Strengthening Competitiveness Through Co-operation

European Research in Information and Communication Technologies

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This is a document of the European Commission services responsible for the management of the Information Society Technologies (IST) thematic priority in the EU's Framework Programme for Research and Technological Development (RTD).

The document highlights the crucial role played by Information and Communication Technologies (ICT) in economy and society; it shows that RTD is key to master and assimilate these technologies; and it proposes objectives and priorities for ICT research.

The purpose of the document is to explore the views of interested parties on these issues.

The document does not represent an official position of the European Commission, nor do its orientations prejudge the form and content of any future Commission proposal or activity in relation to RTD in ICT.

EXECUTIVE SUMMARY

Information and Communication Technologies (ICT) is a key tool to address the policy priorities of the European Union.

An indigenous research capacity is essential to be able to master and assimilate technology and to exploit it to economic and societal advantage. This is particularly true for ICT, where innovation moves at an ever faster pace, where the frontiers of research are increasingly broad, and where people and organisations depend more and more on ICT.

ICT Research at European level has to build on past successes while also reflecting the new realities. In face of the competition in research from all major and emerging economies, European companies and research labs adapt by re-locating their R&D activities and opening their innovation system to embrace knowledge and skills from the outside. At the same time, technology chains become increasingly complex, making it more difficult for any single player – or even Member State – to master the complete range of know-how and technologies needed to establish leadership in any ICT field. Increasingly, action at the European level is the most effective for investment in ICT research.

Progress and breakthroughs in ICT are driven by miniaturisation, by the convergence of computing, communications and media technologies, by the need to build systems that can learn and evolve, and by the cross-over between ICT and other science and technology fields. This next wave of technologies will make systems "smaller, cheaper, and smarter" and "always best connected", and their applications even more wide ranging. It will open the door to new networked devices and systems that will enable people to interact with their surroundings and with each other in totally new ways.

We have to master these developments; we have to find new ways to handle the increasing complexity of ICT devices, platforms and services; we have to lay the foundations for future systems by leveraging the emerging linkages between ICT and other fields of science and technology; we have to build integrated ICT-based platforms on which applications are built; we have to promote innovation from the use of ICT in many application areas; and we have to support new research and knowledge infrastructures. As the research activities deepen and expand, ICT technologists will have to collaborate with a broader set of actors to get insight of a larger set of disciplines and to better understand non-technological elements.

A comprehensive approach is needed to create the right research environment – an environment that improves the attractiveness of Europe for business investment in research, for industry/academic collaboration, and for researchers worldwide to work on European projects.

1. STRATEGIC CONTEXT

In its proposal for the European Union's financial framework for the period 2007-2013 the European Commission has identified three policy priorities[1]:

(1) "The Internal Market must be completed so that it can play its full part in achieving the broader objective of **sustainable development,** mobilising economic, social, and environmental policies to that end;

(2) The political concept of **European citizenship** hinges on the completion of an area of freedom, justice, security and access to basic public goods;

(3) Europe should project a coherent role **as a global partner,** inspired by its core values in assuming regional responsibilities, promoting sustainable development, and contributing to civilian and strategic security."

As we reach out for these goals, the EU faces major challenges.

Higher economic growth is a basic precondition for any other economic or social advance. However, EU's growth lags that of its international competitors, productivity growth has plummeted and, after decreasing for more than five years, unemployment is again on the increase. World-wide competition has become more intense and patterns of specialisation are changing as a growing share of international trade is explained by intra-industry and intra-firm exchanges. Globalisation refers more and more to global sourcing and international fragmentation of value chains. To keep innovating and stay competitive, firms choose different innovation models and organisational forms, including off-shoring and outsourcing, to embrace key technologies, and skills. The race to knowledge, to innovation and to science and technology is global and has direct impact on the economic performance, growth and prosperity of all regions.

In this context, Europe must realise higher economic growth through improving competitiveness and boosting productivity, whilst ensuring a sustainable future. We have to adjust to the changing economic realities brought about by the globalisation of markets and the ever-faster pace of technological change. We have to modernise our public services to meet the needs of our changing societies and lifestyles. Security issues are high on the political agenda and in citizens' concerns. And we have to come to terms with our "greying" population and its implications.

In the face of all these challenges Europe must continue to develop its knowledge and skills and to master the key technologies that will allow people, businesses and governments to meet the challenges and seize the opportunities ahead. Information and Communication Technologies (ICT) play a crucial role in this respect.

[1] "Building our common Future – Policy challenges and Budgetary means of the Enlarged Union 2007-2013", COM (2004) 101 of 10.02.2004

2. THE PATH TO SUSTAINABLE GROWTH

ICT is a key tool to address the three policy priorities of the EU. Virtually every facet of industry, commerce and government is touched by ICT and several depend heavily on it. We see the versatility and impact of ICT all around us, in the way we live, work, play and interact with each other. ICT are main drivers to improving productivity and economic growth; to mastering innovation; to modernising public services and meeting societal challenges. They also underpin progress in all domains of science and technology.

2.1 A Three Pronged Approach to ICT Policy

To fully exploit the potential of ICT, three conditions need to be fulfilled.

- First, we have to stimulate **research, development and innovation** in ICT so as to master and assimilate the technologies that will drive future innovation and growth.
- Second, we have to promote the **widest and best possible use** of ICT-based products and services;
- Third, we have to create the **right regulatory environment**: one that ensures fair competition and eliminates obstacles to the adoption of ICT;

The European Union's ICT policy is built on these three interlinked and mutually reinforcing pillars.

