and optimal transmission (EE-RRM-OT) layer (seven papers). Moreover, three papers deal with cognitive radio networks, belonging to the environment learning & information exchange (EL-IE) layer, while two others deal specifically with component optimization aspects, pertaining to the component baseline layer, and one provides a tutorial on some green radio topics.
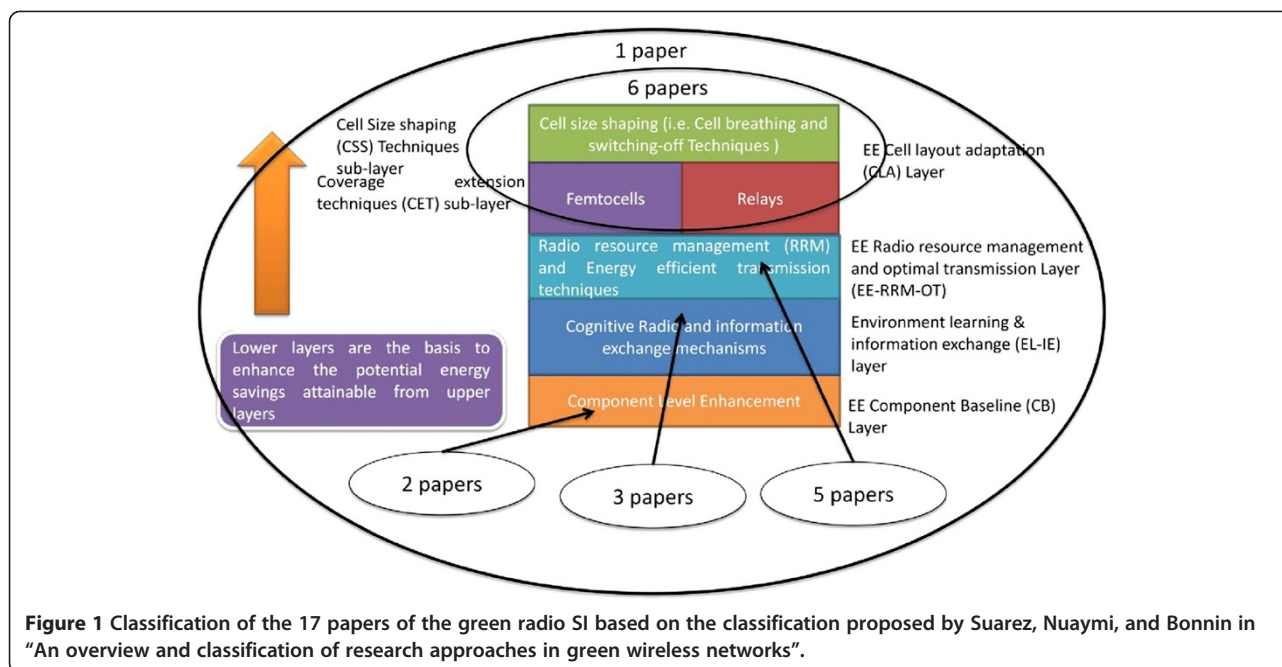
The paper providing an overview of green radio is "An overview and classification of research approaches in green wireless networks" by Luis Suarez, Loutfi Nuaymi, and Jean-Marie Bonnin. It provides an overview of research directions, both at the component level and at the network level. This overview provides an interesting classification, as noted above, and in addition describes major projects dedicated to green radio. It incorporates 76 references, which provide resources for further reading on all aspects of the subject.

Among the six papers dealing with the CLA layer, the paper entitled "Mobile operators have set ambitious targets—is it possible to boost network capacity while reducing its energy consumption?" by Gilbert Micallef, Preben Mogensen, and Hans-Otto Scheck, deals with the challenges faced by telecommunication operators. It quantifies, through a number of case studies, the impact of specific solutions and how the energy consumption trend can be expected to develop over the next decade. It shows that a hybrid macrocell-picocell upgrade is more energy-efficient than a macrocell or picocell only solution. Results show that network operators can get relatively close to their targets, with energy reductions of up to 40%. The next paper, entitled "Evaluation of the potential for energy saving in macrocell and femtocell networks using a heuristic introducing sleep modes in base stations" by Willem Vereecken, Margot Deruyck, Didier Colle, Wout Joseph, Mario Pickavet, Luc Martens, and Piet Demeester, deals with sleep modes for base stations. It derives a heuristic that can serve as a design tool for establishing a baseline. The authors demonstrate

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Figure 1 Classification of the 17 papers of the green radio SI based on the classification proposed by Suarez, Nuaymi, and Bonnin in "An overview and classification of research approaches in green wireless networks".

