GREENET - An Early Stage Training Network in Enabling Technologies for Green Radio

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(Invited Paper)

Marco Di Renzo[1,2], Luis Alonso[3], Frank H. P. Fitzek[4], Andreas Foglar[5], Fabrizio Granelli[6], Fabio Graziosi[2], Christophe Gruet[7], Harald Haas[8], George Kormentzas[9], Ana I. Perez[3,10], Jonathan Rodriguez[11], John Thompson[8], Christos Verikoukis[10]

(1) French National Center for Scientific Research – L2S, UMR 8506 CNRS-SUPELEC-Univ Paris-Sud, 3 rue Joliot-Curie, 91192 Gif-sur-Yvette, France

(2) WEST Aquila srl, University of L'Aquila, DIEI/DEWS, Via G. Gronchi 18, Nucleo Industriale di Pile, 67100 L'Aquila, Italy

(3) Technical University of Catalonia (UPC) – Dept. of Signal Theory and Communications, 08860 Castelldefels, Spain

(4) ACTICOM GmbH, Am Borsigturm 42 13507, Berlin, Germany

(5) InnoRoute GmbH, Postfach 260114, 80058 München, Germany

(6) DISI – University of Trento, Via Sommarive 14, 38123 Trento, Italy

(7) CASSIDIAN, an EADS company – 1 Boulevard Jean Moulin CS 40001, 78996 Elancourt, France

(8) The University of Edinburgh – Institute for Digital Communications (IDCOM), Mayfield Road, Edinburgh, EH9 3JL, UK

(9) NCSR Demokritos, Patriarchou Grigoriou and Neapoleos St., GR–15310, Aghia Paraskevi, Attiki, Greece

(10) Telecommunications Technological Center of Catalonia (CTTC), Av. Carl Friedrich Gauss 7, 08860 Castelldefels, Spain

(11) Instituto de Telecomunicações (IT) – Aveiro, Campus Universitário de Santiago Aveiro, P–3810–193 Aveiro, Portugal

E–Mail: luisg@tsc.upc.edu and cveri@cttc.es

***Abstract*—In this paper, we describe GREENET (an early stage training network in enabling technologies for green radio), which is a new project recently funded by the European Commission under the auspices of the 2010 Marie Curie People Programme.**

Through the recruitment and personalized training of 17 Early Stage Researchers (ESRs), in GREENET we are committed to the development of new disruptive technologies to address all aspects of energy efficiency in wireless networks, from the user devices to the core network infrastructure, along with the ways the devices and equipment interact with one another.

Novel techniques at the physical, link, and network layers to reduce the energy consumption and carbon footprint of 4G devices will be investigated, such as Spatial Modulation (SM) for Multiple–Input–Multiple–Output (MIMO) systems, Cooperative Automatic Repeat reQuest (C–ARQ) protocols, and Network Coding (NC) for lossy networks. Furthermore, cooperation and cognition paradigms will be exploited as additional assets to improve the energy efficiency of wireless networks with the challenging but indispensable constraint of optimizing the system capacity without degrading the user's Quality–of–Service (QoS).

***Index Terms*—Seventh Framework Programme, Marie Curie Actions, The People Programme, Initial Training Networks, Enabling Technologies for Green Radio.**

I. Introduction

CURRENT 4G vision envisages higher data rates and multi–standard radio interfaces to provide all users with a continuous seamless connection. The large number of foreseen devices coupled with the surge in power requirements for future emerging handsets raise significant challenges in terms of reducing the energy consumption, the amount of electromagnetic radiation, and the emissions of CO2 [1], [2].

In particular, state–of–the–art multi–standard devices have high energy requirements for maintaining two or more radio interfaces. In [3], it is envisaged that a dramatic increase in the energy consumption of 4G devices will make active cooling a necessity. Indeed, from the manufacturer's perspective, the issue of energy consumption is becoming a key concern since there is a continuously growing gap between the energy required by emerging radio systems and what can be actually achieved by: i) the evolution on battery technology; ii) the progress on scaling and circuit design; iii) the design of novel system level architectures; and iv) the development of novel thermal and cooling techniques. Without new approaches for energy saving, there is a significant threat that 4G mobile users will be searching for power outlets rather than for network access, thus being restricted to a single location and being forced to lose their ability to roam freely.

In typical mobile terminals for cellular systems up to half of the energy consumption comes from communication–related functions, such as baseband processing, RF, and connectivity procedures [4]. Therefore any reduction in the power consumption of all these functionalities can have a substantial impact on the battery lifetime. The importance of this problem has already motivated solutions and protocols designed to allow dedicated switch–off periods for energy saving and for increasing the battery lifetime [3].

