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COST IC1004 Position Paper on Horizon2020

Research Challenges on Communications Networks and COST Actions role in the future European Research Framework

Narcis Cardona, Alain Sibille, Alister Burr, Jan Sykora, Buon Kiong Lau, Sana Salous, Luis Correia, Silvia Ruiz, Claude Oestges, Erik Ström, Thomas Jansen, Wim Kotterman, Roberto Verdone,
Members of COST IC1004 Action

Editor: Prof. Narcis Cardona
Chairman of COST IC1004
iTEAM Research Institute
Universitat Politecnica de Valencia
ncardona@iteam.upv.es

Abstract

This document summarises the position of COST IC1004 Action on Cooperative Radio Communications for Green and Smart Environments towards the future Research Framework in Horizon2020. The European research in the area of Communication Networks has many open challenges to become competitive under the current evolution of the wireless communication services and the exponential growth in the spatial density of data traffic demand. The position of COST IC1004 related to research challenges is grouped in six main topics: Energy Efficient Cooperative Networking, Networks beyond the Cellular concept, Smart Adaptive Antennas, Efficiency and Security at the Terminal side, Wireless Communications for Traffic Safety and Efficiency, and Testing the Adaptive Distributed Cognitive Mobile Systems. The document also describes how COST Actions can play a significant role in Horizon2020, becoming a strong instrument for scientific networking between academia and industry in Europe.

1. What is COST IC1004

IC1004 is a European COST Action (www.cost.esf.org) on Cooperative Radio Communications for Green Smart Environments.

The Action builds substantially on the work of the previous one, COST 2100, and its predecessors (COST 273, COST 259, COST 231, COST 207), whose remarkably continuous success for nearly three decades is a strong encouragement to pursue this European collaboration in IC1004 for 4 more years. This sequence of COST Actions has provided an important platform for result-sharing, discussions and cooperation in wireless network technologies, particularly in radio channels, radio algorithms and networking issues. Valuable contributions in radio channel models and over-the-air test methodology have been standardised, contributing to GSM, UMTS and HIPERLAN.

The scientific scope of IC1004 is on Radio Communication Systems and Networks, within the framework of Energy Efficiency and Smart Environments. A Smart Environment (SE) is a physical space populated by sensors, actuators, embedded systems, user terminals and any other type of communicating device, which cooperatively pursues given tasks by exchanging information and shares resources of all types such as radio spectrum or energy. Examples of SE can be found in domains such as health (body area networks), transports (smart cars), energy (smart metering) and many others. The radio channel is central to the paradigm of GSEs. The optimal exploitation of this resource through its study and modelling, through the development of cooperative transmission techniques and through the design of self-organising and energy efficient protocols and algorithms, is the major goal of IC1004.

After one year of activities, IC1004 is one of the largest COST Actions in terms of participants, a total of 275 individuals from research institutions and companies. IC1004 meetings are attended by more than 100 experts, only 1/3 of these being MC members. The fact that the majority of participants to COST IC1004 meetings cover the expenses from their own resources, clearly indicates that the activity in IC1004 is generating significant results, not only in terms of the meeting discussions with colleagues, but mainly in the scientific networking of methodologies, standards, references, techniques, models and tools.

2. Research Challenges on Radio Communication Networks Technologies

Two very substantial challenges remain for wireless communications in the next ten years and beyond: to keep up with the exponentially **increasing demand for data bandwidth**, and to **reduce energy consumption**. These are of course interlinked, in that data bandwidth needs to increase without increasing energy consumption in proportion, but needs even to reduce it. From the COST IC1004 point of view, future scenarios of wireless communications services will require the following aspects on Communications Networks Technologies to be considered as major challenges for research in Horizon2020:

2.1. Energy Efficient Cooperative Networking

The rapidly developing "Internet of things" (IoT) applications (essential to supporting the "grand societal challenges" which are central to Horizon 2020) will require dramatically reduced energy consumption, to enable long-endurance self-powered nodes, or nodes powered by energy harvesting, while radio spectrum and overall energy resources remain strictly limited. To give some numerical values, in the medium term (~10 years), wireless access systems should provide throughput densities up to 10 Gbit/s/km^2 outdoors, 100 Gbit/s/km^2 indoors. Especially for IoT, total energy requirements of 1 pJ/bit/node (including all contributions to node energy consumption) will probably be necessary.

