
European Commission
net-tech
future
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communication
internet
networks
access
architecture
generation
Future internet, batteries included
Precision dance of ring-based networks
Towards the internet of the "what"
things
efficiency
Digital Agenda Europe

net-tech *future*

Published by

The European Commission's CONNECT-Communication Networks, Content and Technology Directorate-General

Unit E1- Network Technologies

ISBN 978-92-79-25364-5

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FOREWORD

Welcome to the first edition of *Net-Tech Future*, which features some of the most eye-catching and important results in communication networks research coming out of EU research programmes funded by the European Commission.

We make every effort to address and enable a broader understanding, beyond the specialist research community, on how communication networks science and technology can have a valuable impact on the EU economy and society, both now and in the future.

We are devoted to communicating science and technology to a wider audience. We are aware that you – as concerned citizens as well as industry watchers – are more than curious about European research efforts and science in general. We understand from the latest EU 'Science and Technology' special Eurobarometer report that you want researchers and engineers to put more effort into communicating their work and you believe that governments and public authorities should do more to interest the general public and young people in particular in scientific and technological issues.

Net-Tech Future is our concrete response to all this. We showcase European research breakthroughs, emphasising the crucial role of network communications technologies in daily lives, at home, at work and on the move. We would like to be the communication channel and the meeting point for the people and communities whose dedication makes these discoveries and progress possible.

We are confident that European research and actions will deliver the next generation of network technologies enabling smart connectivity for all, anywhere, any time, and at the highest speed and efficiency to meet society's overwhelming demand both today and in the future, as communications technology becomes the core infrastructure of the 21st century.

We hope you enjoy reading this inaugural issue of *Net-Tech Future*! With your support and ideas for subsequent issues we very much hope it will become a regular and popular addition to the stable of European research and technology publications.

Luis Rodriguez-Rosello
Head of Unit Network Technologies

NET-TECH FUTURE INSIGHTS

We never had it better as devices get smaller, faster, more efficient and, arguably, 'smarter' every day. But these prized developments rarely happen by chance. Behind every new internet app, gadget, or boost in networking performance lies weeks, months and even years of research and technological development.

Net-Tech Future is all about technologies that put ultrafast internet connectivity at your fingertips. It sheds light on how communications technologies are shaping the future networks landscape, from developments in ultrafast broadband internet to clever mobile networks, from network infrastructure and architecture to green technologies. And with each EU-funded project that we showcase, we will give you a glimpse not only of the 'what' but a little of the 'how' and 'why', and even 'what next' so you can see how these developments can make a difference to you, your organisation and your community.

ICT, FUTURE NETWORKS AND THE FUTURE INTERNET – A EUROPEAN PERSPECTIVE

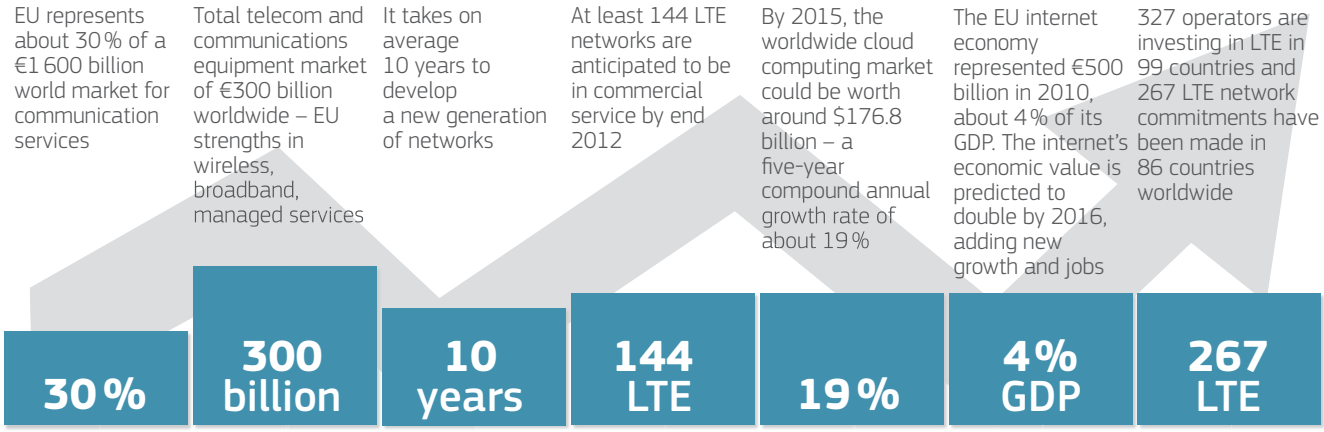
THE MISSION: WHAT LIES BEYOND

Directorate E, the 'NET Futures' activity of the European Commission's DG Connect, focuses on what lies beyond the current internet architecture, software and services. NET Futures pursues policies, strategies, roadmaps and measures to stimulate cloud development in Europe and foster innovation and growth in the ICT industry.

The 'Network technologies' Unit (E1) supports research activities on wireless, optical and satellite communication technologies able to meet expected network traffic in the future internet. Specifically, the aim is to:

- reinforce European know-how and leadership in ultra-fast broadband access and core networks based on infrastructure able to support a 1000-fold growth in traffic by 2020;
- develop European industrial leadership on networks and architectures capable of supporting novel internet usage and innovative applications like information-centric content, distributed computing, machine-to-machine communication, and the internet of things; and
- reinforce industrial, academic and SME partnerships to develop and test sustainable network technologies that are ultrafast, low-power, low-energy, low-radiation, and make the most efficient use of spectrum.

MARKETS AND TRENDS



TRAFFIC AND SPEED

50 %
Internet traffic is increasing by 50% every year

2/3rd
Two-thirds of the world's mobile data traffic will be video by 2015

x100
Mobile internet traffic is expected to increase several hundred-fold between 2010 and 2020

100 Mbps
Recent EU research shows that new optical access architectures can serve 100 Mbps to a 1 000 users at distances of 100 km

62 %
Mobile internet take-up grew by 62 % to 217 million mobile broadband subscriptions

2015
Mobile-connected traffic from tablets will generate as much traffic in 2015 as the entire global mobile network did in 2010

AND
EU research is contributing to the next generation of LTE Advanced and beyond

CONNECTIONS AND JOBS

95% of Europeans have access to a fixed broadband connection

Communication networks enable other strategic EU areas, such as healthcare, transport, security, space, energy and environment policies

15 million Europeans connected to the internet for the first time in 2011

ICT sector now accounts for 7 million jobs and 6% of EU GDP

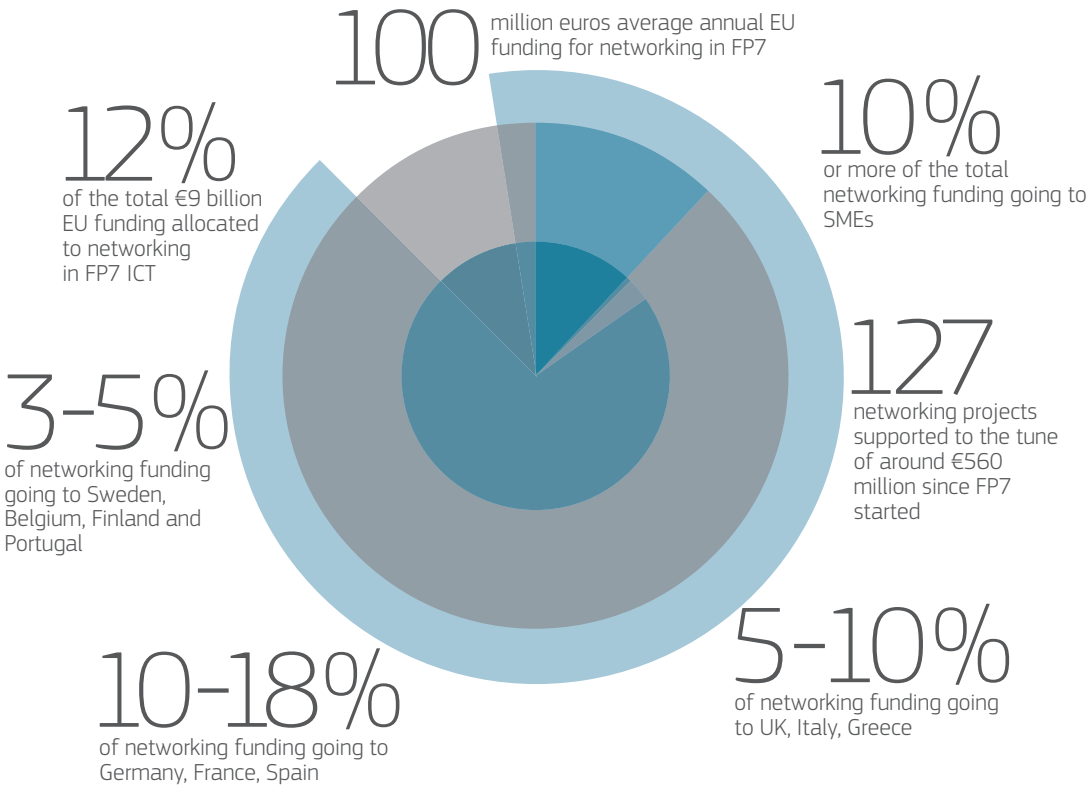
Multi-billion-euro world markets are available for ICT. Europe is home to the world-leading industries, a vibrant SME sector with a range of inward investors and a world-class academic sector

Studies published at the G7 Internet event in 2011 indicate that for every job lost 2.6 new ones are created thanks to ICT