Furthermore, the need of radio networking solutions that can greatly improve energy– and resource–efficiency does not only make commercial sense for telecommunication operators supporting sustainable and profitable business, but, more important, can be extremely beneficial for the global environment. As a matter of fact, the whole world of telecommunication and information communities is facing a more and more serious challenge: on the one hand, the request for multimedia–rich data is exploding at an astonishing speed, and, on the other hand, the emission of CO2 that is due to Information and Communication Technology (ICT) is rapidly increasing. It has been pointed out that "currently, the 3% of world–wide energy is consumed by the ICT infrastructure that causes about 2% of the world–wide CO2 emissions, which is comparable to the world–wide CO2 emissions by airplanes or one quarter of the world–wide CO2 emissions by cars" [5]. According to [2], energy costs account for as much as half of a mobile operator's operating expenses.

Therefore, the ICT sector should set itself ambitious targets for improving its own energy and carbon footprint. Furthermore, ICT can lead to the biggest energy–efficiency gains if used in the wider economy with the aim of lowering greenhouse gas emissions, reducing power consumption, and achieving efficient recycling of equipment waste.

II. GREENET VISION

Moving from the considerations above, one of the biggest challenges for future wireless communication systems is the need to limit the energy consumption of battery–powered devices, with the aim to prolong their operational time, avoid active cooling, and reduce the environmental impact of ICT overall. Thus, within the framework of "Green Communications", a number of paradigm–shifting technical approaches can be expected, including, but not limited to, energy–efficient network architecture and protocols, energy–efficient wireless transmission techniques (*e.g.*, reduced transmission power and reduced radiation), cross–layer optimization methods, and opportunistic spectrum sharing without causing harmful interference pollution.

As a consequence, there is a clear need for new disruptive strategies and technologies to address all the aspects of energy efficiency. To mention just a few examples: i) novel physical (PHY) layer technologies seem to be required to cope with the increased complexity and power inefficiency of both single and multiple–antenna wireless communication systems; ii) advanced Medium Access Control (MAC) protocols and Radio Resource Management (RRM) procedures are required to support low energy consumption; and iii) a radical paradigm shift needs to be adopted on network routing and management to enable a significant energy saving. Although some energy–efficient solutions are today available, they usually sacrifice Quality–of–Service (QoS) to reduce power.

In GREENET, we intend to present a new vision to enable green communication and networking. The core tenet is to reduce overall the energy consumption within the challenging but indispensable framework of optimizing the system capacity and maintaining the user's QoS.

To this end, it is crucial that the next generation of researchers working in the ICT sector is aware that telecommunication and networking technologies should, at the same time, i) set themselves ambitious targets for improving their own carbon footprint, and ii) be used across all sectors of the economy and society to reduce the worldwide energy consumption. This also agrees with a recent European Commission Press Release (reference: IP/09/393, date: 12/03/2009) [1], which pushes ICT for a greener Europe and to make people more aware of how they use energy.

To achieve these goals, we believe that ICT's scientists should have a solid grasp and understanding of multidisciplinary research fields (information theory, protocol design, optimization theory, game theory, signal processing, cross–layer/holistic design, *etc*.) at different layers of the protocol stack. These topics, however, are unlikely to be covered even by advanced academic courses. Thus, the ambitious goal of the International Training Network (ITN) GREENET is to provide advanced training to Early Stage Researchers (ESRs) interested in using and improving the efficiency of ICT with the aim of reducing the emissions of CO2 without renouncing to the "anywhere, anytime, everywhere" requirement of several wireless applications.

A. Objectives

GREENET targets the main following objectives:

1) To recruit ESRs with the clear and long–term goal to conduct top–notch research and to pursue research excellence at the national, European, and international levels.
2) To develop training and career plans that are as personalized as possible to meet the needs and desires of each ESR.
3) To allow the ESRs understanding and addressing key research challenges on energy–efficient communications, which yield pivotal societal and economic concerns for Europe in the mid–to–long run.

4) To offer to each ESR top–level training and research programs with the twofold objective to reinforce and corroborate their own background, and to complement it with the active participation in a multidisciplinary network of research scientists.
5) To complement typical competencies of "applied research" with aspects related to project management, intellectual property rights, writing of patents, presentation and communication skills, writing of technical papers, exploitation of technical results and creation of start–up companies.
6) To guide and help the ESRs to build a bridge from academia to a high impact professional career in either the private or public sectors.