that sleep modes can lead to significant improvements in energy efficiency and act as an enabler for femtocell deployments. The paper "HopScotch—a low-power renewable energy base station network for rural broadband access," by Colin McGuire, Malcolm R Brew, Faisal Darbari, Gregour Bolton, Anthony McMahon, David H Crawford, Stephan Weiss, and Robert W Stewart, describes an example of broadband access to communities in sparsely populated rural areas running in the Scottish Highlands and Islands. Base stations are powered by a combination of renewable sources creating a low cost and scalable solution. The authors argue that the reliance on renewable power (wind turbines) and the intelligent use of frequency bands (WiFi at 5 GHz and UHF "white space") makes this approach an economical green radio technology that can address the problem of rural broadband access. The next paper entitled "Low energy indoor network: deployment optimization" by Siyi Wang, Weisi Guo, and Tim O'Farrell investigates indoor deployment with a minimum of energy to achieve downlink Quality of Service (QoS). It performs an analysis of two access-technologies (LTE femtocell and WiFi) in a realistic dynamic multi-user and multi-cell interference network. Thanks to a novel theoretical framework, the paper's results show that optimizing the location of access points both within a building and within individual rooms is critical to minimizing the energy consumption. The paper "Dynamic power control for energy harvesting wireless multimedia sensor networks" by Mohammed-Amine Koulali, Abdellatif Kobbane, Mohammed El Koutbi, Hamidou Tembine, and Jalel Ben-Othman deals with wireless multimedia

sensor networks equipped with photovoltaic cells. It proposes a new complete information Markov Decision Process model to characterize a sensor's battery discharge/recharge process and considers the structural properties of optimal transmit policies. Finally in this section the paper entitled "Energy efficiency analysis of one-way and two-way relay systems" by Can Sun and Chenyang Yang provides an in depth and theoretical analysis of energy efficiency for one-way relay transmission and two-way relay transmission and compares these to direct transmission. The paper shows that even relaying, which is often claimed to be a low-energy consumption technique, is not always more energy efficient than direct transmission.

Among the five papers dealing with the RRM and Optimal Transmission Layer, the paper entitled "Resource allocation for energy-efficient cellular systems" by Stefan Videv, John S Thompson, Harald Haas, and Peter M Grant proposes a new scheduler that takes into account energy costs for OFDMA cellular systems. When the energy consumption is dominated by the energy used for data communication as opposed to control channel overhead transmission, a bandwidth expanded mode allows the scheduler to decrease a user's energy consumption by allocating more resource blocks (RBs) and maintaining a constant data rate. The paper further considers a time compression mode, which is a technique that is complementary to bandwidth expanded mode. It allows for energy savings through a reduction of the number of RBs allocated to a user when the energy consumption is dominated by the transmission of signaling traffic. In a realistic framework, the scheduler saves about 38% of energy compared to a

frequency selective proportional fair benchmark. The next paper "An energy-efficient opportunistic multicast scheduling based on superposition coding for mixed traffics in wireless networks" by Xing Zhang, Qinzi Li, Yu Huang, and Wenbo Wang discusses with an energy-efficient opportunistic multicast scheduling technique that is based on superposition coding (SC) for multiple mixed unicast and multicast traffic transmission in wireless networks. To improve energy efficiency and system throughput, it considers a combined unicast and multicast SC scheme, which superimposes the unicast or multicast information used by fewer users onto other multicast information used by many users, after dividing all of the traffic into "hot" and "non-hot" traffic based on a certain user number threshold. The paper "Ultra-spectra communication system (USCS): a promising way to energy-efficient green communication networks" by Bin Li, Zheng Zhou, and Weixia Zou proposes a new communication system, named *ultra-spectra communication*, which combines single cycle modulation with pulse modulation. A performance analysis demonstrates that the overall transmission scheme can indeed be realized within an ultra-low-power framework. The next paper "Energy efficiency in multiaccess fading channels under QoS constraints" by Deli Qiao, Mustafa Cenk Gursoy, and Senem Velipasalar discusses with transmission in a two-user multiaccess fading channels under QoS constraints in the low-power and wideband regimes. Three access types are considered: time-division multiple-access, SC with fixed decoding order, and SC with variable decoding order. The final paper in this grouping, entitled "An energy efficient semi-static power control and link adaptation scheme in UMTS HSDPA" by Yi Huang, Jie Xu, and Ling Qiu, addresses power consumption of the HSDPA system. It proposes a new power control and link adaptation strategy, in which optimal modulation and coding schemes are determined for optimal energy efficiency. This new power control and link adaptation scheme has been extended to the multiple-input multiple-output case and simulation results prove that the gain in energy efficiency is significant and the method is robust.