To achieve such goals will require extensive research on implementation technology, especially low power hardware architecture and **energy-efficient signal processing**. Since these goals are close to theoretical limits, it will also require a paradigm shift in wireless system design to dramatically improve efficiency in terms both of power and spectrum. Notably the existing "layered" protocols, with their requirements for retransmissions, multiple acknowledgements, etc, may be highly inefficient, and in multihop networks result in bottlenecks that prevent them scaling as required both for high capacity density access networks and large scale IoT networks. However in principle such **multihop, cooperative networks** have the capability to greatly increase capacity density and reduce energy consumption by bringing the access network closer to the end-user.

Wireless Network Coding (WNC – a.k.a Physical Layer Network Coding, PLNC) is a technique that has potential to become a "disruptive" technology for such networks. It has the capability of naturally solving problems related to dense, cloud-like, massively-interacting networks of nodes. It can also be regarded as an example of the more general concept of the "network-aware physical layer", in which functions (such as routing) conventionally performed at high layers of the protocol are more efficiently carried out at the physical layer, which alone has the capability of processing signals directly, without loss of information.

These networks will nevertheless need to be self-managing to optimise their efficiency, adapting to varying demands and resource availability. This will require **new cognitive methods**, implemented using distributed artificial intelligence, based on tools such as game theory.

2.2. Networks beyond the Cellular concept

Mobile terminals have ceased to be the edge of the wireless communications networks, and are becoming a local area communications node entity for many of the current scenarios. The first decade of the 21st Century has seen how the computer and the phone have converged into a single concept of user terminal, making mobile telephony and nomadic computing facilities coexist in a single device. In this second decade European Research has to focus on the **communications networks evolution**. There is already a natural trend in the infrastructures of mobile networks to reduce the range and hence the size and complexity of the base stations, while increasing the number and bandwidth of the physical connections between smaller cell sites. The reason for this is the continuously **increasing data traffic** demand, which generates new opportunities for the provision of new services, which at the end give rise to a further increase of traffic capacity and throughput requirements. The wide deployment of optical communications networks, with fibre connections closer to the end users, make sense also for those wideband connections between small cells, changing the current basic concept of traffic-scaled cellular deployment to a modern view of **opportunistic spectrum-access based cooperative networking**.

How is this managed when a network is designed?: The deployment of new radio networks is based on facilitating access to wireless devices by installing small cells or access nodes, which are interconnected in groups by high speed (optical) networks, and cooperate within the group to manage the resources in a joint (local or wide) cooperative area. Given this trend in mobile communications networks, the whole concept of "cellular" will in future be replaced by "cooperative", and the major infrastructure embodied in base stations will be replaced by a connected sub-network of small cells.

Putting together these two concepts – wireless terminals as a local manager of radio communications not only to the user but to the surrounding smart devices, plus the reduction of cells size and the changes to the cellular based deployment concept – leads to a view of a future convergence between a mobile device and a small base station, acting as a local access enabler, either via a fixed connection to the fibre loop or by a wireless connection to another access point or mobile device.

This scenario of wireless access enablers, both fixed and mobile, is also an **inclusive approach for the current technologies being investigated and developed in Europe**. To mention a few: Mobile Opportunistic Relaying, Cooperative Networking, Distributed Antenna Systems, Dynamic Spectrum Resources Allocation, Cognitive Radio, Distributed MIMO.

The evolution towards “the smaller the better” will bring radio network architectures to consider the roaming user device (on the bus, in the street, inside the car, at home, etc) as a sort of relaying node able to provide coverage extension and to act as access points to the Internet for the “things” equipped with IP(v6) address; similar service will be provided by urban radio backhauls deployed using non-cellular low-energy and low cost radio interfaces; this will make the IoT paradigm become true through a network of mobile and fixed gateways interconnected according to the random mobility behaviours of humans. Delay tolerant M2M applications will emerge where roaming people will be available to act as data mules.

2.3. Smart Adaptive Antennas

Antenna systems are crucial for any wireless network. The conventional approach to antenna system research has been to optimise certain antenna parameters in terms of antenna-level properties such as impedance matching and radiation patterns. Such an approach is no longer adequate to deal with the stricter performance requirements imposed by new technologies such as multi-antenna systems, mm-wave communications and cognitive radio.

In this context, future antenna system research will undergo a paradigm shift. Specifically, it will account for various interactions between the antennas and their surroundings to achieve optimal system-level performance, including interactions between the antennas and the user, as well as the antennas and the propagation channel. One important aspect in these interactions is **smart adaptability**, not only to changes in the surroundings, but also to different application requirements (e.g., flexible bandwidth on demand for cognitive radio). Existing work in these topics is in its infancy, partly limited by the slow but steady development of various enabling/supporting technologies such as new materials and circuit components (e.g., MEMS).