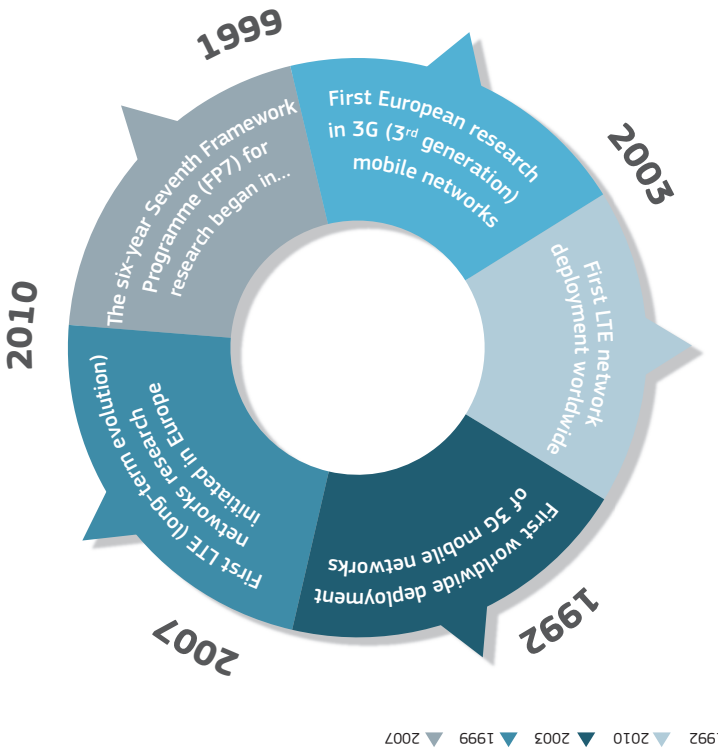
68% of Europeans go online regularly and 170 million are on social networks

Major international ICT companies have an R&D presence in Europe, attracted by leading academic centres, and Europe's critical mass of industry, markets, innovation and standards bodies

NETWORKING R&D IN NUMBERS



MATCH THE YEAR AND MILESTONE



EUROPEAN NETWORKS RESEARCH PROGRAMMES

Future networks are ICT's cogs and gears ... core infrastructure connecting the future internet of people, content, clouds and things, helping the European Union meet its Digital Agenda targets. EU research and initiatives must carve a clear trail supporting the development of future broadband (fixed and mobile) networks which will be energy-efficient, secure, and robust, and will use spectrum flexibly and efficiently.

How to achieve this?

In its 2013 work programme, of the EU FP7 Research Programme, the 'Future Networks' funding objective has set five technology priorities to meet the demands of the future internet:

a) Next-generation heterogeneous wireless and mobile broadband systems, based on flexible spectrum usage and reduced EMF and interference.	€48.5m*
b) High throughput, low-latency infrastructures, based on dynamic all-optical networks and hybrid wireless and cable networks.	IPs (min. 50%)
c) Internet architectures enabling innovation in network virtualisation, specifically through programmability of network functions and protocols.	
d) Tighter integration of satellite and terrestrial communications technologies, as a critical infrastructure, in particular for public safety/security applications.	STREPs (min. 30%)
e) Coordination and support actions for (re)structuring the research effort in the sector.	CSAs (€2m)

* Call: FP7-ICT-2013-11 (opening on 18/09/2012, closing on 16/04/2013 http://ec.europa.eu/research/participants/portal/page/cooperation#ict)

SMART NETWORKS: FAST, MOBILE AND GREEN

EUROPE'S MOBILE MILESTONES: STAY TUNED FOR MORE TO COME!

Did you know that many of the basic concepts and technologies used in current third-generation (3G) 'universal mobile telecoms system' (UMTS) standards and the newer 'long-term evolution' (LTE) standard had their origins in Framework Programme collaborative research projects, co-funded by the European Union? Well they did, and Europe should be proud of this foresighted investment in future communications networks.

Not only does it stimulate scientific endeavour and important industrial leadership, but when the conditions are right it gives a valuable boost to the economy in the form of job creation, product development and export earnings. That's good for everyone. Collaborative research provides the opportunity to quickly exploit research results through standardisation, leading to the global deployment of new ICT systems.

The information and communication technologies (ICT) sector now generates 6 % of European GDP, with an annual value of €660 billion. ICT has become a ubiquitous technology and investments in ICT are responsible for at least 50 % of European productivity growth in recent years.

The growth of mobile communications, in particular, since the launch of the GSM system on the market in 1992, has been phenomenal. Mobile communications have changed people's lives for the better the world over by enabling people to communicate anytime and anywhere. Mobile communication drives productivity, growth and economic performance across all sectors of the economy and is expected to continue to do so for many years to come, as we move more and more from e-commerce towards mobile- or m-commerce on the back of the predicted growth in the smart phone market and expected further roll-out of ultrafast wireless broadband for mobile users.

We can already see a dramatic increase in data traffic on converged mobile and fixed communications networks generated by smart city, smart energy, environmental monitoring and ehealth applications. By 2020, enormous growth in network traffic is expected. Continued investment in collaborative research will no doubt keep Europe at the forefront of mobile communications developments.

1992

GSM was commercially introduced in 1992. EU pooled R&D, industry and political will to provide mobile phone users with what would become a mobile standard covering 85 % of the world's land area.

2001

EU-backed R&D drove progress towards **3G UMTS** (introduced in 2001), making modern broadband multimedia mobile communications possible, including voice and video services and mobile internet.

2010

EU-supported R&D contributed to the **LTE system** (introduced in 2010) wich provides high-speed mobile broadband connectivity, including cloud services to today's laptops, smart phones, tablet PCs and other mobile devices.

20XX

European know-how is driving national broadband and 'future internet' progress, especially the internet of services and things (M2M communication), and energy-saving 'green technology' trends. **Stay tuned!**

Source: Net!Works

Future Networks and Mobile Summit (4-6 July)
If you weren't at the event in Berlin, it's your loss. Building on strong tradition, the Summit reached a peak of interest this year, as delegates and exhibitors witnessed something of a convergence of two decades of work; where the mobile guys can finally sit down as equals to the fixed networks guys and say, "let's get beyond bandwidth obsessions and start talking about what we do with it anywhere, anytime. Don't miss the 2013 edition to learn how green, lean, ultrafast, anywhere networking will change the way you do business.
www.futurenetworksummit.eu

Net!Works Video Blog
Net!Works, through the eMobility NetWorld project, supported the Future Network and Mobile Summit 2012 and published a series of video blog clips during the event. Please go to http://www.networks-etp.eu/ to view short interviews with speakers and participants.

UNLEASHING ULTRAFAST INTERNET FOR EVERYONE

European researchers have developed technology that can cost-effectively deliver more than one gigabit per second (Gbps) both to your front door and within the home network. And that's just the start, they say.

Gigabit-speed access for end-user tends to be the preserve of countries with advanced national broadband network programmes. But European scientists set out to change that, making it easier for all countries to set up ultrafast access networks without breaking the bank or turning cities into building sites.

Researchers in the 'Architectures for flexible photonic home and access' (ALPHA) project developed technology that can affordably deliver in excess of 1 Gbps both to your front door and within existing home networks – with ten times more than that technically possible but currently not feasible for the market.

That is much faster than currently called for in most national broadband plans. The extra speed, say the ALPHA team, is required for emerging data applications and developments in upcoming ultra-high-definition TV (4K and 8K) and video on demand, next-generation content delivery platforms, augmented reality and gaming, as well public services solutions behind future 'smart cities'.

Europe's Digital Agenda has set its sights at a fraction of that speed, seeking broadband of 30 Mbps for everyone by 2020 with half of European households subscribing to connections of 100 Mbps or higher. This modest ambition acknowledges the magnitude of the task, but with new developments the bar could be set higher.

"EU broadband targets are based on today's networking paradigms," says Mikhail Popov, ALPHA coordinator and technical manager. "But we're working on technology to meet demand for lightning-fast internet for smart cities and citizens of tomorrow, and beyond."

The European Commission has announced a €9 billion-plus broadband investment scheme to tackle this complex but important vehicle for sustainable, smart and inclusive growth. It says more needs to be done to cut the costs of setting up new networks for high-speed internet and to encourage more public-private investment in broadband, including projects to develop national broadband networks.

WHAT IT TAKES TO GET THE JOB DONE

There are dozens of technologies and enabling systems all along the broadband pipe, from core- and metro-area networks to in-home outlets. According to the team, each enabling technology has several – potentially contending – technical solutions, each with their own advantages and disadvantages. And those solutions are all evolving rapidly.

For example, take active and passive optical networks (AON and PON) which are the physical heart of ALPHA's work. AONs use electrically-powered switching to manage signal distribution, while PONs use optical splitters. PONs are efficient and reliable due to a simple passive-only fibre infrastructure in the field, but they have a lower range than AONs and require somewhat more complex equipment. Data transmissions can also slow down during peak load, because bandwidth is not dedicated to individual subscribers, but split among a number of them.

AONs rely on Ethernet technology, which makes interoperability among vendors easier to achieve. Subscribers can select hardware that delivers an appropriate data transmission rate and scale up as needed without having to restructure the network. But AON deployment can be more costly than PONs.

Then there is the optical fibre itself, with a choice between glass single-mode, glass multi-mode and plastic, each with its own advantages. There are routers, switches, multiplexers, amplifiers and dozens of elements that handle bandwidth from the backbone to end-user, each with their set of constraints and demands. What's more, all the work has to meet European and international standards and norms.

"The EU's Digital Agenda broadband targets are based on today's networking paradigms. But we're working on technology to meet demand for lightning-fast internet for smart cities and citizens of tomorrow, and beyond."

FAST, GREEN AND SMART SOLUTIONS

Despite these challenges, ALPHA was able to dislodge some bottlenecks in the access network – which delivers broadband to the front door – and in building networks for the home and office. Further, the team defined new network models and standards to deliver blistering speeds at the lowest possible cost and with the most logical upgrade path. The work included test beds and validations to demonstrate that the ALPHA proposals can cope with massively rising bandwidth requirements.

In particular, the ALPHA team developed a hybrid multiplexing system, delivering 10 Gbps over a PON as well as solutions assuring quality of service in Ethernet-based optical access networks for supplying broadband connections to the home or office. The PON solution even supports radio-over-fibre, a technology for handling the support of mobile broadband in wired networks.

For home networks, ALPHA promoted the use of a polymer optical fibre, resembling a thicker fishing line, for retrofit installation inside the houses. The team developed a commercial prototype of a gigabit transceiver which boosted the performance of this type of fibre from 100 Mbps to a vastly fatter and thicker broadband pipe of 1 Gbps .

Today, gigabit broadband is realistically achievable in very few places. But thanks to the architecture and transmission solutions developed by ALPHA, it will be easier for networks to be upgraded to these levels within the EU 2020 deadline. In all, ALPHA's work led to nine patent applications, over 300 scientific papers, including a joint White Paper on next-generation home networks together with the EU-funded OMEGA project (see page 20), and made significant contributions to standardisation efforts.