Support for ICT research at EU level helps mobilise the industrial and research communities around high-risk long-term goals, it facilitates the aggregation of public and private research efforts on a European scale, and it helps making Europe an attractive place to conduct ICT research.

Policy initiatives, notably eEurope, promote the wider deployment and adoption of ICT-based products and services in businesses, in administrations and in public sector services. They stimulate application and content development on a widely available broadband infrastructure.

The development of a regulatory framework aims to encourage competition, to improve the functioning of the internal market and to guarantee basic user interests that would not be guaranteed by market forces. The regulatory actions should create a set of rules that would be simple, aimed at deregulation, technology neutral and sufficiently flexible to deal with fast changing markets.

By addressing R&D and innovation, deployment and regulatory measures simultaneously, EU policy aims to ensure that Europe is able to master these technologies, to ensure European leadership and to enable all citizens and businesses in the enlarged Europe to benefit from their development. Europe has been, and remains, most successful in areas where the research and innovation effort has gone hand-in-hand with deployment and regulatory initiatives.

2.2 Enabling Higher Economic Growth

According to recent studies, more than half of the productivity[2] gains in our economies today are attributed to ICT[3,4]. In the EU for instance, of around 1.4% productivity growth between 1995 and 2000, 0.7% was due to ICT. Other evidence suggests that Europe's productivity gap with the US is to a large extent explained by its weaker investment in ICT. The gains stem both from the production of innovative high value ICT-based goods and services as well as from improvements in business processes through the wider diffusion, adoption and use of ICT across the economy.

Investments in ICT contribute half of Europe's productivity gains

ICT represents a substantial – and increasing – part of the added value of products and services. ICT-intensive sectors include manufacturing, automotive, aerospace, pharmaceuticals, medical equipment and agro-food, as well as financial services, media and retail. In automotive, for instance, an estimated 70% of innovations over the last 20 years are ICT-related gains. These are important European markets with good growth prospects and effective exploitation of ICT is essential for these industries and service sectors to maintain and improve their competitive edge.

Over the last decades ICT has been the enabling and leading factor in organisational change and innovation, and there is now a large body of evidence on its impacts on industrial value chains. This is all the more true today as firms become more agile to be able to operate profitably in an increasingly competitive environment of continually and unpredictably changing market needs.

ICT for business. Benefits reported by firms as a result of increased use of ICT include: faster product development, cost and overhead reductions, faster and more reliable transactions, better relationships with customers and suppliers, improved levels of customer service and support, and enhanced collaboration opportunities.

2.3 Meeting Societal Demands

European society is being transformed on many fronts. It is more culturally and socially diverse. Our work patterns are becoming more flexible, blurring the boundaries between work and leisure. At the same time, we are getting used to a 24/7 economy and demanding more personalised services. The population is ageing, resulting in higher levels of dependency and a steady rise in demand for health and social care. Some parts of the European society feel excluded and marginalised. Increased awareness of environmental and other issues make us more concerned about the consequences of our actions. And as increasingly active citizens we are looking for more direct involvement in public life and the democratic process.

Increasingly, ICT is a key enabler for the modernisation of public services and administrations. Here, use of ICT is significantly improving access to and interactivity of existing services, allowing

[2] Productivity at macro economic level expresses the GDP per capita.
[3] "The Policy Agenda for Growth" and "The Sources of Economic Growth in OECD Countries", OECD, 2003
[4] "ICT Investments and Growth Accounts for the EU", van Ark et al., 2002

a broader spectrum of society to enter and participate in public life and enabling services to be delivered more efficiently. It is also leading to completely new customised services that are truly citizen-, customer- and business-friendly.

ICT for healthcare. Developments in micro- and nano-technology are making possible a new generation of "smart" medical sensors and implants that offer major advances in clinical diagnosis and treatment. New ICT tools enable health practitioners to collaborate, while remote monitoring allows care to be delivered at the point of need, for instance in the home. And by bringing together data from medicine, genomics and the neuro-sciences researchers aim to develop highly personalised treatments for diseases such as cancer.

2.4 Building Security, Safety and Trust

Security and trust are key determinants for the effective functioning of the European economy and society. Increasingly, however, the European social fabric is exposed to threats and risks from many directions: natural disasters, terrorist threats, serious urban vandalism and crime, and fears of major acts of political and criminal cyber-terrorism. Security - spanning both the physical and virtual worlds - has become a key social priority.

ICT allows improved planning and control across the risk management chain, from risk assessment right through to emergency response. ICT provides the necessary protection and security for knowledge, values and digital assets to be exploited, transacted and shared in ever growing open and networked environments. ICT is also increasingly instrumental to the operational safety of everyday systems such as cars, trains and aircraft.

A further dimension relates to the dependability of information and communication systems and networks. The infrastructures of modern life, such as banking and finance, healthcare, energy, transportation and others, rely on ICT and are mutually dependent. It is essential to make the current infrastructures less fragile and vulnerable to failures, whether they are accidental or malicious.

2.5 Underpinning Research and Innovation

By enabling access to "knowledge anywhere anytime" ICT fosters new ways of interaction, co-operation, learning and innovation. Technology enhances the capabilities of human beings, individually and collectively, to create and share knowledge.

The research community is the frontrunner. High-speed, high-capacity communication networks and other ICT tools have changed the way research is conducted in virtually all science and technology disciplines. ICT plays a crucial role in areas such as decoding of the human genome, the design of new drugs, and the modelling of climate change.