2.4. Efficiency and Security at the Wireless Terminal side

Wireless terminals remain an open challenge for the radio communications evolution in the coming decade, and avoiding efforts to make them more efficient and secure would impact the competitiveness of future European Telecommunications Industry. In this sense, the major challenges are to develop:

- Terminals able to exploit the full potential of nanoscale hardware and devices in terms of performance and low power, e.g. massive multi-core hardware, which opens the route to novel physical (PHY) and higher layer algorithms.
- Terminals with extra wide band capabilities and mainly digital RF, which will require a major evolution of PHY schemes and design in order to mitigate the more significant imperfections resulting from these very wide capabilities (in terms of spurious, reduced dynamic range, enhanced interferences, harder linearities to cope with...) and exploit the full potential of these terminals
- Massive wireless device deployment of highly variable capabilities, which will require networks able to recognise and integrate these devices and compensate for their limited performance through various means
- Much enhanced security, combining PHY layer security, cryptography and protocols to ensure the highest confidentiality and integrity of data in the case of wireless connectivity
- Extremely simply self-configured but controllable connectivity of devices to the various wirelessly accessible environments (BAN, PAN, WLAN, MAN, etc.), allowing a simple switch to one or another according to user demand
- Seamless (but user controllable) integration of the various localisation techniques and location providing systems (GNSS, network based, UWB, and/or any other) for a fully transparent use with extremely limited need for user intervention
- Extremely fast (Gbit/s) wireless download/upload of data at local connectivity points for multimedia mobile devices

2.5. Wireless Communications for Traffic Safety and Efficiency

An emerging area of great significance for the safety and comfort of people as well as for the environment is cooperative traffic safety and traffic efficiency applications. Such applications require vehicles and road infrastructure (road signs, traffic lights, toll booths, etc.) to exchange information to make the transport safer (less accidents, injuries, and fatalities) and more efficient (less traffic jams, fuel consumption, and emissions). Hence, wireless communications is a crucial enabling technology for these applications. Although much is known about traditional cellular wireless channels, this is not the case for the vehicle-to-vehicle or vehicle-to-road side channels due to low antenna heights, high mobility scenarios, complex propagation environments, and particular constraints for antenna systems installed in vehicles.

To make an efficient design of a wireless communication system requires detailed channel knowledge, which currently is lacking. Hence, this lack of knowledge needs to be addressed with channel measurement campaigns and channel modelling work. Once this task is completed, we can conduct research on antenna systems, coding, modulation, medium access control, and other subsystems. The research output will allow us to provide scientifically sound advice on how to evolve the wireless standards being developed by ETSI technical committee on Intelligent Transport Systems.

2.6. Testing adaptive, distributed, cognitive mobile systems

Few people will realise that the mobile phones they might be using daily, are normally 100% tested for software, for radio frequent performance and compatibility but not for operation under realistic conditions, even twenty years after the advent of GSM. Part of this is caused by the fact that the standards do not demand such testing and that the mandatory testing is already an appreciable overhead. The notion of how much overhead testing under realistic operational conditions may add, seems to work paralysing. First steps are now taken by ETSI 3GPP to reach a standard on this so-called Over-the-Air testing for MIMO devices at the end of 2012.

As this first step is already difficult enough, it aims at emulating single device performance over a realistic channel, incorporating the influences of antennas at both ends. But, only the downlink is tested, the device is still under central control and the smart, adaptive features of LTE or LTE Advanced are switched off, those features that were designed into the system for increased performance compared to earlier generations.

However, when (link and antenna) adaptivity will be used to the full, when central control gradually shift towards distributive, and when cognitive functions using dynamic spectrum access are exploited – likely evolutions that have already been described in this document - testing has to assess how devices more or less on their own operate in environments and networks that become increasingly chaotic and crowded. Implementing these types of technology with thorough testing is not an option but a revolution of test technology itself is required to cope with such challenges. The conclusion is that the development of operational testing of systems should be concurrent with the evolution of communication systems and is a serious theme for future research programs.