But the work doesn't stop with ALPHA, according to Dr Popov: "To meet growing demand, new solutions, focusing on cost- and energy-efficiency, are going to be needed to generate higher speeds of up to 10 Gbps peak for potentially thousands of users per feeder, and with greater penetration – up to 100 km."

Meanwhile, he predicts, smart cities of tomorrow will demand fast and green home networking with smooth transitions to mobile broadband services and platforms underpinning the future internet.

That is really unleashing ultrafast internet for everyone!

'Architectures for flexible photonic home and access' (ALPHA) *www.ict-alpha.eu.*

More info: ALPHA project was funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

THE FUTURE INTERNET, BATTERIES INCLUDED

High-quality mobile multimedia content is energy-hungry, and battery technology is struggling to keep up. Boosting the energy efficiency of portable wireless devices will not only improve everyone's online experience but is also good for the planet.

There was a time when connecting to the internet meant being tethered to a desk and chained down by cables. Recent advances in wireless and mobile technology have meant that users are able not only to surf the online world virtually but they can do it on the move through a plethora of portable devices, including laptops, smart phones and tablets. Moreover, mobile and wireless users are increasingly using broadband to access heavy multimedia content.

Though this shift has been enabled by the incredible progress in the miniaturisation of technology that has occurred, one major constraint is the increased energy requirements of portable devices and the relative inability of battery technology to keep pace. And this challenge is likely to grow more acute with time, as future applications become even more energy-hungry.

Greater data consumption and a shift to mobile technologies (such as smart phones) and mobile services (such as 3G internet, music streaming and webmail) are the most significant trends in the ICT sector.

"The future internet seeks to create a system of wireless networks delivering to end-users a plethora of multi-content services over an internet highway," explains Dr Jonathan Rodriguez, senior research engineer at Portugal's Instituto de Telecomunicações. "However, a key concern from the end-user's perspective is the battery lifetime of the devices and operational time has been identified as the number one criteria by the majority of the consumers purchasing a mobile device."

In fact, Dr Rodriguez notes that fear of running out of power or accelerating the dissipation of the battery is one major reason behind user reticence to access advanced multimedia services more often.

What's more, the growing demand for juice is not just an individual concern but is becoming a global environmental worry. According to Dr Rodriguez, the entire ICT sector currently accounts for only about 2 % of the world's CO_2 emissions, which is roughly equivalent to aviation. "In this so called 'green society', energy consumption has now become an important design metric for wireless systems," he points out.

However, this figure is set to skyrocket as more people access the web wirelessly. Global mobile subscriptions are estimated to reach 6 billion by 2014 to cross the 7 billion mark by 2015 and reach almost full parity with the global population. And according to CISCO, global mobile data traffic grew more than twofold in 2011 – more than doubling for the fourth year in a row – and will expand a massive 18-fold in the five years between 2011 and 2016.

ESCAPING THE "ENERGY TRAP"

These statistics highlight the urgent need to improve not only battery performance but also the energy efficiency of mobile and wireless devices. Not acting can lead us to fall prey to the "energy trap", or the gap between what battery technology can deliver and the expected growth in power requirements of future devices.

Towards that end, Dr Rodriguez coordinates the three-year, EU-backed project 'Cognitive radio and cooperation strategies for power saving in multi-standard wireless device' (C2Power). "To avoid the foreseen 'energy trap' and to free users from their dependence on the nearest power socket and enable them to enjoy a truly mobile experience, C2Power is developing technology to make mobile phones lean in terms of energy consumption," he states.

With €3.45 million in EU funding, C2Power – whose partners include academia, private research bodies and telecom operators – is focusing its efforts on two complementary approaches to improving the energy efficiency of handsets. The first are cooperative technologies which allow nearby devices to work together to find the most efficient way to access the web. The second approach employs cognitive technologies built into the device which allow it to make smart decisions about which network to connect to, and how.

"These two technologies, exploited in tandem, will allow the mobile network to exploit available energy gains, leading to devices that are energy efficient, thereby increasing battery lifetime," notes Dr Rodriguez. C2Power estimates that the energy savings could amount to as much as 50 %.

Two years in, the project has already achieved significant results, including demonstrating how collaborative clusters can improve energy efficiency, employing game theory to choose the most energy-efficient cluster, as well as developing methods for intelligent network and node scanning.

PAINTING EUROPE GREEN

C2Power's technology has wide applications in the commercial handset market. Over and above this, industrial partners in the consortium are working to develop a new line of efficient multi-mode handsets, including commercial 'long-term evolution' (LTE), for public safety agencies, while academic partners will exploit the acquired know-how to train the next generation of engineers and researchers.

"The future internet seeks to create a system of wireless networks delivering to end-users a plethora of multi-content services over an internet highway… However, a key concern from the end-user's perspective is the battery lifetime."

C2Power is one of a number of EU-funded projects which seek to boost the energy efficiency of future networks. This 'green cluster' also includes EARTH (see related story). "While C2Power targets energy saving on the part of the actual devices, EARTH is the only major international research project that considers energy-saving on the network side."

In Dr Rodriguez's view, this is a clear illustration of the kind of socio-economic value EU-funded collaborative research can create. "I think the EU has a critical role to play in shaping research towards future networks, which don't always focus enough on the needs of citizens and the environment," he asserts. "Thanks to EU intervention, mainstream research has shifted from a market-driven road map towards preparing EU citizens and industry for tomorrow's world."

'Cognitive radio and cooperation strategies for power saving in multi-standard wireless device' (C2Power)
http://www.ict-c2power.eu
More info: C2Power is a Specific Targeted Research Project (STREP) funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

THE FUTURE INTERNET'S FRIENDS OF THE EARTH

As we move towards an unplugged, wireless society, the energy consumption of the internet's infrastructure is set to skyrocket, but urgent action is being taken to bring it down to Earth.

In the space of a couple of generations, Europe has gone from a situation in which computers were relatively rare and expensive to the ubiquitous proliferation of information and communications technology (ICT) in today's 'wired society', with powerful computing technology built into hundreds of millions of desktops, laptops, phones, handheld devices and tablets.

This fast-paced progress has come at a cost, rapidly spiralling energy consumption, with the associated economic and environmental price tag this involves. Although computer technology has generally become more efficient in terms of the energy required to process a given amount of data, our insatiable hunger for data-rich content means that the ICT sector currently represents some 8 % of the EU's electricity consumption and almost 2 % of its carbon footprint, according to a recent Europe-wide study.

Now we stand on the cusp of a new revolution in which the wired society is being rapidly transformed into a wireless one, especially as the fourth generation (4G) of ultra-broadband mobile devices penetrates the market. A reflection of this new reality is the fact that, internationally, mobile broadband subscriptions passed the one billion mark last year, while hundreds of millions more are accessing the web through local WiFi connections. In fact, it is projected that wireless internet traffic, which is set to grow tenfold by 2015, will exceed traffic from fixed networks in the same year.

This growth in power-hungry wireless traffic is set to lead to a massive upsurge in the ICT sector's energy consumption, particularly by telecoms networks, unless urgent action is taken. "Access to the future internet will be dominated by wireless devices," explains Mr Dietrich Zeller of Alcatel Lucent's Bell Laboratories in Germany. "The resulting explosive traffic growth challenges the sustainability of mobile networks."

PUTTING THE ENERGY INTO SYNERGY

Advances in technology and the right innovations can ensure that the unplugged internet of the future delivers more versatility for less energy. It is with this notion in mind that the EU-backed 'Energy aware radio and network technologies' (EARTH) project embarked on a 30-month endeavour to reduce by half the power consumption of next-generation mobile broadband networks.

"When we kicked off the EARTH project two years ago with the ambitious goal of reducing the power consumption of mobile networks by 50 % we could not be sure that we would be able to reach this goal," says Mr Zeller who coordinates this collaborative research endeavour, which has received €9.5 million in EU funding. "Now, 30 months later, we can state categorically that we have surpassed all expectations. EARTH has provided hardware, network management and deployment solutions for mobile infrastructure, yielding together more than 70 % energy savings."

EARTH has focused its efforts on providing integrated solutions, both at the level of individual components and the network as a whole. It has developed techniques to boost the energy efficiency of the vital 4G base stations – which are the most energy-intensive components of a mobile network. The project set up an Energy Efficiency Evaluation Framework (E^3F) that assesses the consumption and energy efficiency of a network, modelling an individual base station's power consumption as a function of load and radio conditions, which it then maps on to an overview of different deployment areas. "EARTH's methodology for quantitative analysis of energy consumptions is being adopted by other research initiatives and is having an impact on standardisation," asserts Mr Zeller.

The EU EARTH project won the Future Internet Award at the Future Internet Assembly in Aalborg for developing unprecedented energy efficiency solutions for wireless communication networks. The project found solutions to optimise the energy use of 4G/LTE (long-term evolution) base stations, which account for the highest energy consumption in the mobile network.

European Commission Vice President Neelie Kroes said: "The ICT sector is growing but its carbon footprint should not follow. I congratulate the partners of the EARTH project who have found ways to deliver the services we need while reducing CO_2 emissions and cutting down on energy bills."
www.future-internet.eu

"We have surpassed all expectations. EARTH has provided hardware, network management and deployment solutions for mobile infrastructure, yielding together more than 70 % energy savings."

For its savings, EARTH exploits the fact that traffic demand differs in terms of time and place and then adapts the network and radio interface (e.g. bandwidth) – and thus energy efficiency – to the required traffic load in any given location following the changes over time.

AWARD-WINNING FLAGSHIP

The challenges EARTH addresses are common European ones and, for that reason, the project pursued a collaborative EU approach in developing its solutions. The consortium brings together 15 partners from 10 Member States, including key industry players – such as Alcatel-Lucent (DE), Ericsson (SE) and Telecom Italia (IT) – and leading academic institutes, including the University of Surrey (UK) and the Technical University of Dresden (DE).

"The EARTH consortium is a role model for cooperation for open innovation," notes Mr Zeller. "The high impact of the project was made possible only through the credibility of such a strong group of key stakeholders, speaking with one voice and coming up with solutions integrating the work of the different partners."

This recognition of EARTH as a "flagship project" is reflected in the fact that it has won a prestigious Future Internet Award whose expert jury described the project as having a "strong scientific and technological impact".

For EARTH's partners, cooperation was not just confined to within the consortium but extended far beyond. It is involved with other EU-backed projects focusing on the energy efficiency and sustainability of the future internet, known as the 'green cluster', including C2Power (see related story), ECONET and TREND.

