GRAND-CRU Report Summary

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Final Report Summary - GRAND-CRU (Game-theoretic Resource Allocation for wireless Networks based on Distributed and Cooperative Relaying Units)

Project context and objectives

GRAND-CRU (Game-Theoretic Resource Allocation for wireless Networks based on Distributed and Cooperative Relaying Units) is a two-year research project that has involved two host institutions, the Dipartimento di Ingegneria dell’Informazione of the University of Pisa, Pisa, Italy (the return host), and the Department of Electrical Engineering of the Princeton University, Princeton, NJ, USA (the outgoing host).

The main research theme investigated by GRAND-CRU has been the design and optimization of next-generation wireless systems, in which the ever-increasing demand for high-speed ubiquitous wireless communications calls for efficient solutions in terms of energy expenditure and bandwidth occupation. The candidate technologies that aim at meeting this ambitious goal must exploit the most promising state-of-the-art techniques to achieve a high level of spectral and energy efficiency, as is apparent in recent draft versions of fourth-generation (4G) cellular communication standards and the foreseen fifth-generation (5G) systems.

Within the context above, the main goal of the GRAND-CRU project has been to devise innovative techniques to address the issue of energy-efficient resource allocation, by making use of self-enforcing schemes. The innovative idea has been to include the following aspects into the formulation of the problem, which, to the best of our knowledge, have not been sufficiently investigated before in the available literature:

i) The concept of energy efficiency: although this criterion is highly used in the context of resource allocation for wireless communications, there are many important aspects of the network that can significantly benefit from an energy-efficient and green approach.

ii) The need for low-complexity, scalable, and distributed algorithms, which make use of signal processing techniques at large to include the effects of practical parameter estimation. This approach is particularly appealing to propose viable solutions that are suited for realistic environments, with possible application in the industry sector.

Main project achievements

The line of research has been basically twofold. On one side, we focused on improving the energy efficiency of existing 4G standards, by studying algorithms specifically tailored for the contention-based network association in OFDMA systems such as LTE, LTE-Advanced, and the IEEE 802.16 standard family. Within the GRAND-CRU project, we have derived a low-complexity and scalable procedure based on a game-theoretic formulation, that allows each terminal and the base station (BS) to locally choose the transmit power and the detection strategy so as to obtain a good tradeoff between detection capabilities and power consumption. Numerical results, based on a simulation platform containing physical-layer parameters specified by existing standards (including spreading codes), and using estimated parameters fed back by the BS, have been used to
highlight the advantage of the proposed solution with respect to existing alternatives based on a deterministic increase of the transmit power (with or without contention resolution methods). Computer simulations have revealed the energy efficient and time saving nature of this technology; when compared to existing protocols, this novel scheme proved to be as much as 18 times faster and 25% more power saving, using the same amount of resources in terms of feedback from the BS. Moreover, it prevents the network from performing periodic synchronizations (as many as 30 synchronizations per second), which consume large amounts of power at the mobile side and increase the network overhead both in the downlink and the uplink.

On the other side, we focused on improving the energy efficiency of next-generation wireless networks, that aim at meeting the ambitious goals of 5G communications by including the most promising state-of-the-art solutions, such as relay-aided communications and integration of existing macrocellular networks with small cells. This kind of networks, appearing to be a promising solution to achieve the objectives of the Horizon 2020 work programme for advanced 5G networks for the future Internet, poses many challenges and open issues, such as: i) resource allocation for self-organizing, spatially distributed entities; ii) interference management, especially concerning cross-tier interference; iii) tradeoffs between spectral and energy efficiency of the network; and iv) mobility management, with particular emphasis on cross-tier handoff operation.

To answer these questions, we investigated a distributed resource allocation scheme for the joint power loading and subcarrier allocation in the uplink of an multicarrier OFDMA-based multicellular heterogeneous network, in which the mobile terminals are modeled as utility-driven rational agents that aim at maximizing the number of bits correctly delivered at destination per unit of energy consumed, under quality-of-service (QoS) constraints in terms of minimum rate requirements. Using a noncooperative game-theoretic approach, we derived a scalable and adaptive low-complexity distributed algorithm, that lets the user terminals properly allocate the resource across the network using a fractional programming approach. Numerical results show that the energy efficiency of the users is highly improved compared to an iterative waterfilling criterion, also leading to an inherent orthogonalization of the subcarriers for users sharing the same cell and bearing a very low complexity and a short convergence time compared to typical channel coherence times.

Potential impact of the project

In addition to scientific results published in many international peer-reviewed journals and conferences, the socio-economic impact achieved by the GRAND-CRU project lies in patentable algorithms and techniques, that mainly consist of software that can be employed by the network nodes of mobile wireless systems. This includes BSs in existing 4G networks, access points in heterogeneous networks and relay units for 5G networks, and user mobile terminals for both 4G and 5G networks, with possible interest from most companies and service providers working in developing next-generation broadband wireless communication systems.

Furthermore, the international network of collaborations initiated between the project team and many research centers and universities across Europe during the project, in addition to the cooperation well established across the two project team institutions, shows potential for future collaborations for European public projects and for some industrial spin-offs in the field of 5G heterogeneous networks.

**Related information**

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<th>Wireless communication to become greener</th>
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