3. Research Priorities in Europe for Horizon 2020

According to the research challenges described in the previous sections, some research priorities to be included in Horizon2020 are:

Networks beyond the Cellular concept:

- Scale of Radio Channel Modelling to small and complex scenarios, by numerical electromagnetic techniques.
- Evolution of Self-Organised Network Protocols for Energy Efficiency
- Development of cooperative spectrum-sharing techniques in non-homogeneous bands
- Heterogeneous radio network architectures where human mobility acts as enabler for capillary coverage and access to the network

Energy Efficient Cooperative Networking:

- Deployment of Wireless Network Coding Systems applied to dense, cloud-like, massively-interacting networks of nodes
- Implementation of new cognitive radio methods, using distributed artificial intelligence and game theory
- Harmonisation and gathering of experimental data, by setting up an international experimental network which provides remote access to users to configurable infrastructure, and a database of wireless measurements in different environments to enable efficient design of novel wireless networks and experimental test beds for the evaluation of emerging wireless network technologies.

Smart Adaptive Antennas:

- An understanding of the fundamental limits of the antenna systems in future wireless communications, which will provide the performance benchmark for smart adaptability.
- A complete strategy to the design of future antenna systems, which are able to take advantage of, rather than suffer from, interactions with the surrounding environment, including interactions with the user and the propagation channel. In addition, the health-related issues in the antenna-user interaction must also be taken into account.
- An integrated approach to the implementation of future antenna systems, where the system-level performance can be effectively optimised by appropriate sensing of the physical environment and adaptation of the relevant antenna system parameters.

Efficiency and Security at the Wireless Terminal side:

- Efficient integration of adaptive techniques at PHY, MAC and NET layers and beyond to allow the generalised use of multi-antenna techniques combining the operation of all possible frequency band and wireless access technologies in a given device with instantaneous aggregation or switch according to spectrum availabilities at a given instant and location.
- Seamless and transparent integration of multi-RAT technologies, ensuring fully resilient >Mb/s wireless connectivity, which requires: dominating the propagation loss curse through a combination of generalised diversity systems and techniques (such as

cooperation) and an excellent assessment of the characteristics of propagation in all relevant physical media

Wireless Communications for Traffic Safety and Efficiency:

- Acquire detailed understanding of the vehicle-to-vehicle (V2V) and (V2R) radio channels through measurement campaigns and channel modelling activities
- Analysis and design of efficient PHY and MAC layers for V2V and V2R communications to support traffic safety and efficiency applications

Testing adaptive, distributed, cognitive mobile systems

- Understanding how to reduce the amount of features of the mobile channel to the bare minimum without impairing the assessment of devices' performances, as straight-forward implementations of nowadays comprehensive models or high-resolution measurements have prohibitive complexity even for a single link.
- Developing a feasible strategy for testing full-duplex communication incorporating realistic channels both on down- and uplink
- A paradigm shift from testing a single device in isolation over a single communication link towards the testing of communication performance in lively networks over multiple, distributed links, not necessarily in the same frequency bands

4. <u>The role of COST Actions in Horizon 2020</u>

(COST as an instrument for research developments in HORIZON2020 to deliver EU industrial leadership and high-quality jobs creation in Europe)

COST Actions have succeeded in providing one of the best networking instruments of FP6 and FP7. In COST the research excellence of universities meets the technological leadership and applied view of the Industry, increasing the synergies between both, and getting mutual benefit from joint discussions. The new framework should use and reinforce this model as the reference for scientific coordination activities between Academia and Industry, and the role of COST Actions in Horizon2020 has to be based on the following strengths:

a) To keep promoting scientific networking in COST without the partnership restrictions of projects,
b) To evaluate and grant COST Actions in terms of their outcomes, real dimension and industrial participation,
c) To keep serving as an open forum for Early Stage Researchers,
d) To keep attracting Industries to meet Academia for research discussions in COST
e) To establish formal procedures to link COST Actions to other FP instruments, and
f) To evolve mature COST Actions towards stable Networks of Knowledge,

a) COST Actions: Networking without partnership

COST Actions base their success in the networking effects produced within its framework, which are not relying on any partnership contract or specific funded competitive objectives, but on the bottom-up approach of sharing results, and the technical discussions among its participants. COST actions are better understood as a networking instrument, where results from projects funded by many different sources are discussed, and a natural coordination between the participating researchers' interests is reached.

