
**University of Macedonia**

**Master Information Systems**

**Networking Technologies**

**Professor: A.A. Economides**

# *Co*operative and *Op*portunistic *Com*munications in Wireless Networks (COOPCOM)

**ELPEKOGLOU EVAGGELIA**

**Student ID: 01/09**

**THESSALONIKI**

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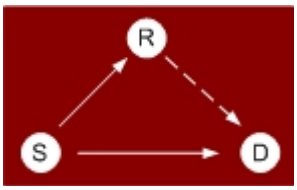
# ABSTRACT




Coopcom is a research project that aims to advance the state of art of cooperative and opportunistic communications in both theory and practice. The two concepts have been recently developed in a way that changes the way that engineers think about wireless system design. The main target is to maximize the spectral and power efficiency at the system level, as cooperation and opportunism have their origin at information theoretic studies. In the field of wireless communications, cooperation and opportunism, under a successful incorporation, are going to have a very important role, as these two concepts are expected to be long-term research topics in communication area. Although, in order to have satisfying results, this incorporation requires the solution of complicated theoretical and practical matters. For example, when does it pay off to cooperate, how the terminals should be synchronized, how do we recruit cooperators/relays, what is the complexity of associated terminals. [1]

***Cooperation* and *opportunism*** are two concepts that have emerged from this point of view. At the network level, opportunism means that, during each time slot, only the user with the strongest channel transmits. It exploits the fact that, at each time instant, it is very likely that (at least) one user is connected to the access point with a strong channel, and maximizes the total system throughput. On the other hand, cooperation exploits the broadcast nature of the wireless medium and builds *virtual* multiple-antenna systems, resulting in improved rate and/or reliability.

Wireless communication systems have attracted enormous research interest recently due to the exponential growth of the demand for wireless services. The main differences between the wireless and the wired systems are the *multipath propagation* and the *broadcasting nature* of the wireless channel.

With the term multipath we refer to the fact that the signal arrives at the receiver through many paths (after reflections, refractions and scattering). As a result, the wireless channel *fades randomly* due to the constructive or destructive effects of multipath propagation of the electromagnetic signal from the transmitter to the receiver as well as the changes in the environment which are caused by the motion of the transmitter, the receiver or the intervening obstacles. For a long time, fading has been considered as a "curse," because it significantly degrades the wireless channel's communication capability.

The broadcasting nature of the wireless channel refers to the fact that a signal transmitted from a source and to a destination is *overheard* by other mobile devices. A direct implication of this fact is *interference*, which has also been considered as a "curse" for a long time.

However, recently, new results have been derived, which prove that, under appropriate conditions, we can exploit both the fading and the broadcasting nature of the wireless channel for our benefit. [21]

## OBJECTIVES

The aim is to present the advances that will allow the deep understanding of theoretical and practical aspects of cooperative and opportunistic communications, leading to their successful implementation. This is expected to have considerable technological and social impact. In addition, we plan to explore new communication paradigms for portable devices by exploiting synergies between cooperative and opportunistic transmission modalities. The end target is to attain an order of magnitude higher combined data rates than what is at present envisioned in 4G researches, while supporting much tighter QoS guarantees.

In order to reach this target, the COOPCOM project will attack, logically, the next main scientific and technological problems:

- Study of performance limits of cooperative and opportunistic schemes through information theoretic and asymptotic large-system analysis. We shall investigate capacity regions and attempt to derive improved capacity bounds thereby discovering (quasi-) optimal communication schemes and improving the understanding of ultimate performance limits. We shall formulate and study a combined cooperative-opportunistic scenario, in order to explore promising synergies between cooperation and opportunism.

- Development of proficient cooperative and opportunistic communication strategies and codes, in order to optimally exploit the reliability and capacity gains offered by cooperation and opportunism in a multiuser/multicast context. We plan to exploit the specificities of the cooperative-opportunistic scenario, like, for example, the fact that the channel statistics of the various users may differ widely.
- Study and development of efficient resource allocation with limited feedback, including decentralized resource allocation. We shall target the proper exploitation of various grades of CSI (full, noisy, partial) at the transmitters, in order to achieve the finest possible performance in each scenario. Best design under partial or inaccurate CSI is a focal point of current research for several COOPCOM partners, owing in part to its practical significance and potential role in 4G systems. Decentralized resource allocation under deficient CSI is a capable unidentified research topic.
- Test-bed execution of selected cooperative and opportunistic schemes, in order to completely comprehend practical implementation constraints, overcome problems encountered when taking the critical step "from-theory-to-practice", consider the benefits gained by exploitation of cooperation and opportunism in pragmatic environments, and support proof-of-concept. [2]