GÉANT - the world-leading research network. The research network GÈANT is connecting almost 4000 universities and research centres in 43 countries across Europe. The fully enabled IPv6 network operating at speeds of up to 10Gbps is revolutionising the way research is conducted by offering unprecedented capabilities to European researchers based on innovative collaboration services.

2.6 Competing in a Global Industry

Europe's ICT industry is also a major economic sector in its own right, covering information technology, telecommunications and audio-visual markets. The sector has grown from 4% of EU GDP in the early '90s to 8% today[5]. While the industry has been unable to compete in all market niches, a strong commitment to innovation has kept European firms among the world leaders in key areas. These include semiconductors, digital media and consumer electronics, wired and wireless communications, and business software.

Europe's ICT sector has grown from 4% of EU GDP in the early 90s to 8% today

Of course, the sector in Europe has not been immune from the forces shaping the ICT industry worldwide. Over the last decade, joint ventures, mergers and acquisitions, together with a healthy rate of new start-ups have transformed the industrial landscape. To stay competitive, major industry players have disbanded their units and processes and relocated their sales offices, production sites and R&D centres to sites worldwide according to supply and demand conditions. At the same time, ICT firms have had to embrace a greater range of competencies as products and services have become ever more sophisticated.

Competing in nanoelectronics. Current investment in electronics accounts for some 30% of overall industrial investment and at just under €700 billion the worldwide market is now bigger even than the automotive market. The microelectronics value chain represents nearly one percent of global GDP.

For almost two decades, EU, EUREKA[6] and national research programmes have successfully supported large-scale efforts to bring micro-/nanoelectronics research in Europe on a par with that of competitors worldwide. While US company Intel is leading the worldwide chip market, the three major European semiconductor manufacturers (STMicroelectronics, Infineon and Philips Semiconductors) have figured among the global top ten for the past ten years. On the process equipment side, ASM Lithography has become a true European success story by gaining world leadership in the lithography market – the most essential equipment for semiconductor fabrication.

[5] The total value of the IT, telecommunications and audio-visual markets in Europe amounts to 890 billion €, or 8% of GDP, IDATE DigiWorld, 2003

[6] EUREKA is a pan-European network for market-oriented, industrial R&D, see www.eureka.be

3. EXPANDING THE EUROPEAN ICT RESEARCH EFFORT

Today we are far from exploiting the possibilities that progress in ICT can offer to people, businesses and governments. Further progress in ICT will allow industry to develop higher value products and services and it will make existing ICT applications more reliable, secure and easier to use. In addition, research will allow companies and the public sector to improve efficiency and become more responsive to markets, customers and citizens: in short to become more innovative.

In labs all around the world, researchers pursue the technology race for ever smaller-size, cheaper and higher gigahertz computing power and terabit memory capacity, and for gigabits per second communication bandwidths. They pave thus the way for the commodisation of computing and networking. At the same time, several other complementary disruptive technologies are emerging based on advances in sensor, software, knowledge and cognition technologies: intuitive and natural interfaces and interactive and inter-communicating systems. ICT also begin to play a major role in combination with many other sciences, mainly those related to new materials (e.g. in nano-electronics), bio- and life sciences (e.g. in biosensors). Increasingly, it is noticed that the most novel and innovative ideas stem from the intersection of many different S&T disciplines.

As people and organisations rely more and more on ICT, greater attention is paid to the problems associated with design, deployment and use of ICT devices and large-scale systems and networks. Today, many large ICT systems are characterised by budget overshoots, development failures, unpredictable behaviour and breakdowns. As such systems become critical infrastructures, the cost to economy and society of their failure grows. The knowledge to overcome these shortfalls requires research to take account of both the technical capabilities of ICT as well as the ways in which people engage with ICT in operational settings. It is clear today that in order to be effective investment in ICT needs to be combined with investments in structural reorganisations, process transformations and further skills development. It also poses several social and ethical dilemmas and challenges such as digital inclusion, privacy and trust issues.

Objectives and priorities for ICT research to be undertaken at European level will need to reflect these trends and be set in a context of (1) the current EU research policy, (2) a globalised ICT research environment, (3) a worrying trend in ICT investments in Europe, and (4) a clear justification for European added value.

3.1 Research on the Political Agenda

Research and development is a key factor to maintain and improve a competitive industrial base and to transform the European Union into a dynamic knowledge-based economy and society[7].

[7] "Building our common Future – Policy challenges and Budgetary means of the Enlarged Union 2007-2013", COM (2004) 101 of 10.02.2004

An indigenous research capability is essential in being able to assimilate technology and exploit it to economic and societal advantage. Studies show that those countries that are more research-intensive and that experience faster technological change are performing better than those where the technological research effort is lower[8,9]. Countries with a strong indigenous research base are in a better position to take advantage of technology developed worldwide. Furthermore, the level of business R&D reflects the ability of the business sector to absorb technology from external sources, whether from academia or overseas firms.

"Free riding" strategies based on exploitation of new technologies developed by others are not effective

The EU's research policy aims to pursue simultaneously three related and complementary goals[10]:

- To accelerate the implementation of the European Research Area (ERA) to create an efficient internal market for research and technological development, as well as a space for a better coordination of national and regional research activities and policies.
- To raise the European effort on research to 3% of EU GDP by 2010 with two-thirds coming from the private sector.
- To support and strengthen excellence in research, development and innovation throughout Europe by providing direct financial support at European level as a complement to national programmes.

The EU Framework Programme for research and technological development is a key instrument to support these objectives[11]. It helps bridge the gap of public investment, provides a stable framework for leveraging private funding, and complements and strengthens national efforts.