Moreover, EARTH's solutions are already on their way to seeing the light of day. Key components of the EARTH system have been integrated into hardware and software prototypes which are undergoing validation testing at Telecom Italia's test plant in Turin.

'Energy aware radio and network technologies' (EARTH)
http://www.ict-earth.eu/
More info: EARTH is an Integrated Project (IP) funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

MAKING SURE THE INTERNET REMAINS OPEN FOR BUSINESS

The internet is growing rapidly and many new types of devices are being added to it all the time. The future internet, an internet of things and objects – both living and inanimate – will soon outstrip the internet of today. And that trend will continue apace, according to experts. But how can the internet cope with this expanding traffic and purpose? European researchers have come up with nifty solutions to manage this shared network of the future with all the competing demands.

The internet is much more than simply a communication system, it is now the backbone of modern society. European future networks activities will ensure that society's backbone does not break under the strain of constantly rising demand for bandwidth and services. EU-funded research projects are testing new networking solutions which should enable the internet to evolve and adapt over time.

Take, for example, the large EU-funded project called Trilogy, which set out to "re-architect the internet" and develop new technologies to support the emerging future internet. It is vitally important work which is why Trilogy attracted leading players in the field, including the project leader BT Innovate & Design group, as well as NEC Europe, Roke Manor Research and University College London, all in the UK.

The consortium also included world-renowned groups, such as Nokia (FI), Eurescom and Deutsche Telekom (DE), along with the Université Catholique de Louvain (BE), Universidad Carlos III de Madrid (ES), the Athens University of Economics and Business (HE) and Stanford Law School (US).

Trilogy studied problems with current internet standards, particularly the 'transmission control protocol' (TCP) conceived by Vint Cerf and Bob Kahn back in 1974. It is a remarkably efficient protocol that has performed well as the internet has mushroomed. But it could be better, and this was a central focus of Trilogy's work.

A FINE LINE

But any new internet developments must walk a fine line, according to the project. Anybody who wants to create protocols for the internet must make sure that their innovation does not create technological dead ends down the road. So, Trilogy researchers developed multipath TCP (MPTCP), a protocol that allows a regular TCP connection to use multiple paths at the same time. This boosts the resilience of the network, because the connection works even if one path fails. The protocol also leads to greater network efficiency by pooling resources; data is sent over several paths simultaneously, and the sender rapidly adapts, sending more of the traffic over the emptier paths and less over paths that are congested.

Multipath TCP could be deployed to enable much better data mobility that adapts to a receiver's location, regardless of the network. For example, MPTCP could start to download a film over 3G or 4G and then draw on WiFi capacity when the user is in range of a hotspot.

As part of the MPTCP work, Trilogy developed a congestion control algorithm that balances traffic between multiple paths, moving data transmission away from congested paths to exploit unused capacity elsewhere. And the team came up with a so-called 'congestion exposure' (CONEX) protocol that lets all IP devices along a path see the total, end-to-end (E2E) level of congestion. CONEX provides more detailed information to help operators deal with bandwidthmanagement.

Congestion exposure also helps end-users; their operating system can optimise E2E quality-of-service – during a period of heavy congestion, for example, the user's videoconferencing could continue at full rate while a file downloading could be paused, optimising the available resources.

Trilogy's work also provided support for the transition 'internet protocol version 4' (IPv4) to IPv6, which is an important step for the future internet because the number of available IPv4 addresses – believed in 1974 when they were first assigned to be an "endless" supply – is running out, based on demand trends.

Trilogy, which received €5.82 million (of €9.82 million total budget) in research funding under the EU's Seventh Framework Programme (FP7), placed particular emphasis on the definition and development of standards, and the team has been very active within the Internet Engineering Task Force (IETF), the body that standardises internet technologies.

The Trilogy project carefully considered how to deploy the protocols it developed, so they can be adopted incrementally. To this end, it developed a Linux implementation of the Multipath TCP protocol which it hopes will form part of the Linux kernel. The project was instrumental in the foundation of two new working groups at the IETF focusing on MPTCP and CONEX.

'Architecting the future internet' (Trilogy)
http://trilogy-project.org/

Congratulations to Professor Mark Handley for receiving the 2012 IEEE Internet Award and his outstanding contributions to internet developments!

Professor Mark Handley, whose research team from UCL Computer Science was involved in the EU Trilogy project, has won the 2012 IEEE Internet Award for his contributions to internet multicast, telephony, congestion control and the shaping of open internet standards and open-source systems in all these areas. The Institute of Electrical and Electronics Engineers (*www.ieee.org*) is the world's largest technical professional association for the advancement of technology.
Trilogy project developed a long-term solution to internet traffic congestion and received the Future Internet Award during FIA Poznan (PL) for its contribution to internet architecture and protocols leading to faster, more reliable connections.
www.fi-poznan.eu

IT'S NO OPTICAL ILLUSION – BETTER NETWORKS

OPTICAL BRILLIANCE… IT DOESN'T HAPPEN OVERNIGHT

Like a fishing line is invisible to an unsuspecting fish, optical networks are the hidden lifeline of today's optical networks, transporting some 90 % of Europe's data traffic. And as demand rises for 'thicker fishing line' capable of carrying ever-more traffic at ever-increasing speeds, the role of fibre-optics looks certain to grow. As, too, the importance of advanced research into better, greener, faster networks fit for the future internet.

European research Framework Programmes have played a pivotal role in developing several generations of optical networks over the last 25 years. This kind of optical brilliance doesn't happen in a year or even five years. It takes consistent funding and dedicated teams.

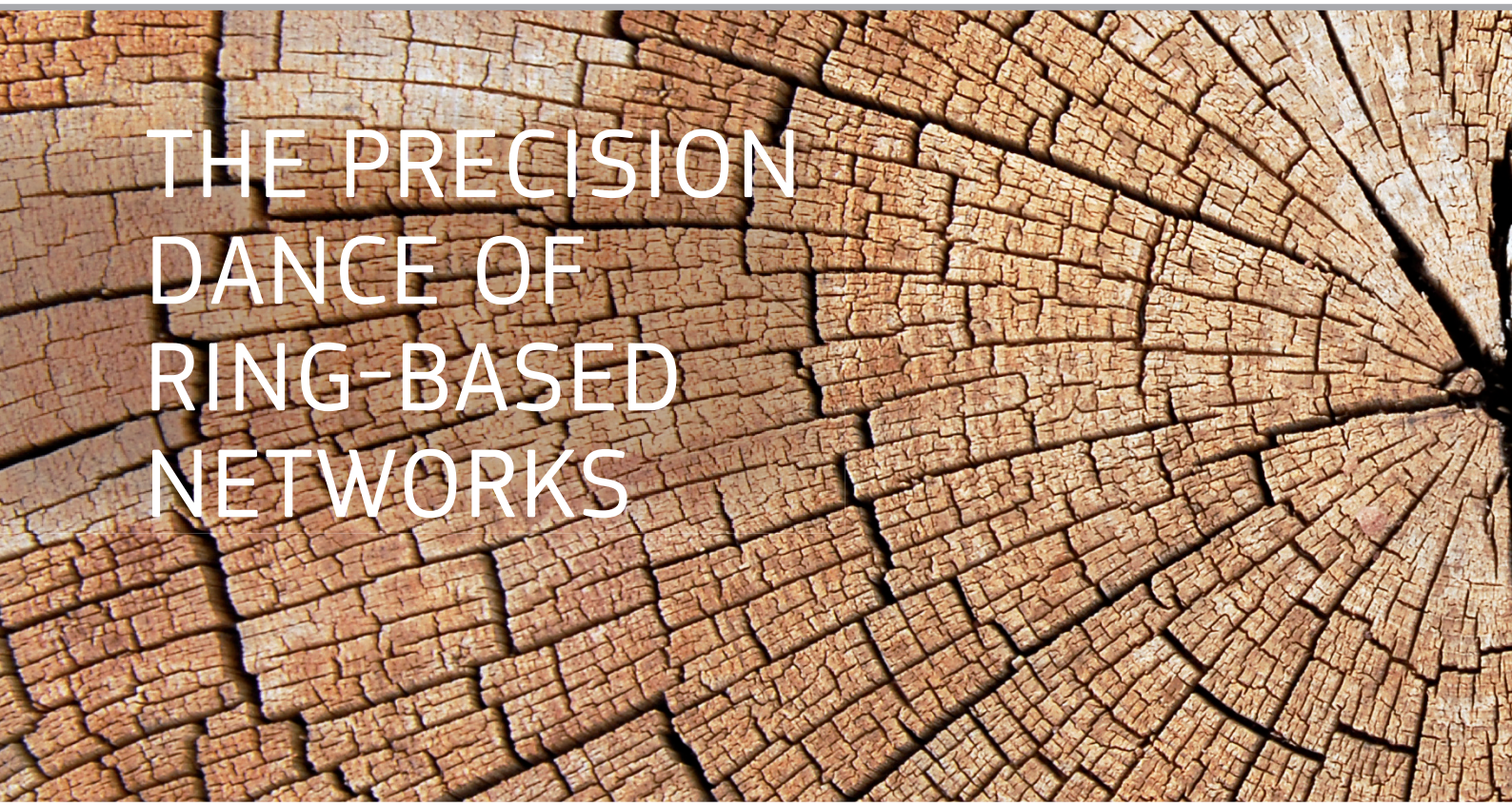
From ground-breaking discoveries in optical fibres and light amplifiers, to new products such as wavelength-division-multiplexing systems and optical switches, to global standards for digital, optical transmission, Europe has been at the forefront of optical communications R&D for nearly 50 years. Funded projects behind many of these developments have been recognised for their role in driving network performance to the next level.

By 2020, at least a ten-fold further increase in fibre capacity and terabit-per-second network speeds will be required to meet the massively growing demand for data-heavy multimedia and video applications. This means fibre communication will move closer to the user and will become critical infrastructure in all types of networks, including data centre backplanes, enterprise networks and home, vehicle and sensor networks. Based on its strength and expertise and continued long-term investment, Europe is well positioned to respond to these challenges.