B. Expected Benefits

The following long–term benefits can be expected from GREENET:

- Overall, it is expected that the research activities conducted in GREENET provide significant scientific, industrial, and economic benefits by contributing to the reduction of the energy demands in 4G handsets and related carbon emissions.
- From a scientific point of view, the design of new physical, medium access control, and routing techniques that take advantage of cooperation and cognition without security and QoS degradation represents the main distinguishable feature of GREENET.
- From an industrial point of view, the exchange of scientific results among the partners (industrial and academic) will be the fundamental enabler to create impact within standardization bodies (*e.g.*, 3GPP, IEEE P1900.4 & 6, IEEE 802.16j, IEEE 802.15.4, ETSI, ITU, *etc.*), and to drive the deployment of innovative commercial solutions based on the scientific outcomes of the ITN.
- On the economic side, the know–how acquired during the activities of GREENET will be transferred to innovative products targeting "energy efficiency without QoS degradation". This will potentially open new market opportunities for European device manufacturers, service and application developers.

C. Partners

GREENET foresees the fruitful collaboration of 10 European partners, among which 3 universities, 3 research centers, 1 company, and 3 small/medium enterprises. In particular, the partners are as follows:

1) Universidad Polytecnica de Catalunya (UPC), Spain (project coordinator).
2) The University of Edinburgh, United Kingdom.
3) Università di Trento, Italy.
4) Instituto de Telecomunicações, Portugal.
5) National Centre for Scientific Research (NCSR) Demokritos, Greece.
6) Centre Tecnolgic de Telecomunicacions de Catalunya (CTTC), Spain.
7) WEST Aquila s.r.l., Italy.
8) ACTICOM GmbH, Germany.
9) CASSIDIAN, an EADS Company, France.
10) INNOROUTE GmbH, Germany.

III. Research Program

The workplan of GREENET is articulated into 8 WorkPackages (WPs): 1 WP (WP0) devoted to the project management, 1 WP devoted to training (WP6), 1 WP (WP7) devoted to dissemination, and 5 technical WPs (WP1–WP5). In particular, the technical WPs are organized in a matrix structure where three (WP1, WP2, and WP3) "horizontal" WPs aim at studying novel breakthrough technologies at the PHY, MAC, and network (NET) layers, respectively, to improve the energy efficiency of future wireless systems, and two (WP4, WP5) "vertical" WPs aim at addressing interdisciplinary and novel paradigms, such as network cooperation and cognition, for the design of energy–efficient wireless systems in which the secure and safe delivery of data can be guaranteed with high reliability through the network.

In what follows, we provide a brief description of the research program for each technical WP (WP1–WP5).

A. WP1: Energy–Efficient and Low–Complexity PHY–layer Techniques

Multiple–antenna techniques offer a practical way to extend the communication capabilities of the next generation wireless systems [6]. They can be used to accomplish a multiplexing gain, a diversity gain, or an antenna gain, thus enhancing the bit rate, the error performance, or the signal–to–noise–plus–interference ratio of wireless systems, respectively. However, the benefits of Multiple–Input–Multiple–Output (MIMO) systems cannot be achieved, unfortunately, for free. The main drawbacks of any MIMO scheme are the increase in hardware and signal processing complexity, energy consumption, and component size at the transmitter and at the receiver [7]. However, due to the clear advantages of MIMO techniques it must be a clear research goal to develop new approaches for multiple–antenna transmission, either centralized or distributed, to mitigate the practical limitations while retaining the key advantages.

In GREENET, we are committed to a comprehensive analysis of a new recently proposed transmission technology for MIMO systems, which promises to solve some of the issues mentioned above. It seems to be suitable for the design of energy–efficient MIMO schemes and for their actual implementation in the next generation wireless communication systems and networks. The new transmission technology is called Spatial Modulation (SM) [8]. Our research will encompass the development of novel modulation and coding schemes, low–complexity detection units, efficient channel estimation algorithms, and the development of novel methodologies for computing the error and capacity performance for realistic settings. More specifically, we will aim at achieving low–energy requirements via optimized coding and modulation schemes at the transmitter, opportunistic power allocation mechanisms to exploit the randomness of the wireless channel, and low–complexity implementations of detectors and channel estimators at the receiver.

B. WP2: Energy–Efficient Design of MAC and RRM Protocols

To reduce the footprint of wireless networks it is necessary to address the design of proper RRM and MAC schemes. RRM deals with assignment of radio resources to wireless devices, while MAC is related to managing the access to such shared resource. Several approaches are available in the literature targeting the study of energy–efficient MAC and RRM strategies in wireless networks [9]. However, the results available so far have pointed out that no single best strategy for energy–efficiency is today available, as well as that adaptivity is the way forward.

In GREENET, novel RRM and scheduling techniques that optimize energy efficiency with QoS constraints will be studied. Furthermore, solutions that mitigate intra– and inter–cell interference will be considered. In addition, improvements in the design of MAC protocols for wireless local area networks with low energy consumption will be investigated.