However, more research alone is not enough. We also need to improve its efficiency and effectiveness. Partnering and networking actions that bring together main players around key research and technology developments create essential links also for the translation of research results into products and services, their deployment and use. The research environment is improved through measures for e.g. intellectual property protection and for standards setting. Various public financing instruments can be used, individually and in combination: direct measures, fiscal incentives, guarantee schemes, support of risk capital[12].

[8] For instance, in OECD studies, 2003: "Investing in knowledge an increase of 1% in business R&D (publicly or privately funded) generates 0.13% in productivity growth; a 1% increase in foreign R&D generates 0.44% in productivity growth; 1% increase in public R&D generates 0.17% in productivity growth"

[9] "EU Productivity and Competitiveness: An Industry Perspective", O'Mahony and van Ark, 2003

[10] "Science and technology, the key to Europe's future – Guidelines for future European Union policy to support research", COM(2004)353 of 16.06.2004

[11] Annex II provides an overview of recent orientations for EU research support mechanisms.

[12] See also "Investing in Research – An Action Plan for Europe", COM (2003) 226 of 30.04.2003

3.2 The ICT Research Environment

The international context of ICT research, development and innovation has changed considerably over the past couple of decades. Mirroring the globalisation of sales and of production, research and development activities are organised increasingly on a global scale. Faced with growing international competition, firms are increasingly obliged to relocate their research facilities to any country or region offering comparative advantage. This applies just as much to technology-intensive SMEs as to large corporate laboratories.

Global competition is increasing – also in R&D

Researchers, too, are more mobile internationally, including from the less-advanced economies. In the global economy, scientific and technological knowledge and skills are readily transferable, either by foreign direct investment, other forms of global sourcing, or by the growth of electronic networks. This gives a new significance to the location of R&D staff and the knowledge-sharing networks they create.

In this globalised research environment, the future benchmarks for Europe are just as likely to be China, South East Asia, India or Latin America, as they are the United States or Japan. These fast-developing economies offer not only research skills at low cost, but also high quality researchers and large size markets. Increasingly, countries, sectors and firms have to play to their strengths focusing on those parts of the value chain in which they have a comparative advantage. This international fragmentation of the value chain also reinforces the importance of interactions within regional clusters and networks so as to leverage the knowledge and skills of the indigenous research base.

"Open Innovation" – embrace innovation from outside

Today, firms have to innovate in more flexible ways. Rather than generating, developing and commercialising all their ideas in-house, firms are opting to embrace innovations from outside, to partner in developing them, and to look beyond their traditional markets. "Spin off, spin out, buy in" is the new mantra. Thus, the innovation environment is becoming more open: in a world of abundant knowledge, global markets, and increasingly complex technology, there is no other way.

One upshot of this more flexible and open innovation system is the increasing acceptance of collaborative R&D. Many firms now routinely seek to undertake R&D projects on a collaborative basis: it is an inherent part of the business case, allowing the sharing of risks, costs, technologies and skills. Partnering - for so long a distinguishing feature of the EU Framework Programmes for R&D - is now part of the mainstream.

3.3 ICT Research Investments – Reversing the Trend

The importance of research in ICT to economic and social change is reflected in research budgets worldwide. ICT represents more than 30% of the total R&D budget in all major OECD countries. Furthermore, the intensity of the research effort in ICT is directly correlated with productivity growth. Within the EU, countries that invest the highest levels in ICT research, like Ireland, Finland and Sweden, also have the highest productivity growth rates[13].

ICT represents more than 30% of the total R&D budget in all major OECD countries

Overall, however, Europe still invests much less in ICT research than its main competitors. For instance, investment in ICT research in the EU is around one third that of the US and is 30% lower than Japan[14]. The picture is similar for both private and public investment. For instance, in 2002, only 8% of investments in microelectronics were done in Europe, whereas the Asia Pacific region and Taiwan and China in particular accounted for 62% of the investments. EU public investment in ICT research is about €8bn compared to roughly €20bn for the US public effort. In fact, the gap in ICT research investment represents half of the total gap in research spending between the EU and the US. Furthermore, the dynamics are worrying. Based on the latest data[15] from the eight EU ICT companies in the top 100 R&D spenders worldwide, they have reduced their R&D investments by 20% between 2001 and 2002 (from €22bn to €18bn). The public research effort has at best stabilised but has not grown to compensate the loss.

Europe must and is certainly capable of reversing the trend and of remaining a key player in these strategic technologies. A renewed and more intensive effort in ICT research applies to both private and public investments. It is clear that public investment in ICT research is instrumental not only for preparing the next waves of innovation but also for attracting and stimulating private investments. The exploitation of this investment is maximised through solid industry-academia cooperation. To strengthen these interactions, the role of ICT research supported at European level is key.

3.4 European Added Value

A strategic approach to ICT research over recent years under the EU Framework Programmes has served Europe well. Experience has shown that in the areas where a focused research effort was undertaken at European level important successes were achieved[16].

ICT Research at European level needs to build on these past successes while also reflecting the new realities. In face of the competition in research from all major and emerging economies, Europe

[13] "ICT and Economic Growth: Evidence from OECD Countries, Industries and Firms", OECD, 2003
[14] "Investment in ICT Research, Comparative Study", IDATE, 2002
[15] "Top 100 R&D Spenders", IEEE, October 2003 (data from Standard & Poor's database)
[16] Annex I gives examples of success stories of partnering at European level.

needs not only to increase its public research effort but also to improve its attractiveness to private investment in research. As companies and research labs are adapting to the new context, by re-locating their R&D activities and opening their innovation system to embrace knowledge and skills from the outside, the research scene becomes *de facto* international. It is the EU as a whole that can offer to companies the best pooling of high quality research resources.