€350 billion	**700 000**	**100+**	**7**	**6**	**2**
telecom infrastructure market	jobs in Europe directly or indirectly impacted by optical networks	innovative SMEs & labs providing innovation and support in networks, systems, or components	out of the world's top 20 network operators are headquartered in Europe	out of the 20 largest optical equipment manufacturers have major R&D centres in Europe	out of the top three component manufacturers have major operations in Europe

Source: Net!Works and Photonics21

Collaborate to create
Nearly two decades of EU-sponsored research and actions in the field of optical communications have supported a network of experts and provided skills and training which contributed directly or indirectly to over 100 000 skilled jobs in Europe. Collaborative projects foster consensus building on central topics such as optical network evolution, management and control. Results from research, widely disseminated in publications and through standards bodies, lay a solid foundation for participating industry partners and network operators to roll out new products and services.



THE PRECISION DANCE OF RING-BASED NETWORKS

Catalonian folk dancing is not your usual starting point for new communications technology, but researchers in the Sardana project are not your usual folk. Inspired by the precise movements and elegant strength of the concentric rings in the dance, they came up with a prize-winning, low-cost solution to get super-fast internet speed, more robust connections and greater network capacity, even in remote areas of Europe.

Already today, many European network operators are struggling to meet rising demand for internet bandwidth. They can either spend billions on new infrastructure – passing on the cost to end-users – or find cheaper, smarter ways of extending the capability of current fibre-optic infrastructure.

But there is a viable alternative, according to the University of Catalonia's Josep Prat, who leads the EU-funded project 'Scalable advanced ring-based passive dense access network architecture' (Sardana). Sardana has developed a novel access network architecture using fibre-to-the-home (FTTH) which boosts and extends the performance of 'passive optical networks' (PONs), the mainstay for broadband today.

Sardana's work on PONs shows it is technically possible to deploy networks in even the most remote locations, whether deep in the forests of Finland or the mountains of France. "And it needn't cost the earth or take forever to connect everyone to broadband by the EU's Digital Agenda 2020 target," suggests Prof. Prat.

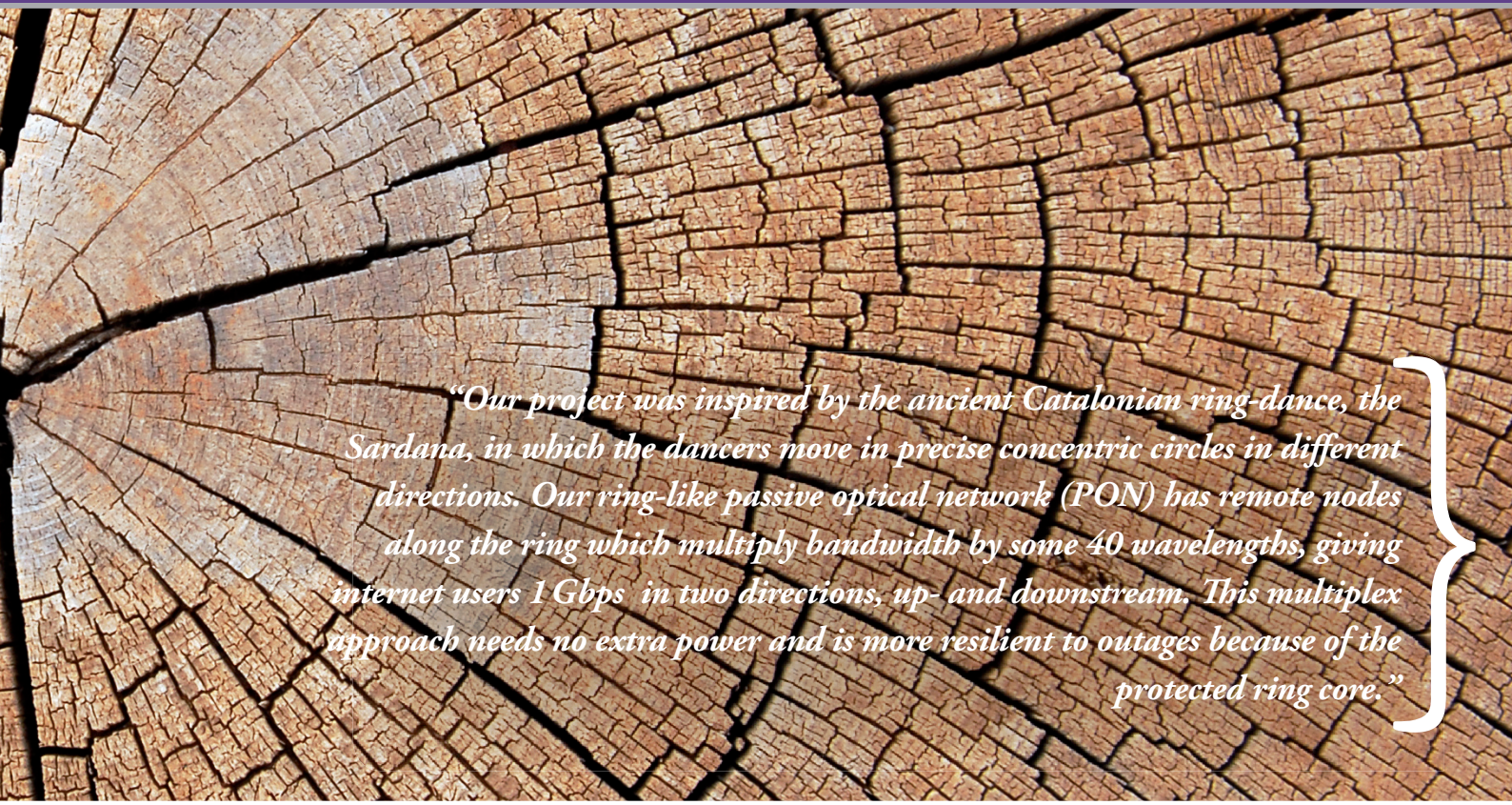
INSPIRED BY PRECIOUS RINGS

The project was inspired by the ancient Catalonian ring-dance, the Sardana, in which the dancers move in precise concentric circles, in both directions. Like each dancer who plays a role in the chain, the PONs have remote nodes along the ring which multiply bandwidth by some 40 wavelengths, giving internet users 1 gigabits-per-second (Gbps) in two directions, up- and downstream.

"That's ten times faster than the latest ADSL broadband connections and up to 200 times faster than many users access the Net in Europe today!" stresses Prof. Prat. "And our network assures broadband connectivity to thousands of homes in a wide area, even during outages, thanks to the protected ring core."

Conventional 'passive optical networks' have a tree-like structure, with the telephone exchange central office at their root, he explains. 'Passive' refers to their use of optical splitters which do not need additional power. From there, a thick main trunk of cables spreads out into smaller branches to homes and businesses.

Tree PONs use 'time division multiplexing' (TDM), which is supposed to transfer signals simultaneously as sub-channels in one communication channel, but in reality the signals are taking turns. This means, for example, that a 5 Gbps connection at the central office dissipates into a 30 Mbps downstream connection by the time it reaches the home, with upstream bandwidth a fraction of that.



"Our project was inspired by the ancient Catalonian ring-dance, the Sardana, in which the dancers move in precise concentric circles in different directions. Our ring-like passive optical network (PON) has remote nodes along the ring which multiply bandwidth by some 40 wavelengths, giving internet users 1 Gbps in two directions, up- and downstream. This multiplex approach needs no extra power and is more resilient to outages because of the protected ring core."

Unreliable streams could mean a loss of sound or broken image just as the doctor issues his diagnosis during a tele-medicine consultation. Or a signal delay during the final scene of a Hitchcock thriller. Annoying!

So, instead of a single big tree, Sardana uses multiple smaller trees branching out to end-users from a main ring. The ring transmits signals bi-directionally from the central office using 'wavelength division multiplexing' (WDM), which can carry different signals on the same optical fibre using different wavelengths of laser light. At remote nodes along the ring, the signals split off on to single fibre trees to homes and businesses using TDM technology.

COMMERCIAL KUDOS

Sardana merges the metro network and access networks to extend the reach of fibre connection up to 100 km compared to traditional PON standards and covers up to 1 000 homes – a single 'optical-line-terminal port' (OLT) can then serve 15 to 30 times more consumers than today.

This sort of merger or "convergence" makes business sense too, suggests project partner Dan Kelly, Tellabs executive vice president: "Using 'passive' products helps to reduce operating costs, and consolidating locations pares down labour costs, property tax, maintenance and other office-related expenses. Sardana helps with all that."

What's more, the infrastructure is already there: rings exist in metropolitan areas and trees are widely used. With the technology expected to reach "operational status" in 2015, a household would be able to download a high-definition DVD in just seconds, watch internet TV on multiple devices… all while uploading heavy media files.

"Sardana shakes up PON technology and brings the potential for a new suite of high-quality services to our customers," says Sardana partner, Dr Philippe Chanclou of Orange-France Telecom. "The field trials in Lannion, France, proved the viability of the network solution in both urban and rural scenarios."

The project is also contributing to several standards bodies, including the International Telecommunication Union (ITU) group NG-PON, with a view to commercial deployments in the next three years, predicts Prof. Prat.

Once deployed commercially, Sardana's dance-inspired network solutions would mark a giant leap forward in fibre network performance, directly addressing one of the biggest challenges currently facing service providers and consumers in today's economy – more speed, lower costs.

'Scalable advanced ring-based passive dense access network architecture' (Sardana)
http://www.ict-sardana.eu/

More info: SARDANA project was funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

Sardana blog (learn about the dance):
http://www.ict-sardana.eu/index.php?name=News

TEACHING TELECOMS NETWORKS TO RUN THE FUTURE INTERNET BETTER

As the internet continues to grow exponentially and increase in diversity, European researchers are developing promising new cognitive systems that will enable telecommunications networks to "learn" how to run the network more efficiently.

The internet has evolved to become a veritable global information Universe. To get some idea of how fast this process has moved ahead, it is estimated that, during the late 1990s, the traffic on the internet expanded by an average of 100 % per year and the number of internet users grew by as much as 50 % annually. Since the new millennium began, the number of internet users has mushroomed to over 2 billion from just under 400 million.

In addition to the massive socio-economic and cultural impact of this evolution, the recent pervasiveness of the internet has had a fundamental impact on telecommunications networks. This tectonic shift is reflected in the fact that, in the early 1990s, the internet made up only 1 % of information flowing through our telephone lines, with voice representing the lion's share of telecom traffic. Today, more than 97 % of bandwidth is taken up by the World Wide Web, according to one study.

And this mindboggling rate of growth is likely to continue well into the foreseeable future, not only as more people come online but also as they interact differently with the Web using a variety of different devices in myriad places and ways.