C. WP3: Energy–Efficient Network–Coded Wireless Architectures

In today practical communication networks, information is delivered from a source to a destination through routing. Network nodes simply store and forward data, and processing is accomplished only at the end nodes. Network Coding (NC) breaks with this assumption: instead of simply forwarding data, the nodes may recombine several input packets into one or several output packets. The potential advantages of NC over routing include resource (*e.g.*, bandwidth and power) and computational efficiency, as well as robustness to network dynamics [10], [11]. Although NC was originally proposed to maximize the throughput in wireless networks, recent results have clearly shown that it can be used as an efficient technique for energy saving by exploiting the broadcast nature of the wireless medium [12], [13].

In GREENET, we aim at exploiting the NC paradigm for reducing the energy consumption of wireless communication systems and networks by adopting a cross–layer design methodology. More specifically, our main commitment will be the design of novel (cross–layer) joint channel and network decoding algorithms to improve the performance and the energy–efficiency of wireless networks. In particular, we are interested in developing novel solutions that can efficiently work over realistic fading channels and can take into account the realistic operation of cooperative networks.

D. WP4: Cooperative Networking for the Design of Energy–Efficient Wireless Networks

Recent studies have shown that using cooperation in wireless networks can significantly improve the performance and provide an intrinsic robustness against the impairments of the wireless channel [14]. The net result turns out to be a lower packet–error probability and a better QoS. Cooperative communications are an active field of research in various European projects (*e.g.*, CODIV, REWIND, SMARTNet). However, effective energy–efficient cooperative solutions for wireless networks are still unavailable in the literature.

In GREENET, we aim at proposing innovative cooperative paradigms that overcome the limitations of state–of–the–art solutions. To this end, we aim at exploiting novel PHY–layer technologies (*e.g.*, SM described in WP1) and advanced encoding functionalities at the NET–layer (*e.g.*, NC described in WP3) for performance improvement and significant energy savings. In addition, we plan to design efficient short–range cooperative MAC protocols (as described in WP2), and Cooperative Automatic Repeat reQuest (ARQ) strategies to further reduce the energy consumption. Furthermore, the proposed solutions will be designed to be robust to possible security threats.

E. WP5: Cognitive Networking for the Design of Energy–Efficient Wireless Networks

Another promising way to improve energy efficiency of wireless systems lie in cognitive approaches in which learning is used for better adaptation [15]–[17]. A Cognitive Radio

(CR) is characterized by an adaptive, multi–dimensionally aware, autonomous radio system empowered by advanced intelligent functionalities, which interacts with its operating environment and learns from its experiences to reason, plan, and decide future actions to meet various needs. This approach can lead to a significant increase in radio resource (spectrum) efficiency, networking efficiency, as well as energy efficiency. Cognition can be used at the spectrum level for spectrum coexistence and interference management. Interference mitigation directly results in energy saving. Cognitive approaches can also be applied at the network layer to integrate heterogeneous networks and let energy efficiency becomes one of the primary optimization concerns to provisioning services across those networks. CR is a hot research asset in several European–funded projects, *e.g.*, PHYDYAS, ARAGORN, CogNet, Self–NET and E3. However, none of them explicitly deal with the exploitation of CR for energy saving.

In GREENET, we target the design of cognitive algorithms and protocols, which encompass energy–efficient detection capabilities for cooperative spectrum sensing, vertical handover procedures based on context information, dynamic spectrum management, and self–organization. Furthermore, the proposed solutions will be designed to be robust to possible security threats.

IV. Training Program

GREENET is committed to recruit 17 ESRs for a time period of 36 months each. Each ESR will be recruited through a competitive process, and will be supervised by more than one partner of the consortium. Each ESR will develop his/her research program within the premises of one of the partners of the ITN, and will spend a period of the duration of 6 months in the premises of at least another partner of the consortium. The training program of each ESR will be personalized through a well defined individual personal career development plan.

Training will be accomplished in many forms in the ITN:

1) Traditional training by means of Ph.D. courses, tutorials, seminars, workshops, and international conferences.
2) Training through research, which foresees the development of an individual research program by each ESR.
3) Complementary training, which foresees the attendance of specific courses aiming at improving presentation, paper writing, patent writing, *etc.* skills.

V. Conclusion

In this paper, we have described GREENET, a new recently–funded European project that aims at designing next generation energy–efficient wireless networks. GREENET foresees the collaboration of 10 European partners equally distributed among academia, research centers, and industry, which will synergically work to provide advanced training to 17 ESRs recruited by the whole consortium. The main objective of GREENET is to design new PHY, data–link, NET protocols, along with cooperative and cognitive paradigms to reduce the carbon footprint of ICT, and, at the same time, to enable a more efficient utilization of ICT across all sectors of the economy and society with the target to minimize the worldwide energy consumption.

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