# TECHNICAL APPROACH

## Analysis and design of cooperative and opportunistic schemes

Different from conventional point-to-point communications, cooperative communications and networking allows different users or nodes in a wireless network to share resources to create collaboration through distributed transmission/processing, in which each user's information is sent out not only by the user, but also by collaborating users. Cooperative communications and networking is a new communication paradigm promising significant capacity and multiplexing gain

The coopcom project will be carried out in the following main stages:
Cooperation and opportunism in both theory and practice, as the key purpose is to advance the state of their art. In this first stage, we try to reveal the theoretical performance limits of cooperative and opportunistic schemes. Moreover, at the same part, we mentioned

information about the development and the analysis of communication schemes with limited feedback. Finally we also examine the large system analysis of cooperative gain and capacity assessment.

It is fact that cooperation is more effective at low SNR (Signal-to-Noise-Ratio), and as we prefer to use simple relays, we consider a cooperation scheme with binary input and relays that simply forward to the destination their symbol-by symbol decisions, without fully decoding their input, which is time and energy consuming. This cooperation scheme termed Demodulate-and Forward (DF). This protocol is the most capable for applications that demand very low outage probability and higher power efficiency.

Afterwards, we consider the ergodic capacity of a fading Multiple-Input-Multiple Output (MIMO) wireless link, as we plan to uncover optimal transmission strategies. The ergodic capacity is affected by the quality and the type of the channel state information at the transmitter. The amount of channel state information available at the transmitter is the most important restricted factor in resource allocation, mostly in multi-user systems where the feedback from each user terminal must be limited. Finally, at this first stage of the project research we consider a more efficient implementation of CDMA (Code-Division-Multiple-Access) relay channel in terms of mutual information maximization. There were developed schemes that exploit multi-user diversity with limited feedback in multi-user systems.[3]

**Development of efficient strategies and coding schemes**

At the first stage of Coopcom project we investigated the theoretical bounds of cooperative and opportunist schemes. At this second stage, we will mention the efficient strategies and coding schemes of cooperative and opportunistic communications. In other words, the main goal of this part is to turn the potential into a reality, and all these by proposing and assessing schemes exploiting either opportunism or cooperation, or even both simultaneously. Firstly, it is mentioned the Amplify-and-Forward (AD) scheme which is more efficient than the Demodulated-and-Forward (DF) in cases where the source delay channel is bad. In this situation, the relay simply amplifies its partner's signal and forwards to its destination. Moreover, we consider the Multiple-Input-Multiple Output (MIMO) communications with perfect channel knowledge at both the transmitter and the receiver.

A very important subject that is concerned in this stage is scheduling. A number of user-base pairs equipped with multiple antennas which are simultaneously active.

Furthermore, there are considered some other strategies like the decentralized resource allocation or the scheduling in a Multiple-Input-Multiple Output Multiple Access set up.
Finally, at this stage we refer the cooperative multi-cast beamforming, a strategy where the population is to be served by several access points and the goal is to serve all or most of the users with their Quality of Services (QoS) at the minimum overall power.

**Implementation of selected cooperative and opportunistic schemes**

At the third stage of Coopcom project, we aim to complement the theoretical studies of the first stage and the practical developments of the second one by implement ting the most promising cooperative schemes on a test-bed. We expect to have a complete view of advantages and disadvantages of the implement schemes. We consider of software and hardware functionality, complexity requirements and expected enhancements and finally the implementation of schemes. [6]

## DELIVERABLES

Coopcom is composed of five Work Packages. The main research work is distributed in three work Packages (WP1-WP3), while WP0 and WP4 are concerned with management and dissemination issues. In such a project, it is expected that there will be continuous flow of information and interaction between the various Work packages. Firstly, WP1 and WP2 work independently but as the project progresses, they will communicate heavily. WP3 depends on WP1 and WP2. The main challenge of the project is to keep track or the activity in all WPs.
In each WP there are some deliverables that must have been completed at their due dates.
These are the deliverables of Coopcom project:

**D.0.1 Project management plan and quality plan**
(Due Date: 31-12-2006)

The present deliverable validates the different management bodies, their composition and their respective roles for quality guarantee of the project. Additionally, it defines procedures to coordinate document and deliverable production and exchanges between workpackages as well as within the Coopcom consortium. Finally, it provides a set of general rules (standards)

that will be used for the uniform presentation of the project towards the outside world. The scope of this project management and quality plan is confined to the necessary procedures and rules that will facilitate the flow of information and quality control throughout the project, by applying a logical level of commonness. [8]