In addition, two main trends dominate R&D in ICT today:

1. **Increasing complexity**: Progress in key technology fields requires, more than ever before, the mastery of increasingly complex technology chains. In ICT these span across a range of components, devices, infrastructures and services. It is very rare that any one organisation or country in the EU today can afford the costs[17] and cover the know-how, capabilities and skills needed to master the complete range. Partnering between companies and between companies and public labs is essential to be able to compete and lead world wide.
2. **Increasing interdependencies between technology, products and services**: In all major R&D fields, the exploitation of research results implies their integration in services and solutions to be applied across countries and regions. Partnering at international level helps ensure that research results and solutions are applicable across Europe and beyond; it enables consensus building and the development of EU- and world-wide standards and interoperable solutions.

Thus, in today's world, partnering in research has become the norm. Business strategies, market dynamics and technology chains all point towards this being the case. Furthermore, it is apparent that partnering at European level represents the optimal approach to ICT research investment. While research will continue to be undertaken at regional and national levels, increasingly it is at European level that the necessary leverage is to be found. It is through cooperation and coordination at European scale that critical mass can be created, that leadership can be built and that common goals can be pursued.

Now more than ever, partnering at the European level is the way forward

Community supported research provides a stable institutional framework for rapid partnership development. The collaborative effort enables risk sharing between industry actors and with the public sector. It also helps create positive competition at European scale and stimulates excellence. This framework is essential not only for cooperation between organisations, industry and academia, across Europe but also as a means to foster coordination between member states' policies and research actions.

[17] For instance, the costs of developing a new generation of semiconductor technology has increased ten-fold in 20 years to reach a level of several billion Euros.

European research cooperation needs to go deeper and wider than in the past. Only through a renewed and more intensive pooling of the research effort at European level will we be able to make the most of the opportunities; exploit new global markets; and respond to emerging societal and economic challenges. Developments in technology, in markets and in society all point towards the need for Europe to do more ICT research, to do it together, and to do it at European scale. To reach the level of our main competitors Europe must triple its investments in ICT, including the support at European level.

4. OBJECTIVES AND PRIORITIES FOR EUROPEAN ICT RESEARCH

The future offered by ICT research is wide open: we are free to move in any number of directions and pursue any number of objectives and priorities. Faced with such an unbounded landscape, it is essential for Europe to plan and prioritise. By choosing we may miss out on some areas. But by not choosing we may lose it all.

4.1 Objectives for European ICT research

Europe's R&D culture is very different to that of our major competitors. In the United States, R&D has a strong military and security rationale, an orientation that has increased further with the greater emphasis on homeland security. Defence R&D represents 55% of the total federal R&D spending, with ICT featuring high in the present R&D strategy. In Asia, spending on ICT R&D is growing rapidly and is currently focused primarily on near-term market opportunities.

Europe has to choose its own way. We need a distinctively European approach; one that plays to our strengths, enables us to seize new opportunities and recognises European specificities. Research supported at European level will be essential to back industrial and technological leadership in key fields including mobile and broadband communications, microelectronics, microsystems and consumer electronics. Mastering of ICT and its applications is also crucial to the future of major industries such as automotive, aerospace, telecommunications, manufacturing and media. And, it is central for addressing societal challenges such as those related to the ageing population and security. In addition, competition and deregulation has opened the door to a range of new players whose involvement is key for future technology development and use. As new ICT become more and more the fabric of our economy and society, Europe must ensure its independence with respect to provisioning and controlling key underpinning ICT.

European ICT research should be guided by objectives that reflect the new global reality. We have to find a balance between continuity and change. While realising the vision adopted in previous Framework Programmes, we also have to align research in a way that responds to the emerging policy and market contexts and put us in a position to exploit future opportunities. The objectives of European ICT research should be threefold:

1. **to strengthen the competitiveness of European industry***:* by building on strengths and fostering the ability to master ICT for innovation and growth.
2. **to reinforce the competitive position of the European ICT sector**, by enabling it to build industrial and technology leadership; and
3. **to support EU policies**, by mobilising ICT to meet public and societal demands.

In addition, and as a function of these three objectives, ICT research should aim **to strengthen the European science & technology base** in ICT-related fields, including the opening up to **co-operation at the international scale**. This "horizontal" objective cuts across the other three.

4.2 A focused approach: shaping the future of ICT in Europe

In pursuing these objectives, the priorities for European ICT research should follow a number of directions that reflect the global reality and challenges.

Over recent years, EU supported ICT research has focused on a new generation of ICT applications and services that are more people-centred and easier to use. It foresees a world where users - citizens, students, workers, patients - are able to access and benefit from ICT in a much more convenient way. Progress towards this vision - which has become known as "Ambient Intelligence" - has been the guiding vision of ICT research under the last two EU Framework Programmes (FP5 and FP6, 1999-2006) and has influenced ICT research orientations across Europe.

As companies and labs around the world are competing to shape this next generation, the challenge facing Europe now is to lead and accelerate the developments. In so doing, it will be necessary to strengthen the research effort and to address both hard technological problems and specific business and societal ambitions and concerns.

Progress and breakthroughs in ICT are driven by miniaturisation, by the convergence of computing, communications and media technologies, by the need to build systems that can learn and evolve, and by the cross-over between ICT and other science and technology fields.