But if almost all available telecom bandwidth is already being used up by the internet, how will the future internet deal with the expected explosion in traffic?

"Future telecommunication networks will be of a highly heterogeneous nature: they will employ different transmission technologies, different switching paradigms and support very diverse services with different 'quality of service' requirements," observes Prof. Rubén M Lorenzo of the University of Valladolid (ES). "The current internet will not be able to meet future needs through simple incremental growth – the very concept of the internet must evolve."

According to Prof. Lorenzo – who coordinates the EU-funded project, 'Cognitive heterogeneous reconfigurable optical network' (CHRON), which is seeking creative solutions to this dilemma – part of the answer lies in the more effective and efficient use of available telecoms capacity through "cognitive networks". Because they are cognitive means they are able to detect the current conditions of the network, adapt to them and then learn from these adaptations to enhance future performance.

"The key idea behind this concept is 'learning'," he explains. "When we have to make a decision, we analyse the situation, balance the pros and cons, and take into account our previous experiences. That is exactly what cognitive networks are about."

KNOW THYSELF

Equipped with some €2.3 million in funding from the European Commission, CHRON is working to develop the next generation of "smart" systems which utilise sophisticated cognitive algorithms to manage and control telecoms networks efficiently and effectively.

With partners drawn from academia and industry, CHRON's 'cognitive decision system' architecture is based on developing

Greater data consumption and a shift to mobile technologies (such as smart phones) and mobile services (such as 3G internet, music streaming and webmail) are the most significant trends in the ICT sector.

heterogeneous reconfigurable optical networks capable of observing, acting, learning and optimising their own performance.

By enabling operators to squeeze more data into the available bandwidth, CHRON's cognitive networking technology, in addition to facilitating some of the expected growth in traffic, will also help improve quality and bring down costs. "It will also lead to greener telecommunication networks, because energy efficiency criteria are also incorporated in the CHRON cognitive decision system," adds Prof. Lorenzo.

Some two years into its three-year term, the project has already delivered significant results. One important breakthrough has been the development of new methods to determine which optical connections a network operator has to establish in order to support the expected amount and type of traffic which needs to be transported.

"We have demonstrated that the results improve with time as the network learns, and are significantly better than those obtained without the inclusion of the cognitive techniques," points out Prof. Lorenzo.

CHRON has also developed several solutions to deal with routing and resource allocation issues in the context of the so-called Routing, Modulation Level and Spectrum Allocation (RMLSA) problem. In addition, the project has created a reliable and fast quality-of-transmission estimator which is able to calculate in advance whether a particular optical connection is up to the job of transporting the required data at the necessary quality before it is actually established in the network.

FROM COGNITIVE NETWORKS TO KNOWLEDGE NETWORKS

CHRON's consortium attributes part of its success in achieving their ambitious objectives to date to the opportunity they have received thanks to EU support, which helps them to overcome the current economic squeeze on long-term research, especially in the private sector, and enables them to work across disciplines and borders. "European funding has enabled us to form a strong group of interconnected researchers coming from different realities who blend their ideas in the same pot," says Prof. Lorenzo.

Led by the University of Valladolid, the CHRON network is made up of seven partners, including five research institutes – from Spain, Denmark, Greece and Italy – and two industrial partners from Germany and Poland.

The project has not yet sought partners to commercialise the technology and will not do so until all the experimental validation has been completed. However, CHRON is already working on its initial business and exploitation plans, and developing standards based on the project's results.

In addition, the presence in the consortium of the telecoms operator Telekomunikacja Polska (PL) and the equipment vendor Huawei Technologies (DE) should facilitate future commercialisation efforts. The project also has the support of an industrial advisory committee made up of leading telecoms firms, such as British Telecom, Telecom Italia, Telefónica, Siemens and Ericsson.

'Cognitive Heterogeneous Reconfigurable Optical Network' (CHRON)

www.ict-chron.eu

More info: CHRON project is funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

SPEEDING AWAY IN THE INTERNET'S FAST LANE

The technology explosion has made us all impatient. Information and services must be instant in the highly competitive internet world. The OMEGA project's new home network meets this challenge by setting a new standard in transmission speeds while providing the connectivity and portability that web users need in this fast-moving society.

User expectations are high when it comes to the internet of the future. People want really fast connections which are as simple to access as utilities like water, gas and electricity. They want smart, small and elegant devices with "no new wires" and they want to get the information and web services from anywhere inside or outside their homes.

Users not only want portable services, but they want them to be personalised, seamlessly following them from place to place and device to device, at any time, with no delay or interruption of service.

Home networks will have to address all these demands and be designed so that consumers do not need to be technology experts to set them up. For example, unless access is simple and smart, this could be a major barrier to continued broadband penetration to the final X% of the population with little or no IT skills.

OMEGA Home Gigabit Access project, a European ICT project co-funded by the European Commission, has developed a home network which addresses these demands, and more.

OMEGA increases data transmission speed to 1 gigabit-per-second (Gbps) by connecting home devices to the internet and to each other through power-line communications and wireless connections making this fast, user-friendly system a new global standard for ultra-broadband home area networks.

With OMEGA's solutions, users will get easy access to high-bandwidth information and communication services such as tele-presence, 3D gaming, enhanced interactivity, virtual reality, high-definition video, as well as e-health applications and services for the exchange of user-generated business or multimedia content.

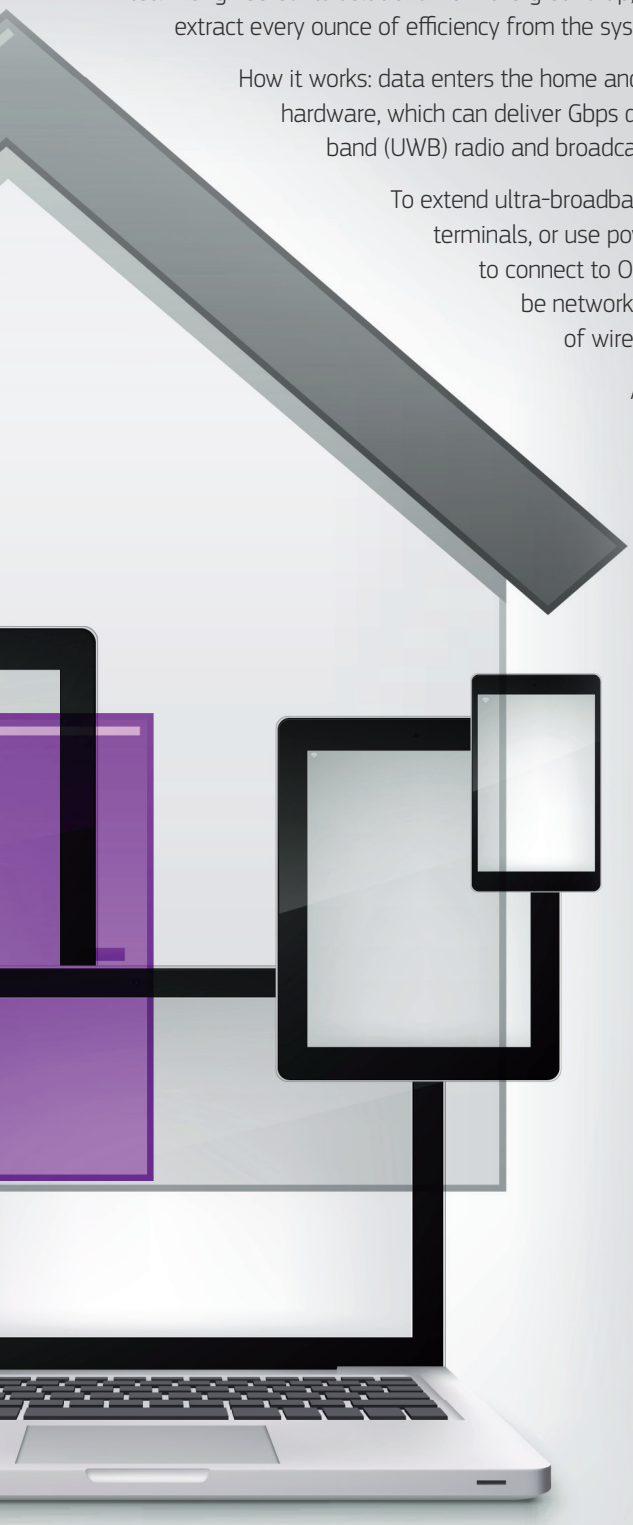
"OMEGA demonstrates how different wired, radio and optical communications technologies can be combined to create a hybrid network for high-speed communications," says Jean-Philippe Javaudin, the project coordinator from Orange Labs, France Telecom.

ENHANCING CONSUMERS' LIVES

The enhanced visual communications made possible by the faster home network means richer and more interactive online experiences both for entertainment and home care. The elderly could maintain their independence as they age, for example by offering easy-to-use remote healthcare and by allowing them to communicate with their family to reduce any sense of isolation they may have. The network will provide consumers with the ability to control their virtual as well as their physical environment.

But to meet potentially growing demand for technology assisted care, the performance of the home network must be high enough to maintain several services simultaneously, each with very different requirements. Furthermore, it must be low-cost and easy to be manufactured in volume. This is why OMEGA's research team engineered its solutions from the ground up, to extract every ounce of efficiency from the system.

"To improve the quality while keeping the network simple for the user, the OMEGA home network automatically switches between the best communication technology available at any given time."



How it works: data enters the home and is routed by the home gateway. The gateway in turn is connected to OMEGA hardware, which can deliver Gbps data transmission. Room-area communications is provided through ultra wide band (UWB) radio and broadcasting by use of visible-light communications (VLC).

To extend ultra-broadband penetration, the gateway can also use lower frequency RF to connect to terminals, or use power-line communications (PLC) beyond the current state-of-the-art 100 Mbps to connect to OMEGA bridges within the house. Bridges can alternatively or complementarily be networked by means of a high-speed radio "backbone", leading to the first hybridisation of wire-line and wireless connectivity.

At the heart of the new system is a technology-independent media access control layer called Inter-MAC. This layer controls the multiple-technology gigabit network and provides services as well as connectivity to any number of devices in any room of the building. The Inter-MAC layer also allows the service to follow the user from device to device.