**D.0.2: Mid-term report to Management Board**
(Due Date: 31-03-2008)

This deliverable describes the progress of the COOPCOM project towards its milestones and objectives. Milestones include technical meetings, distribution of the results, testbed implementation of certain cooperative and opportunistic schemes, contrast of the achieved results with the considered primary project objectives and timely delivery of periodic management reports and scientific deliverables. [9]

**D.1.1: Year 1 research report on performance limits, analysis and design of cooperative and opportunistic schemes.**
(Due Date: 01-10-2007)

The main goal of this deliverable is to uncover the theoretical performance limits of cooperative and opportunistic communications that will serve as reference point for more applied studies. The work that D.1.1 contains is related to theoretic information analysis and development of cooperative and opportunistic schemes with limited feedback. Moreover, there are information about large system analysis for quantification of cooperative gain and capacity assessment. [10]

**D.1.2: Year 2 research report on performance limits, analysis and design of cooperative and opportunistic schemes.**
(Due date: 01-10-2008)

In this deliverable, we present the results derived by the consortium in the second year of the COOPCOM project under the framework of WP1. [11]

**D.2.1: Year 1 research report on efficient strategies and coding schemes for cooperative and opportunistic communications.**
(Due Date: 01-10-2007)

Firstly, in this deliverable, we present the efficient strategies and coding schemes for cooperative and opportunist communications. It is composed in technical terms and its purpose is to present the main body of the Coopcom project. D.2.1 is concerned about development and evaluation of efficient coding schemes for cooperative and opportunistic communication, the analysis decentralized schemes for efficient recourse allocation and cooperative multicast beam-forming. All the above are the results came from the first year of the project. [12]

**D.2.2: Year 2 research report on efficient strategies and coding schemes for cooperative and opportunistic communications**
(Due date: 01-10-2008)

The purpose of this deliverable is to report the results obtained during the second year of the project in WP2 [13]

**D.3.1: Software and hardware support functionality for first selection of schemes to be implemented**
(Due Date: 01-10-2007)

This deliverable is concerned in hardware and software platform on which the implementations will take place. In other words, it is described the software and hardware functionality, the implementation and testing of schemes. [14]

**D.3.2: Preliminary results on implementations – Software and hardware support for second selection of schemes to be implemented.**
(Due Date: 01-10-2008)

WP3 is divided into three tasks:

T3.1 “Software and hardware support functionality,”
T3.2 “Complexity requirements and expected performance enhancements,” and
T3.3 “Implementation and testing of schemes”.
This deliverable is concerned with all three tasks. During the first year of the project, five schemes were selected for implementation, namely: amplify-and-forward (AF), detect-and-forward (DF), distributed space-time coding (DSTC), opportunistic cooperation (OC), and opportunistic multi-user MIMO with antenna selection (MUMIAS). Hardware and software functionality support functionality to enable the implementation of these schemes were also developed, and described in the first deliverable of the workpackage, i.e., D3.1. [15]

**D.4.1 Web site**

This deliverable refers the numerous aspects of the web site *www.coopcom.eu.org* that has been organised under the framework of the Coopcom project. The goal of this web site is to make possible the collaboration of the partners and the dissemination of the results to the academic and industrial community and the public. In addition, we have the description of the web site from the user’s and from the programmer’s point of view. There are provided information about the web site structure, layout and services. Moreover, there are some technical information, like installation and maintenance. [16]

**D.4.2: Plans for dissemination to academic and industry community**

The current dissemination plans of COOPCOM project are the main subject of this deliverable, which is the second of the forth WP. These plans are going to be tested either in industry or academic community. The means to be used in this purpose are the internet, some international meetings and conferences and finally technical journals and magazines. [17]

**D.4.3: Exploitation plan**

This deliverable describes the current exploitation plan of the COOPCOM project. The results are expected to be exploited mostly by the research community either in academia or in industry. Due to the nature of the project, the most important actions that will be taken

towards exploitation are linked to distribution of the results through publishing, training, and consulting. [18]