This next wave of technologies will make systems "smaller, cheaper, and smarter" and "always best connected", and their applications even more wide ranging. It will open the door to new networked devices and systems that will enable people to interact with their surroundings and with each other in totally new ways.

In line with this, the following converging directions have been identified by the industrial and academic research community for ICT research in Europe:

- **Mastering complexity and scalability** - pioneering new approaches to cope with the "infinitely small" as well as the "very large";
- **Accelerating cross-fertilisation with other science and technology fields** - targeting major advances at the cross-over between ICT and other disciplines;
- **Building intelligent environments** – concentrating on integrated systems engineering;
- **Promoting innovation from the use of ICT in many application areas** - bringing services and technology developments closer together and including non-technological elements;
- **Supporting new research and knowledge infrastructures** - reinforcing Europe's research networking and computing infrastructures as well as shared research facilities;
- **Opening Europe further to cooperation in ICT research at the international scale** - with targeted actions specific to each domain.

4.2.1 Mastering complexity, scalability and pushing the limits of performance

Miniaturisation: Towards the" infinitely small"

As we move down to the nano-scale and further progress in the miniaturisation of CMOS[18] technology, we will need to master thermal and other effects and an unprecedented complexity in design. But we need also to prepare the post-CMOS era, notably by better exploiting synergies between a wide range of different nano-electronic solutions into more integrated platforms and by investing in breakthroughs built through (self-) assembly of molecules or even atoms into stable structures or by exploiting quantum effects;

> ***Design of one billion gate systems-on-chip***. As information appliances gain in complexity and product lives and design cycles are shortening, semiconductor design is increasingly demanding. The problem involves the design in-time and at cost, of reliable one billion gate systems-on-chip or systems-in-package. Issues include cost-efficiency, portability of products, power consumption and energy provision that need ***to be addressed as integral parts*** of the technology developments.

Through new concepts inspired from biology and neuro-science we can boost further progress in nano-assembly and bring together on single chips heterogeneous elements combining mechanical, electrical or organic characteristics. These should be able to sense, perceive and act at the micro and nano scale, and in networked environments. By building novel, neuro- and brain-like processing architectures and, through research in (meta-) materials and processes, we can design radically new computing and communication components.

Mastering networked, embedded and wireless systems, providing the broadest bandwidth

At the other end of the scale, as ICT systems and networks become ever larger and more interdependent – with computing, communication and sensing capabilities that span components, devices, networks, infrastructures and services – they are increasingly difficult to design, test, control and maintain. There is a need for composable, open and scale-free architectures to design and build modern ICT systems as well as new engineering methods for gracefully integrating and operating a large number of different heterogeneous elements. We will also need to master the complexity of such systems, to provide them with learning and gracefully evolving capabilities as well as to provide them with self-organising and other self-like properties. This will lead to more secure, robust and dependable systems and software that are optimised in terms of functionalities and resource consumption – from spectrum to power and overall costs.

> ***Converging networks and computing systems***. A broad "systems approach" to research will draw on a range of technologies and disciplines and ***involve the full value chain***. Research will have to address, at the same time, technology developments (microelectronics capabilities, radio access, networking, etc.) and services and content developments, taking account of the fact that the associated cycles of innovation, although interrelated and inter-dependent, are subject to different time constraints.

[18] CMOS is short for complementary metal oxide semiconductor, a widely used type of semiconductor.

Systems that can contextualise, learn and adapt

As an increasing amount of information is captured from the real world, in particular through sensors embedded in applications, technological challenges lie in making this information understandable to people and to machines. Systems that can interpret information are of interest because the ability to interpret enables them to act purposefully and autonomously towards achieving goals. The challenge is that interpretation depends on context. There is a need to build systems endowed with more elaborated learning, cognitive and reasoning capability, naturally interacting with the real world and us, and being (self-) adaptive to changing situations and contexts as well as to our own preferences, expertise and needs. For these, we need to develop new perception and cognition technologies.

> ***Cognitive systems***. To build information processing systems that have capabilities for perception, learning, reasoning and decision making and for communication and action requires the ***bringing together of several disciplines***, including computer science, automatic control, psychology and neuroscience. Research finds inspiration from natural cognitive systems (i.e. humans or animals) and in particular from the brain and neuro-system behaviours.

4.2.2 Accelerating cross-fertilisation with other science and technology fields

The boundaries between ICT and other disciplines are blurring and the prospects for further advances rely increasingly on the *exploration at the frontiers between ICT and other fields*. The accelerated integration of ICT with many science and technology fields is bound to be at the origin of the next revolutions in medicine, energy and many other areas.

Examples of expected breakthroughs include: ICT for advanced modelling and simulation of the living world; ICT for improvement of human health, performance and well being, by continuously monitoring our health, by augmenting human senses and capabilities through intimate sensory, cognitive and neural connections with ICT systems and later through nano-implants; by development of artificial organs, life-like cognitive artefacts, and brain to machine interfaces - and certainly many others, yet impossible to predict.

On the other hand, insights from physics, bio- and materials-sciences promise further advances in components and microsystems as they shrink to nanoscales. Equally, insights on the functioning of intelligent systems from the life-sciences are being imported into ICT systems engineering to address requirements that today's methods cannot.

In addressing these problems, and others, new technology areas – such as nanotechnologies, meta-materials, biosensors and wet interface technologies, biocomputing, cognition technologies and neuro-sciences – will "cross-over" and converge with core ICT "pillars" (processors, sensors, micro-/nano-systems etc.). In so doing they will become integral parts of today's ICT fields (nanoelectronics, ubiquitous computing and communications, interfaces etc.) and open the way to a new generation of ICT systems and applications.

