Integrated Project:
Wide-Area, Time-Coherent Sensor Arrays

EXPRESSION OF INTEREST

to participate in the FP6 Thematic Programmes on

Information Society and Technologies *(major area),*
and ***Aeronautics and Space***

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1. Need and relevance

We are all familiar with digital cameras, which are becoming commonplace and which enhance the capability and ease-of-use of photography. This example of a distributed sensor array makes use of visible light, but sensor arrays can of course also be developed to register many kinds of signals. When the arrays are made time-coherent, such that signal times are registered, it becomes possible to visualise, in two and three dimensions, the parameter fields of interest as they develop with time. Of particular interest in practice are arrays that record both signal amplitude and phase, because they allow the powerful techniques of interferometry to be applied. Examples of passive time-coherent arrays include acoustic, sonar and seismic arrays; radio frequency, microwave, and optical imaging arrays; and lightning location and monitoring arrays. Examples of active arrays would be phased array weather radar and synthetic aperture radar.

The performance of such arrays depends not only on the quality of their sensors, but is also a strong function of the signal transport and combination technologies. Due to limitations in the latter, sensor array functionality has generally been dramatically less than achievable in principle. Sensor arrays have typically also been expensive to implement in practice. Recent developments in optical networking technologies and in high performance and embedded computing capabilities, promise dramatically to improve this situation. One can foresee future sensor arrays in a wide variety of innovative environmental, commercial and scientific imaging applications, especially multi-dimensional applications that make use of other signal vectors than ordinary light. When integrated into the everyday environment, such arrays will provide important "ambient intelligence" that will help make possible the goal of a knowledge-based society.

We propose a project which aims to bring together the multi-disciplinary and cross-sectoral expertise necessary to ensure future European leadership in this generic capability. Trans-national participation is essential to realizing this aim, and the FP6 programme is foreseen as the essential enabling factor. The technologies and many applications fall naturally within the IST theme, probably most closely into the IST subtopics: “Applied IST research addressing major societal and economic challenges: Complex problem solving in science, engineering, business and for society,” and “Communication, computing and software technologies: Communication and network technologies” and “Software technologies, embedded systems and distributed systems,” but they also have relevance to the Strategic Research Agenda of the A&S theme, notably the A&S subtopics “Space: Galileo,” and “Satellite telecommunications.”

The project will provide both an organisational structure to tap the expertise of distributed (and often sub-critical) research groups around Europe and also a clear path for conversion of the research results into socio-economic benefits. In keeping with the wide spectrum of possible applications, three demonstrator projects are planned that in themselves will lead to forefront research capabilities and thereby to strengthening of the European Research Area.

2. Scale of ambition and Critical mass

The ultimate objective of this IP is to demonstrate the extraordinary power and utility specifically of wide-area time-coherent sensor arrays once the necessary networking and processing technologies are improved by orders of magnitude over current capabilities.

Research results will be transferred to the commercial sector in the process and European competitiveness strengthened in both research and commerce. To these ends, the project plan calls for a major multi-disciplinary, cross-sectoral and trans-national RTD effort, followed by a demonstrator program and scientific exploitation.

Research and Technical Development

The project plans to build on the expertise already available in Europe. Participation of research institutes will be organised in a way that counteracts fragmentation of information technology research in separate national projects, and of telecom and information technology companies through public-private partnerships (PPP's), which will ensure that market needs are explicitly taken into account and that the resulting intellectual property is directly available for commercial exploitation.

The proposed RTD program will include development studies in at least the following areas:

1. Control of complex and adaptive arrays of widely distributed and time critical sensors. Operation of complex, multi-tasking and multi-user sensor arrays will require adaptive and self-healing network control and scheduling, taking account of system degradation and rapid response to external perturbations. Resource management and reconfiguration of networked sensors will be prime research topics. Development of a coherent network time-base, using for example the precise clocks of the Galileo satellite system, will be an important area of development.
2. Very high data-rate transmission via an innovative fibre optics network (up to 24 Tbit/s). In designing the transport network architecture, trade-offs need to be made between data speed per wavelength channel, number of wavelength channels, and number of fibres. Precious wavelength and fibre resources can be saved when the data speed per wavelength channel is increased. Investigations will be carried out in systems transporting 160 Gbit/s in a single wavelength channel, and in a number of channels. Also the impact on the network architecture will be analysed, with a view to developing fault tolerant, scalable architectures.
3. Continuous real-time massively parallel, pipeline data processing (up to 40 TFLOPS and 600 TBytes on-line storage in the demonstration arrays). The project will foster RTD into on-demand hardware reconfiguration and into the design of GRID-enabled high-performance and scalable streaming database managers, as well as adaptive query processing combining streamed and stored data for pattern recognition and data mining. Essential to the interpretation of the vast volume of data generated by these arrays will be efficient and flexible visualisation techniques. Foreseen is the development of modes for inspecting the arrays for fault identification, and for perusing the various multi-dimensional data products.
4. Wireless communications. Novel, efficient methods for antenna beam forming, beam shape optimisation, interference suppression and signal processing with applications to both space sciences and Earth-space and space-space wireless communications will be developed. The emphasis will be on practical low cost and low complexity methods suitable for customised implementations in future digital radio systems.
5. On-line communities. Wide-area sensor arrays are foreseen generally to be on-line facilities that are operated by users from their home institutions, in principle anywhere in the world. Experience has shown that the on-line working environment is an important factor in efficiently carrying out research and analyses, and in certain applications in

attracting new users. One of the demonstration arrays will be a shared aperture antenna system allowing up to eight independent measurement programs to proceed simultaneously. Small-scale pilot projects with on-line working environment will be further developed into a large-scale application that can handle such a situation in a sociologically effective way.

6. General public and educational access. Astronomy, space science and geophysics are also fields that enjoy great public interest and are therefore ideal vehicles for promoting awareness of the innovative capabilities that the IP proposes to develop. Siting the wide-area array infrastructure in northern Europe will tap European strengths in these regions and also promote awareness of the project in a wide public located in the heart of Europe. At least one demonstrator array will have an on-line radio frequency measurement beam reserved for public and educational use.

Demonstrators

The project makes several choices regarding demonstrators aimed at ensuring success beyond the straightforward development of important technologies.

1. A first-class, forefront fibre optic network and digital processing facility will be provided as part of the project. These will serve as an infrastructure platform for research and demonstration of hardware and software technologies that have been proven in the laboratory but are not yet ready for the market. The demonstration sensor arrays will also share this common infrastructure. Developments of GRID technologies and of the GÉANT network will play important supporting roles in the project.
2. The research infrastructure will be developed via public-private partnerships to ensure that effective dissemination of the demonstration results into the commercial world takes place and that both commercial companies and a wide range of scientists will be attracted to and participate in exploiting the results of the project.
3. The sensor arrays to be implemented for demonstration purposes will thereafter be exploited for research in astronomy, space physics, geophysics, space telecom and IT research. The scale of these arrays will make them unique research facilities, and forefront research programs are conceived that will help move Europe to the scientific lead in these fields.

Specifically, one demonstrator array will employ over ten thousand receive-only radio frequency sensors distributed over an area some 400 km in diameter. For technical reasons it will be located so that it crosses the borders of the Netherlands with Germany, and extends into southern Scandinavia (www.LOFAR.org). The second, located in southern Sweden and working jointly with the first, will comprise thousands of digitally controlled low-power radio emitters and sensors to form a distributed high-power radar array (www.lois-space.org). The third will consist of a large array of geophones and will be employed for high resolution imaging and monitoring of geological structures to 30 km depth under the array.

Timelines

This choice of demonstrator arrays is based on a particular conjuncture of technological and commercial trends that make this project particularly timely. That is, networking and computing technologies are soon to be available that will make practical radio frequency sensor arrays in which the pointing and focusing functions currently accomplished by the

parabolic dish antennas used in wireless telecommunications are carried out fully electronically and in software. Building on the so-called "software radio" revolution these developments likewise promise to revolutionise future wireless communications and extend the benefits to other sensor array markets. This shift is also of great interest for research applications in, for example, astronomy, space physics and geosciences.