In short, OMEGA's solution offers more than just increased transmission speeds; it simplifies the installation and operation of home networks for domestic and business users, enabling seamless connectivity in every room and putting an end to coverage limitations.

"OMEGA has created a seamless home network," says Mr Javaudin. The end-user will no longer have to bother about which cable or antenna his media content is transmitted, or in which room it is available because "[our] new home network automatically switches between the best communication technology available at any given time".

That is a whole new level of connectivity and portability, making the average home a veritable internet speedway.

'OMEGA Home Gigabit Access'
http://www.ict-omega.eu/
More info: OMEGA project was funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

TOWARDS THE INTERNET OF THE "WHAT"

The internet is currently built around the 'who', the machines connected to the network, but this has severe limitations, especially when it comes to multimedia content and mobile applications. The answer: to reconstruct the internet around the 'what', i.e. information.

The internet started life as a decentralised network of machines communicating with one another. Owing to the dynamic and complex nature of the network infrastructure, the internet is founded on an internet protocol (IP) which reduces complexity by centring most communications and 'intelligence' – with the exception of firewalls, network address translators, web content caches, etc. – on the end nodes through what is known as end-to-end connectivity.

However, as the internet has grown and evolved, this "who" model of the internet has revealed itself to be rigid and to have serious limitations. "For over 30 years, the internet has been coping with ever-increasing traffic and new applications, including voice and video, while retaining its original architecture," explains Mark Ain, a project specialist at the Helsinki Institute for Information Technology (FI). "Despite its enormous success, the internet is suffering from several key shortcomings that stem from a design that appears increasingly unfit to support current, largely unanticipated usage trends."

The current architecture favours the sender which leaves the internet vulnerable to unsolicited traffic (such as spam) and denial-of-service attacks, while IP addresses limit mobility. In addition, the internet's host-centric design prioritises the location of information over its nature, while a lack of built-in caching wastes network resources. "This leads to a situation in which the internet's full potential is not being exploited and trust is corroded," notes Mr Ain.

The solution we should pursue, according to the EU-financed 'Publish subscribe internet technology' (Pursuit) project in which Mr Ain is involved, is to construct an internet of "what", which focuses on information rather than machines.

'Knowledge is power' is a well-known maxim which, in the internet age, could be rephrased to 'information is power'. Recognising that the vast majority of users are interested in information, Pursuit, which has received €3.77 million in EU funds, is working to develop an information-centric internet.

Pursuit focuses on "changing the routing and forwarding fabric of the global internetwork so as to operate entirely based on the notion of information," describes Mr Ain. "The model envisioned in our aspiration elevates information to the level of a 'first class citizen', in the sense that data pieces are explicitly addressed and, therefore, directly embedded into the network," he adds.

Building on the results of a previous EU-backed project, 'Publish-subscribe internet routing paradigm' (PSIRP), Pursuit seeks to develop further information-centric internet solutions in a number of crucial areas, including transport, caching, as well as error and flow control. It is also investigating new techniques for building information-centric wireless and fixed networks, and investigating their potential socio-economic impact.

PURSUING ALL AVENUES

But the project is not just about information. It is ultimately about the user experience. "We are developing a system that is designed to adapt its appearance and functionality according to the changing needs and concerns of its users. In other words, we are pursuing an internet that is designed to work in ways similar to how societies themselves operate," says Mr Ain.

The project pursues a three-pronged 'life-cycle' approach: architecture and design choices, evaluation, and dissemination through engagement. It focuses on harnessing bottom-up ideas and applying top-down rationalisation to them. With partners drawn from both academia and industry, Pursuit takes on-board various ideas, tests them and then integrates (or discards) them into prototype systems based on the results acquired.

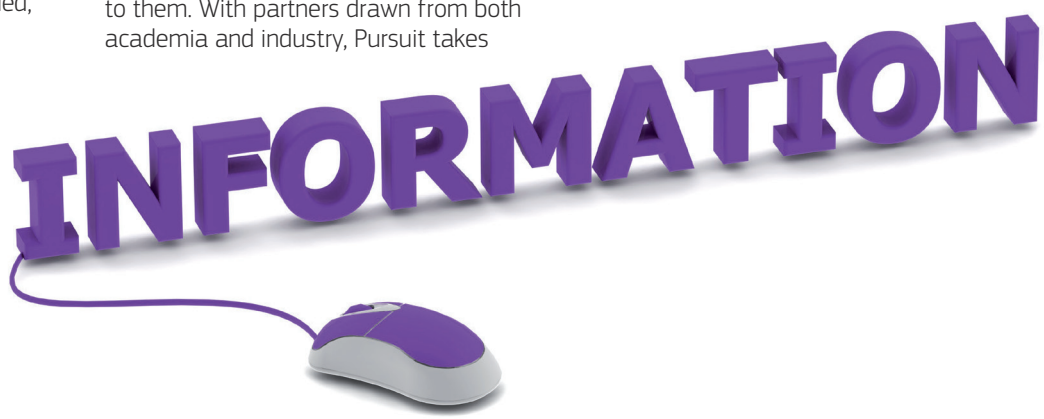
Pursuit has already produced and tested a number of prototypes. These include the so-called 'Blackadder' information-centric networking environment which enables publish and subscribe operations. Blackadder implements the main components of the Pursuit architecture, namely the rendezvous protocol, which allows peers in a network to find each other, its information-centric network topology, and packet forwarding. 'Blackhawk' is another prototype which optimises the publish/subscribe operation internally within the operating system.

"The results of the project will be, to the greatest extent possible, made public through scientific papers and other publications, as well as code releases through liberal licences," notes Mr Ain.

The partners in the Pursuit project are convinced that their architecture and ideas also possess a great deal of commercial potential. "Our vision includes a variety of commercial usage scenarios, including the network as a basis for memory and personalised storage, human-computer interaction, emergency services, healthcare, the media, real-time weather and traffic simulation, massively parallelised computing architectures, and more," Mr Ain points out.

'Publish subscribe internet technology' (Pursuit)
http://www.fp7-pursuit.eu and *http://www.psirp.org*

More info: Pursuit is a Specific Targeted Research Project (STREP) funded by the EU's Seventh Framework Programme (FP7), Future Networks activities



NETWORKS... BUILT TO GROW, ADAPT, HELP

NETWORKS GO BEYOND BUSINESS AS USUAL

The internet's success threatens to undermine its future. Its exponential growth has put a massive strain on the vital telecom networks and infrastructure on which the internet runs. With the available bandwidth already largely taken up by today's World Wide Web, hundreds of millions of new users waiting in the wings with innovative and demanding ways to use up what's left, business as usual is no longer an option. New networking paradigms, new architecture, and new 'opportunistic' ways of using the current infrastructure are all needed to meet demand for ultra-fast, reliable, secure and high-quality internet services, applications, platforms, devices and things.

By 2015, two-thirds of the world's mobile traffic will be video. Demand from tablets alone will generate as much traffic as the entire global mobile network in 2010. With the ever-increasing number of applications and services in the future internet, radio spectrum is set to become an even scarcer – and more valuable – public resource. EU-funded research has done its best to plug the gaps between supply and demand through greater efficiency on the network side. But more still needs to be done to meet expected growth.

Indeed, future networking solutions have been a major focus of the European Union's research agenda for well over a decade. Funding continues to go towards research on new technologies, infrastructure and architectures which could enable the network to evolve and adapt over time with more flexibility and with an eye on how to better serve Europe's citizens.

Preparations for the networks of tomorrow ensure that Europe is in a position to meet future demands, whether it is for services, things or infrastructure. Investment today underpins the next generation of network technologies enabling smart connectivity for everyone, anywhere, at any time at the highest speed and efficiency in order to meet overwhelming demand by society.

And future networks will drive progress towards green, efficient and even 'smart' cities where appliances, sensors and devices all talk to each other or to our cars, homes or transport infrastructure. In smart cities we can then enjoy truly joined-up services and experiences, saving time, money and the environment.

Future Internet Assembly (FIA), Aalborg
It takes more than smart systems and networks to make a smart city. This was the conclusion of 2012 FIA, hosted by Aalborg City and University under the theme, 'Smart Cities and the Internet of Things' (IoT). Smart cities combine the latest technologies and data-driven trends with policies and actions to improve the quality of life of the so-called 'smart citizens' who live in them. Smart cities of the future seek sustainable and intelligent growth – the type of growth that supports the EU's 2020 vision.
www.fi-aalborg.eu and *www.future-internet.eu*

WHEN OPPORTUNITY KNOCKS, CLEVER NETWORKS STEP IN

An aphorist once said, "Opportunity dances with those already on the dance floor." Clever networking solutions by a European research team give this quote new meaning, taking advantage of the 'communicating' nature of smart phones and other radio access technologies to form temporary networks which fill gaps, extend coverage, add capacity and boost broadband mobile networking overall.

Every day you use your smart phone to reach your friends (calling and texting them) and access the internet's huge and ever-increasing services and information. You can do this because operators keep expanding the 'mobile networks' in and around our cities.

A mobile network is basically a grid of radio towers (base stations) spanning the country, so that, at any point, your smart phone can connect to one of these towers. Each of these radio towers is actually permanently connected to the others, as well as to some additional network equipment doing behind-the-scenes things like checking your rights to use this network (your subscription), finding how to reach the person you are calling or the website you are looking for, receiving calls and text messages from your friends and forwarding them to you wirelessly.

But as network traffic and demand for heavy downloads and services like real-time videoconferencing and gaming increase, mobile networks struggle to keep up. More efficient networking solutions are needed which do not require large infrastructure investment to roll out.

Enter opportunistic networks (ON), which take advantage of the 'communicating' nature of all the smart phones and other radio access technologies (like WiFi and Bluetooth) and hotspots dotted around cities and towns. As the name suggests, ONs connect and communicate 'opportunistically', or as needed.

"They are temporary networks created for specific and transitory needs and then disbanded," says Panagiotis Demestichas from the University of Piraeus Research Centre (HE). "They offer the same services, with the same mobility and security as mobile networks… because the ON is under the control of your usual operator and works in complete synergy with the mobile network."

I'M AVAILABLE TO SHARE THE LOAD…

Mr Demestichas is leading a team of researchers in the EU-supported OneFIT project which includes major industry partners like Alcatel-Lucent-Bell Labs (DE), Telefónica I+D (ES), Thales Communications and Security (FR), NEC Technologies (UK), as well as universities and research organisations in Finland, Poland, England, Spain, Serbia and Germany. OneFIT addresses several technical challenges, ranging from dynamic spectrum management and infrastructure-less networks to social networks.