COST Actions should continue to be the inclusive scientific networking instrument in Horizon2020, but COST administration should not run it like projects, which they are not. COST should limit administrative duties and rules to the minimal, and rate Actions according to what they demonstrate, favouring a liberal approach where the reward comes from the outputs as compared to the commitments, where such commitments should be guided by properly evaluated benefits to the European community of Science and Technology.

b) Evaluation and funding of COST Actions

COST should substantially revise its evaluation and reviewing mechanisms, in order to ensure the most profitable success of these Actions towards the benefits of the European populations. Funding should be based on activities, dimension, outcomes, impacts out of COST, participation of industries, ESRs, presence in standardisation and regulatory frameworks, etc. Evaluation of COST Actions success should take into account all that factors, as well as the dissemination activities and impact that the COST joint activities (among participants) has produced in literature, conferences, books, standards or reports.

COST should concentrate its resources on a smaller number of Actions able to demonstrate this capability rather than spreading them among a large number of Actions that are dominated by a minor selection of academic players. The future of COST should be even more ambitious, trying to find ways to evolve, to spread and to promote the success cases, the quality of the Actions and the integration of research synergies between Industry and Academia.

c) The importance of COST for ESRs

Early Stage Researchers (ESRs) are taking advantage of COST Actions like in any other forum in the European Research Area. ESRs find in COST those colleagues who are working in the same topics, both senior researchers from other institutions and young people in their same situation, who in some years will take responsibilities and could propose joint participation to future projects. When a young researcher comes to a COST meeting to show the results of a research work, he or she can expect a long and constructive discussion around it. In addition, the younger researcher can bring back after the meeting some new ideas on how to improve the investigations. The situation is radically different if the young researcher attends a big conference, where a very limited time slot is assigned for the presentation, very few questions are expected and the audience is usually of wider scope.

d) Academia meets Industry in COST

COST should allow the creation of excellent far reaching academic research where deeply novel "clean slate" schemes are investigated by high level and high potential researchers while at the same time encourage industry-driven focused R&D networking. This is because significant benefits are expected from better cross-fertilisation of the two worlds towards short or mid-term societal impact. IC1004 is a good example of COST Actions on this point, with the necessary mix between industry and academia, in the best sense. There is no other benefit for companies to come than grasping what's going on in academia and transferring some of their own needs. It is probably a purer way of interacting than in projects, where funding tends to create some bias.

e) COST Actions related to other instruments

Up to date, COST Actions contracts have been not related to other FP7 instruments. The philosophy of the Actions is to serve as a networking activity, assuming that the individual participants are getting funds from other public or private programs. Inside the COST Action the results of research projects are shown, with COST being a way for dissemination of such results, but also a framework where to discuss the ongoing work, with colleagues who are not partners to those same funded projects. COST Actions have also played a match-making role among their participants, resulting in consortia that obtain large research grants, including those from EU framework programmes.

In Horizon2020, it would be recommendable, and will provide advantages to both sides, if some budget in the new framework projects is eligible, and specifically allocated, to the participation of researchers to COST Actions, since COST has an excellent track record of being a guarantee for successful scientific networking, with its effectiveness orders of magnitude above scientific symposia and conferences. This would reinforce the discussion of relevant results in the COST Actions meetings, and will serve as an effective way of coordinating research projects at the scientific level, as well as creating new relationships between projects researchers for future proposals.

f) Evolution of COST Actions

COST is an excellent platform for the free brainstorming and vivid science & technology exchanges between University and Industry. However, COST should be strengthened by fostering Actions such as COST IC1004 and the previous related Actions of the series, where the continued efforts over the years were able to gather academic and R&D researchers at a highly sustained rate for 20 years.

The creation of the COST Actions followed the basic rule of "inclusiveness at all levels" [2], being nowadays in fact what was intended to: a bottom-up oriented and open networking instrument. In this sense, COST mechanisms have worked very well as for the launch of new Actions. The success of a COST Action in terms of "Networking" is measurable by the number of joint activities, participants, countries, non-funded percentage of participations, industries involvement, published reference documents to standards or policy bodies, joint books, etc. But when a COST Action ends, the group of researchers who have reached good practices, established relationships, attracted industries to participate to the meetings discussions and to other COST Activities like STSMs or training schools, have simply to dismiss the group and close the Network.

What is then the real outcome of a successful COST Action? It's not only the specification of models, references, common scenarios, joint documents or publications, but the "Network" of researchers that after 4 years of activities is consolidated. Why pulling out this result from the Research Framework?

In the future Horizon2020, there should be a way to continue the activities of successful Actions under the funding of the EU, consolidating what has been reached and which is the most valuable outcome of COST: Inclusive Networks of researchers, both from Academia and Industry. Horizon2020 should then set up an instrument for those successful cases of COST Actions that reach a dimension and the expertise enough, to evolve to a formally established **Network of Knowledge**.

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