Progress in these evolving core ICT technologies will require the insights of a broader set of scientific and technological disciplines to address performance requirements that conventional approaches cannot. Partnering at European level will be essential to provide the strategic direction and for pooling the necessary interdisciplinary resources.

4.2.3 Building intelligent environments

Major challenges for ICT research arise today in developing the *underlying platforms* and the *surrounding environments* that support applications and services.

With myriads of interconnected devices, we need to explore how to tap into all this computing and networking power in a way that can be adapted to different needs. To build service-oriented infrastructures that autonomously shares and manages multiple resources across customers, business units and applications is a challenge that requires further research in areas like software, Grid and knowledge technologies.

There is a need to research and develop mock-ups, test-beds and large-scale platforms for simulating, testing and validating systems. Research will address generic capabilities such as modularity, flexibility, location transparency, reliability and security, together with organisational and human issues. The focus will be on aspects such as systematic design methodologies, behavioural modelling and simulation, reconfigurability and dependability.

As ICT meets a growing set of needs, ICT research requires technologists to collaborate with a broader set of actors who better understand the social, individual, economic and organisational contexts in which ICT will be deployed.

> ***Platforms*** could instrument the environment (e.g. the home, or public spaces), instrument objects and artefacts (e.g. augmented reality, or advanced robotics), or instrument and serve the individual (e.g. body and personal environments).

4.2.4 Promoting innovation from the use of ICT in many application areas

More and more innovation comes from the *use* of ICT in a *broadening* range of application domains. For R&D in ICT this means that services and technology developments are brought closer together.

The rapid diffusion of ICT into new markets and its increasing pervasiveness means that issues associated with the effective and efficient use of ICT will increasingly come to the fore. To accelerate the uptake of ICT, it is essential to

> ***ICT for the enterprise***. 3D-digital mock-ups of complex products, modelling and simulation of product behaviour, smart wireless tags for extended products and services, adaptable software for virtual enterprises.
>
> ***ICT for health***. Modelling, simulation, data mining, visualisation and integration of biomedical information for prevention, diagnosis and treatment in health care.
>
> ***ICT for safety***. Sensor infrastructures, dependable software and robust positioning technologies for safer transport.

ensure that research is reliably and sustainably anchored in the applications. The research will need to couple technology developments much tighter to non-technological elements such as organisational processes and individual users.

European ICT research should focus on those application domains where ICT is the main innovation driver. Key domains will include: the enterprise, health and social care, and security and safety.

4.2.5 Supporting new research and knowledge infrastructures

Scientific and technological research is increasingly reliant on collaboration across electronic networks and on access to highly specialised laboratories and facilities. To compete and collaborate successfully at global level, and to attract top class researchers, the European research community must continue to have access to world class high-speed research networks and computing and knowledge grids. ICT empowers researchers by providing the communication, computing and service infrastructures as well as facilities for collaboration, knowledge sharing and experimentation.

There is also a need to support large, shared, single-site infrastructures with a European dimension offering facilities or services in specific fields of ICT, such as micro- or nano-electronics, or embedded systems. The escalating investment costs for such facilities push them beyond the level of individual Member States or market players, providing a clear imperative for action at European level. In addition, the regional dimension to science and technology becomes increasingly important, and incentives to strong local infrastructures and networks of leading industries and research institutes will help strengthen regional capabilities and establish highly innovative regions.

4.2.6 Opening European research to cooperation at the international scale

Co-operation with partners outside Europe is essential in the overall approach to R&D and innovation in ICT.

International co-operation allows European R&D projects to access the best technological know-how, skilled researchers and advanced facilities world-wide. It also facilitates activities in support of global standards and interoperability. In addition, international co-operation helps strengthen business co-operation with a view to developing systems and services that best fit local markets and needs, and to open new markets through the promotion of European solutions. Finally, co-operation with non-European partners enables more effective support to other Community policies, in particular industrial, external relations and development aid policies.

A strategy for international co-operation needs to be devised on a domain-by-domain basis, taking account of the characteristics of the domain and the third country or region being addressed.

5. CONCLUSIONS

Information and Communication Technologies occupy a unique and increasing role in today's economy and society. They are the key to improving productivity; they are central to mastering innovation; and they are essential to modernising public services. If innovation is the engine of the knowledge economy, then ICT are its fuel. Europe has no choice but to be a player in these strategic technologies.

The technologies we see around us today will not be enough to ensure we remain competitive tomorrow. Nor is it the case that all avenues are closed to us. On the contrary, new opportunities are emerging, many in areas where Europe already enjoys industrial and technological leadership.

We have to act now for the longer term through a concerted effort in ICT research, development, innovation and deployment:

- We have to **compete in science** to improve excellence and build the foundations for future innovations and wealth;
- We have to **co-operate in technology** to address the increasing technological complexity and face growing global competition;
- We have to **deploy the resulting innovations** so as to maximise returns from our investment: by generating growth and meeting societal demands.

The future prosperity of the European economy and well being of European society depend on investment in ICT research. Business strategies, market dynamics and technology chains all point towards this research being best undertaken at European level.

ANNEX I: PARTNERING IN ICT RESEARCH – A EUROPEAN SUCCESS STORY

Digital mobile communications – a great success story

Early EU investment in digital mobile communications enabled the development and world-wide adoption of the GSM[19] standard, generating revenues of more than 100 billion euros for Europe's industry in 2003 alone. The deployment of high speed mobile and wireless communication systems will offer the next window of opportunities for productivity growth fostered by the widespread uptake of mobile broadband services.