A multi-sectoral approach is also timely. The downturn in the telecommunications and information technology markets is accelerating the trend in which commercial companies in these sectors are down-sizing in-house RTD. In this critical period, these economically vital sectors can benefit greatly from sharing expertise and resources through projects such as this one. The demonstrators will be used for important multi-national applications. One example is space weather research, aiming at the development of a European space weather forecast service. The importance of space weather on the operational reliability of commercial telecommunications satellites, on electrical power grids in northern countries and for the evolution of climate has recently been recognised and is likely to become a major area of RTD activity in the coming years.

Duration

The project is currently projected to comprise 4 years of RTD and demonstration activities, thereafter to be followed by scientific and commercial exploitation of the demonstration infrastructure. A careful and thorough planning exercise in close cooperation with industry is nearing completion, and indicates that demonstration arrays can be operational in the 2006 timeframe. Operational exploitation is planned to begin thereafter and, motivated by space weather research, will continue at least through the next solar maximum around 2012.

Critical mass

Preparations for this project began already in 2000. A careful analysis in cooperation with industry has produced an estimate of the total cost of the effort of about M€100=, nearly half of which will be necessary for RTD manpower. The proposal under preparation for an Integrated Project in FP6 plans to request about ***M€35=*** for the transnational RTD required and for the demonstration projects. The remaining financing is foreseen from national and commercial sources. Agreements with research institutes are currently being discussed. Industry will be involved though PPP's, which in most cases will follow normal competitive procurement procedures; hence, definitive partners cannot at this time be indicated.

3. Integration

The following activities will be integrated to carry this project to completion.

1. Applied (technological) research. Participating teams plan to carry out technological research in the areas noted in section 2.
2. Applied technological development. An alliance of commercial companies and knowledge institutes aims as part of the IP to develop and demonstrate relevant networking, processing, software engineering and wireless technologies.
3. Procurement of demonstration infrastructure. In addition to providing the desired infrastructure for test and validation purposes, this activity will be designed to ensure effective knowledge transfer to the commercial sector.

4. Knowledge dissemination, public information and education. Knowledge transfer to the commercial sector is foreseen through carefully constructed public-private partnerships. Outreach to the general public will make use of the mass public appeal of astronomy, space research and geosciences all across Europe, and cooperation with public institutions such as schools, museums and planetaria will ensure that the existence of this project and its advanced technologies become widely known. Participating university research groups will be able to attract increased numbers of students into the technical and exact sciences through their high profile participation in this project.
5. Business plan development. Public-private partnerships are foreseen as an important, even essential part of this project. The development of viable business plans that benefit both the scientific and commercial participants will require a certain level of resources from all parties. A specific item in the procurement plan will be involvement of SME's in the business consortia.
6. Fundamental research. Research areas foreseen to use the demonstration arrays range from cosmology to ultra-high energy cosmic rays, coalescing black holes to geological processes affecting the evolution of the local landscape, extra-solar planets to space weather and its influence on the Earth's climate. The demonstrators will provide unique complementary data for planned ESA space physics and astronomy missions and ESO ground-based telescopes (VLT and ALMA), and lead the way in the development of the next-generation radio telescopes and space radars.
7. Project management. Professional full-time project management from industry is planned to ensure adequate control of costs, realization of goals and observance of intellectual property agreements. Work packages for both academic and commercial RTD and demonstrator activities are to be defined and integrated into a coherent program. Project communication will involve bi-weekly videoconferences for work package teams and quarterly to half-yearly face-to-face wider team meetings. Formal documentation of RTD results and of work package progress will be established, and a web-based documentation system will be available to aid in maintaining stable, project wide goals. A secure private web-based forum will be established for the several teams working on specific sub-projects in which intellectual property issues are relevant.
8. Integration activities. During the RTD and most of the procurement phases, workshops and organizational meetings for the technical and scientific teams will be held and a web-site maintained. To integrate commercial groups, a series of information days is scheduled (published in the Official Journal of the European Communities), in which proposals for joint development of advanced capability are solicited. These are to be followed by formal requests for information (also published in the OJEC), requests for proposals (idem ditto), and final selection for procurement (including formation of PPP's). During the initial preparatory phase of the project it has become evident that the interest in these developments among European research and technical development groups is likely to continue to grow during the course of the project. More than 50 companies and groups who already indicated their serious interest in the project. The current participants remain open for additional groups. Integration into the on-going project of all such groups will be facilitated by an openly accessible web-based information and discussion forum.