| **Work Package 0** | | | |
|---|---|---|---|
| **No.** | **Date** | **Description** | **File** |
| 1. | Feb 09,2007 | Project management plan and quality plan | D.0.1 |
| 2. | May 19,2008 | Mid-term report to Management Board | D.0.2 |
| **Work Package 1** | | | |
| **No.** | **Date** | **Description** | **File** |
| 1. | Nov 09,2007 | Year 1 research report on performance limits, analysis and design of cooperative and opportunistic diversity schemes | D.1.1 |
| 2. | Nov 09,2008 | Year 2 research report on performance limits, analysis and design of cooperative and opportunistic diversity schemes | D.1.2 |
| **Work Package 2** | | | |
| **No.** | **Date** | **Description** | **File** |
| 1. | Nov 09,2007 | Year 1 research report on efficient strategies and coding schemes for cooperative and opportunistic communications | D.2.1 |
| 2. | Nov 09,2008 | Year 2 research report on efficient strategies and coding schemes for cooperative and opportunistic communications | D.2.2 |
| | | | |
| | | | |

| Work Package 3 | | | |
|---|---|---|---|
| **No.** | **Date** | **Description** | **File** |
| 1. | Nov 09,2007 | Software and hardware support for first selection of schemes to be implemented | D.3.1 |
| 2. | Nov 09,2008 | Preliminary results on implementations - Software and hardware support for second selection of schemes to be implemented | D.3.2 |
| **Work Package 4** | | | |
| **No.** | **Date** | **Description** | **File** |
| 1. | Feb 20,2007 | Web site | D.4.1 |

## RESULTS

The results and expertise that derived from the Coopcom project will be useful for educational and consulting purposes. Furthermore, these results will be exploited for research and consolidating links with the industry. Here are the most important directions that the exploitation of results will take place in future.

The results that have already come from Coopcom project will be a matter of examination for the scientific research community.

The dissemination plan has been already prepared as a part of project management from the beginning of Coopcom project. Moreover, it has been decided to set up an information point in the Coopcom website. It will contain presentations and tutorial papers, information of great interesting to related projects and laboratories around the world.

As far as it concerns training and consulting that should be taken, Coopcom partners could be engaged as instructors or in tutorial presentations that are held in conferences. Finally, members of Coopcom consortium should be trainers in seminars targeting young researchers.
Due to the world-wide increasing research interest about cooperation and opportunism, it is expected that by the end of the Coopcom project (October 2009), a lot of technological advancements will be made available to the research community and the telecommunications industry. Results and expertise came from Coopcom project could be the beginning of a research and technological development project designed to gain new knowledge with the target to improve and develop products, services and processes.
An investigation for identifying the present standardization activities related to modern wireless systems has been scheduled. Some partners of the project, in future could contribute to these activities such as 802.16j for relaying in 802.16(wi-max).

## Impacts

The main goal of Coopcom project, as we have already mentioned, is to study cooperative and opportunist schemes of communication, both in theory and practice. The two revolutionary concepts, cooperation and opportunism, which are projected by Coopcom are going to play a very important role in the field of wireless communications. The impacts of this project are various, on **scientific and technological research**, **in social and economic life**. Also, Coopcom project's results will definitely help in achievement of **strategic issues.**

## Scientific and technological research

Coopcom project develops new efficient communication strategies and optimal schemes, as it improves the way we understand the ultimate performance limits. It will also have significant impact on recourse allocation and design of large-scale wireless networks.

## Social and economic life

The results of Coopcom are going influence social and economic factors of modern life. Firstly, Coopcom project gives business opportunities linked to networking. It gives a huge motivation for large-scale European research. Additionally, it improves the connectivity and

generally the quality of services. Coopcom sets new pricing models and innovative services and reduces infrastructure costs. Finally, it eases of network deployment.

**Strategic issues**

By the end of Coopcom project we also expect some very important implications at strategic level. Coopcom will suggest new methods to handle the increasing complexity of (ICT). It reinforces the opportunities and it improves the position of ICT at European level. It gives a competitive advantage in scientific and technological areas. It drives productivity and innovation in all European sectors. Coopcom will also find solutions to meet the current economic and social challenges.

Coopcom aims at addressing the emerging expectations which are being put on network by providing a research environment, investigating and experimentally validating highly innovative and revolutionary ideas. The project is an activity which pursues to scope and consolidate the European work in network test-beds. [5]

## FUTURE RESEARCH

In future wireless networks will go beyond the point-to-point or point-to-multipoint paradigms of classical cellular networks. Next generation networks will be based on composite interactions, where the implicated nodes cooperate with one another in direct to advance the performance of their own communication and that of the global network. Cooperative communications which are based on relaying nodes have emerged as a promising approach to raise spectral and power effectiveness, network treatment, and to decrease outage chance. Equally to multiantenna transceivers, relays offer diversity by creating multiple replicas of the signal of interest. By properly coordinating different spatially distributed nodes in a wireless system, one can successfully create a virtual antenna group that emulates the operation of a multiantenna transceiver. [4]

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## Other websites with Coopcom Information

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