Affordable Broadband Technology

The role-out of the new generation of broadband data networks in Europe has been largely based on DWDM[20] optical fibre network technology and low-cost ADSL[21] access modems. European equipment manufacturers have played a leading role in the development and commercialisation of these key communication technologies, which have been supported through European level collaborative research.

Major European electronics poles

The significant spin-off benefits of having semiconductor manufacturers in Europe are apparent from experiences in microelectronic poles such as Dresden in Germany (more than 15000 jobs created at 30 semiconductor-related plants) and Grenoble/Crolles in France (4500 direct and 9500 indirect jobs created to date). These poles offer local employment directly and indirectly in their equipment and material suppliers and ensure secure 'local' sourcing in Europe for systems suppliers. Specialist electronics centres have also developed, such as around the IMEC research centre in Leuven in Belgium.

User-friendly home platform solutions

Early European support also played a crucial role in establishing the DVB[22] standard for digital television. Through a concerted research effort, combined with a light regulatory framework, broadcasters have embraced these Digital TV (DTV) standards, not just in Europe but all over the world. European DTV services already reach millions of households, who enjoy not just television but a whole range of innovative services such as home banking, interactive advertising and internet.

[19] GSM: Global System for Mobile Communications, one of the leading digital cellular systems
[20] DWDM: Dense Wavelength Division Multiplexing, an optical technology used to increase bandwidth over existing fibre optic backbones
[21] ADSL: Asymmetric Digital Subscriber Line, a technology that allows more data to be sent over existing copper telephone lines
[22] DVB: Digital Video Broadcasting

ANNEX II: EU RESEARCH SUPPORT MECHANISMS

In its Communication of 16 June 2004 the Commission has proposed orientations for the development of future EU programmes to support research activities and policies[23]. They imply a significant expansion of the EU research budget for the period 2007-2013. Six major support mechanisms are identified: collaborative research; Technology Platforms; research infrastructures; fundamental research through individual grants; co-ordination of national and regional research; and human resources. Two essential transversal issues cut across these measures: innovation and international co-operation.

The main weight of support for ICT research at European level is likely to be through collaborative research and Technology Platforms. Support for research infrastructures will also be a priority measure. These will be complemented by horizontal measures to support fundamental research, co-ordination of research policies, and development of human resources.

Collaborative research

Collaborative ICT research should address those areas where there are strong prospects for radical innovation, technology breakthroughs and large-scale societal benefits. It should pursue research in a number of core ICT technologies and, at the same time, explore the frontiers with other S&T fields. With industry as a key stakeholder, the research effort should establish strong European "poles of excellence", including both industrial and academic labs, and mobilise an internationally significant concentration of resources. A continuing focus on excellence, longer-term and higher-risk research will require minimising competing constraints such as geographical balance.

Technology Platforms

Technology Platforms should bring together public and private stakeholders in pan-European partnerships for technological research. This top-down collaborative ICT research is based on common research agendas and technology roadmaps established and agreed by the main stakeholders. The Technology Platforms should help draw further investment from industry and bring together funding sources to achieve shared goals and improved impact.

Research infrastructures

In ICT-related research fields there is a need to support different types of research infrastructures: (i) The upgrade of and the wide access to trans-national communications, computing and services infrastructures by all the research communities, (ii) The European-wide access to and use of large, single-site infrastructures, and (iii) The establishment of trans-national/trans-regional "Centres of Competence/Excellence" and multi-site integrated test facilities.

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[23] "Science and technology, the key to Europe's future – Guidelines for future European Union policy to support research", COM(2004)353 of 16.06.2004

Coordination of national and regional research

Co-ordination of research policies across European, regional and national levels, including the networking of existing efforts and programmes, should aim to further enhance the efficiency and effectiveness of the European research system. The targets should go beyond the re-structuring or re-orientation of existing fields or initiatives towards the development of common visions and the creation of new fields, new capabilities and new joint initiatives. Stronger policy links should be established with the ICT cluster projects within the EUREKA framework as an additional instrument to channel national funding towards relevant initiatives, in particular to address downstream market-oriented developments.

Fundamental research through individual grants

Bottom-up fundamental ICT research should support curiosity-driven research without direct links to any particular technology or application. Much of the research will be of an interdisciplinary nature and a part should be dedicated to support research at the crossroads between different science and technology areas. A significant proportion should be directed to basic research areas relevant for ICT.

Human resources

The skills and capabilities of scientists and engineers are central to the competitiveness of European ICT research and its ICT industry. Actions should aim to develop human resources in research and technology, by supporting training, helping remove obstacles to pan-European scientific careers, and promoting researchers' transnational mobility. There should also be a greater focus on exchanges of researchers between the public and the private sector.

International co-operation

International co-operation is an essential transversal issue in the overall approach to research in ICT. Such cooperation has more than one goal: (i) To enable access by European projects to the best knowledge, skills, technology and facilities available in the world, and (ii) To support other Community policies, in particular industrial, external relations and development aid policies. More than one mechanism is needed to achieve these goals: (i) International cooperation as an integral element of the activities of each thematic priority field, and (ii) Activities dedicated to promote EU ideas and interests in other regions in the world considered as strategic.

Innovation

Innovation is also an essential transversal issue. It is a multi-dimensional concept which goes beyond technological innovation to encompass, for example, innovation in services, organisational or business models. Policy initiatives play a crucial role in helping to create the conditions in which firms can boost Europe's competitiveness and growth.