Among papers dealing with energy-efficient components baseline layer, the paper "Green radio despite 'dirty RF' front-end" by Myriam Ariaudo, Inbar Fijalkow, Jean-Luc Gautier, Mathilde Brandon, Babar Aziz, and Borislav Milevsky deals with the "dirty RF" concept, which refers to the situation in which an imperfect analog front end generates perturbations that can be corrected in the digital domain using signal processing. The authors discuss the implications of this approach for green radio. The paper "Wake-up receiver for radio-on-demand wireless LANs" by Suhua Tang, Hiroyuki Yomo, Yoshihisa Kondo, and Sadao Obana deals with the idle state consumption of wireless local area networks access points. The idea is to wake up the access point only during times of active data

communications. It examines the effects of an imperfect radio frequency band pass filter, and suggests soft decision and optimal parameters for both signal detection and signal recognition. The results of the paper confirm that the proposed scheme, for a moderate cost, offers good performance in delivering wake-up signals and controlling false wake-up events caused by wireless local area network signals.

Among the three papers belonging to the EL-IE layer, two papers deal with compressive sensing, which proposed as method for reducing power consumption. Both papers deal with cognitive radio networks. The first of these papers, "A novel reduced power compressive sensing technique for wideband cognitive radio" by Yasin Miar, Claude D'Amours, and Tyseer Aboulnasr, considers sub-Nyquist non-uniform sampling for spectrum sensing to reduce the power consumption of the analog-to-digital converter. The missing samples are estimated by using the expectation-maximization algorithm. The authors show that the proposed sub-Nyquist rate non-uniform sampler is accurate enough to detect the edges of the estimated power spectral density. The second paper, "Efficient blind spectrum sensing for cognitive radio networks based on compressed sensing" by Shancang Li, Xinheng Wang, and Xu Zhou, proposes to improve signal reconstruction algorithms by using ℓ_p-norm $(0 < p < 1)$ minimization instead of ℓ_1 or ℓ_1/ℓ_2 mixed minimization that are commonly used in existing signal recovery schemes. Simulation results show that the proposed solution has a higher spectrum sensing sensitivity and accuracy, and improved reconstruction speed. The third paper dealing with issues at this layer is "Distributed beam forming with phase-only control for green cognitive radio networks" by Xiaohua Lian, Homayoun Nikookar, and Leo P Ligthart. It deals with a new distributed beam-forming technique designed to reach secondary users. By simply controlling only the phase of the transmitted signals, the new method decreases the energy consumption of cognitive radio nodes.

Prof. Jacques Palicot, SUPELEC/IETR, received, in 1983, his PhD degree in Signal Processing from the

University of Rennes. Since 1988, he has been involved in studies about equalization techniques applied to digital transmissions and analog TV systems. Since 1991, he has been involved mainly in studies concerning the digital communications area and automatic measurements techniques. He has taken an active part in various international bodies EBU, CCIR, URSI, and within RACE, ACTS, and IST European projects. He has published various scientific articles notably on equalization techniques, echo cancellation, hierarchical modulations, and Software Radio techniques. He is currently involved in adaptive Signal Processing and in new techniques as Software Radio, Cognitive radio and Green Radio. From November 2001 to September 2003, he had a temporary position with INRIA/IRISA in Rennes. He serves as Associate Editor for EURASIP JASP since 2008. He also served as lead guest editor for several Special Issues on Software Radio, Cognitive Radio, and Green Radio. He was Technical Program Chairman of CROWNCOM 2009 and Co General Chairman of ISCIT 2011. Since October 2003, he is with Supélec in Rennes where he leads the Signal Communications and Embedded Electronics (SCEE) research team.

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standardization task group. From September 2004 to February 2008, he has been with CREATE-NET (Italy), where he leaded its wireless teams in exploring Cognitive Radio and UWB technologies while participated the European FP6/FP7 projects (EUWB, PULSERS2). Dr. Zhang has served as the Chair of the Technical Committee on Cognitive Networks (TCCN) of the IEEE Communications Society (ComSoc) in 2011–2012. He was the Co-Chairs of IEEE Globecom 2008 Symposium. He was the founding TPC Co-Chairs of CrownCom 2006 as well as the Steering Committee Member of CrownCom 2006–2009. In the area of cognitive green communications and computing, Dr. Zhang was the Lead Guest Editor of the IEEE Communications Magazine special issues on "Green Communications". He was the General Chair of IEEE/ACM GreenCom 2010 (2010 IEEE/ACM International Conference on Green Computing and Communications) and the Co-Chairs of the IEEE International Workshop on Green Communications (GreenComm 2010–2011) in conjunction with IEEE ICC/Globecom. He is the co-author/editor of two books with the titles of "Cognitive Communications—Distributed Artificial Intelligence (DAI), Regulatory Policy & Economics, Implementation" (John Wiley & Sons) and "Green Communications: Theoretical Fundamentals, Algorithms and Applications" (CRC Press).

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