"Opportunistic networks are a cost-effective and energy-efficient way to boost current network capacity and management," confirms Mr Demestichas. A typical scenario,

he says, could be a man on the park bench beside you who is out of coverage or lacks bandwidth to handle a heavy but important data transfer. If both smart phones are "advertising" their availability to work in an opportunistic way, yours can automatically perform the transaction for him.

"Security checks, permissions, subscriptions and all the 'back-office' things that usually happen when you surf the net wirelessly take place automatically and out of sight," says Mr Demestichas.

But who pays for this piggybacking? When you act as an 'ON surrogate' like this, it consumes your battery power and resources, but it also means your operator saves resources, so he may pass the saving back to you or offer a credit which you can recoup if you need extra capacity or coverage on someone else's phone later.

"ONs are basically optimising the path used for the traffic – voice, messages, video, web page – flowing between smart phones," explains Jens Gebert of Alcatel Lucent Germany (Bell Labs), OneFIT's technical manager. "For instance, ONs mean you can downstream a video from your friend's smart phone without all the latency of going through the internet."

From an operator's point of view ONs are essential to avoiding unnecessary traffic flowing in the mobile network. "This is the key to tackling the sky-rocketing traffic expected with the future internet in coming years," stresses Mr Gebert. "And it is a way to save power by using the shortest path between users and avoiding electromagnetic exposure."

Now in the final stages of the research, the project has already delivered the ground technology framework including a detailed set of requirements (what features need to be supported by an ON and its hosting mobile network).

They have mapped out the system architecture (what changes/additions need to be made to the existing smart phones and mobile networks). Within this framework, control algorithms (making decisions on why, when and how to create or disband an ON) and protocols (how smart phones and the mobile network will exchange information over radio waves) are being developed by consortium partners.

"OneFIT is a research project in relatively early R&D phase, but we have conducted 'out-of-lab' experiments with some users and actual equipment, and we tested scenarios like a user out of coverage and how a surrogate device can compensate," says the project coordinator.

Meanwhile, to expand the relevance of the work for industry, OneFIT is mapping out the requirements to lodge with the 3GPP mobile broadband standards initiative. "Our experiments show some very promising exploitation paths for 'proximity-based services' that resolve the capacity and coverage use challenge in a cost-effective and efficient way," concludes Mr Demestichas.

Clearly, when commercial opportunity knocks for smart, flexible mobile broadband network solutions to cope with the growing demands of the future internet, OneFIT will be there to open the door.

'Opportunistic networks and cognitive management systems for efficient application provision in the future internet' (OneFIT)
http://www.ict-onefit.eu/

More info: OneFIT project was funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

"Opportunistic networks are a cost-effective and energy-efficient way to boost current network capacity and management."

THE INTERNET'S BIRTHDAY WISH? TRULY MOBILE CONNECTIVITY...

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If the internet could wish for anything on its 40th birthday, it would probably ask for a makeover to cope with today's demands, from online banking to monitoring tsunamis. The internet of tomorrow needs to be more powerful, connected and intuitive – responding to our needs at home, work or on the go.

Research projects funded by the European Commission are spearheading future networks which are fast, flexible and ever-responsive to demands from both humans and machines for access to content, apps and services relevant to the context and location of the user.

This is how the future internet is evolving; as an internet of services, things and infrastructure; from smart appliances that talk to each other to clothes that monitor our health, from cars that cannot crash to mobile technologies and cloud platforms that run our businesses.

Thomas Edwall of Ericsson (SE) believes today's internet is not broken exactly – we still manage to get what we want most of the time. "It just wasn't made for billions of people and machines demanding connectivity while constantly on the move," he says.

New networking approaches can fix it and "make it more relevant" to our needs, says Mr Edwall, but it is not as simple as replacing a microchip or installing fibre optics or boosting wireless coverage everywhere to cope with the "mobile age". No, it takes more fundamental work on the way all the components talk to each other and how applications and content is served up to consumers and end-users, and how the lifeblood of the internet – networks – are optimised to cope with future evolutions.

The EU-backed 'Scalable and adaptive internet solutions' (SAIL) project, coordinated by Mr Edwall, leverages state-of-

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the-art architectures and technologies in developing prototypes which can be test-driven in a vast range of real-world scenarios and use-cases built round three major dimensions in future networks: video, mobility and flash crowds.

HARD AND SOFT

SAIL is an industry-led consortium of 25 operators, vendors, research institutions and SMEs. Combining hard and soft-science approaches to research and technological development, including outreach and dissemination activities, SAIL is a knowledge-rich incubator developing and helping to implement technologies for the future internet, Mr Edwall explains.

SAIL is not only developing technologies for the networks of the future, but also the techniques to streamline the transition from today's networks to future concepts that evolve.

With the help of EU funding and support, the project has even enlisted the help of specialists, Johan Myrberger of Ericsson and Luis Correia of the Technical University of Lisbon, to address the so-called "soft aspects" of SAIL's technologies, including the socio-economics, migration and standardisation groundwork, as well as outreach activities like the SAIL Summer School.

"For research projects like ours, sometimes the hardest part is not the technology or solutions that we come up with but ensuring that they make sense from a human and business perspective as well, and that migration to the new technology is smooth," explains the dissemination expert Mr Correia.

The SAIL Summer School, held 25-28 June in Santander (ES), is an example of the human side of R&D. According to Mr Myrberger, the school was a hit because it really helped to explain the future internet's state of play. One of the highlights was information about the new release of SAIL's NetInf 'network of information' software (available on sourceforge.net). Students learned about the importance of 'information-centric' networks.

"With NetInf, named 'information objects' like the latest episode of your favourite TV-show are the central concept instead of a physical computer, or network 'node', as in today's internet," explains Mr Myrberger.

CLEVER CLOUD

SAIL's high-profile work on cloud computing addresses some of the obstacles to cloud adoption recently debated at the EU's Digital Agenda Assembly cloud workshop – and outlined in the previewed Advances in the Cloud Expert Report. The obstacles included guarantees on data and app portability between providers, better and more reliable connectivity, Europe-wide security certification to increase trust, and harmonised standards and interoperability of clouds and cloud services.

"To bring interoperability in the cloud, we need to consider both the North-bound interface (how customers request resources) but also the East-West interface (how data-centre and network providers actually realise the connectivity)," suggests Mr Edwall.

For the North-bound interface, SAIL is proposing the Open Cloud Networking Interface (OCNI) which extends the Open Cloud Computing Interface (OCCI) API, to include connectivity requirements. For the East-West interface, SAIL proposes a new protocol, Distributed Control Plane (DCP) which allows network and data-centre providers to negotiate the actual parameters to establish end-to-end (E2E) connectivity.

SAIL is adding the network aspect to the cloud to connect and distribute cloud resources in the network. What's more, its 'open' and 'flexible' approach should help with the 'portability' and 'reliable connectivity' barriers.

NEW TACK

SAIL's NetInf, cloud networking solutions and approach to open connectivity round up the project's overall vision of designing technology that understands intuitively (from the ground up) that information and apps should be mobile – able to follow you anywhere – and found in different places on the network.

"Users need to be able to 'address' content directly, not through disparate servers dishing up a close copy of it," says Mr Edwall. "Application providers need to be able to move their apps and content around the network quickly and automatically to meet varying demand.

"And of course the network needs to adapt rapidly to connect apps and end-users, and take advantage of all available resources," he concludes.

This is where SAIL's technologies and solutions offer a fresh tack on networking paradigms of today, helping the internet of tomorrow more efficiently carry out the myriad new tasks we demand of it.

'Scalable and adaptive internet solutions' (SAIL)
http://www.sail-project.eu/

More info: SAIL project was funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

BUILDING A WIRELESS WEB FOR ALL ON TV ‘WHITE SPACE’

As the internet goes increasingly mobile and wireless, the gaps between frequencies used for television, known as ‘white space’, can help all citizens gain access to broadband through the airwaves.

To a writer or artist, ‘white space’ sounds like the portions of a page unoccupied by words or images, and leaving enough of these empty areas is crucial to the art of making text or graphics visually attractive and to avoiding unnecessary ‘noise’ and interference.

A similar principle used to apply to the broadcast media. Analogue TV once required large swathes of white space between channels to preserve their quality of broadcast, enable antennae to pick them up and avoid interference between adjacent channels.

However, as technology has progressed, much of this white space has become redundant. Moreover, the switchover from analogue to digital TV, which is set to be completed in the EU by the end of this year, has freed up additional space on the spectrum (mostly, between 470 and 790 MHz).

Yet despite all this unutilised white space, there exists the paradoxical situation of an apparent shortage of spectrum. “Spectrum is a scarce resource and there are conflicting spectrum requirements across the telecommunication industry,” explains Dr Paulo Marques, senior research engineer at Portugal’s Instituto de Telecomunicações. “As with any other limited resource, proper management of the frequency spectrum is important in maximising its value to society.”

Consumers' rapidly-growing appetite for online video and other data-intensive services via mobile devices poses a challenge for network operators. Furthermore, machine-to-machine (M2M) communications are rapidly developing as major applications, with an anticipated 50 billion devices being connected by 2020. The rapid penetration of data-hungry smart phones and new M2M applications will generate unprecedented demand for radio spectrum. Meeting this demand in line with the objectives of the EU's Digital Agenda depends on how efficiently spectrum can be exploited.

One way to achieve this is to utilise locally available white space, which Dr Marques calls a "once in a lifetime" opportunity that could be worth as much as €6 billion a year. "Through advances in technology, such as cognitive radio, these white spaces can be reclaimed and used to provide wireless access services to citizens," he notes.

SMART TRAFFIC CONTROL

Given that the availability of white spaces depends on the location (with more spectrum typically available in rural than urban areas), the mobility of users, as well as the fluidity and diversity of applications, exploiting this unused spectrum effectively and efficiently is no easy matter. But this is exactly what the 'Cognitive radio systems for efficient sharing of TV white spaces in European context' (COGEU) project, which has received €3.4 million in EU funding, set out to do.

COGEU is working to extract the maximum digital dividend from locally available white space. The project – which brings together research institutes and private technology companies from Portugal, France, Ireland, Germany, Poland, Slovakia, Greece and Cyprus – employs cutting-edge cognitive radio technology to automatically allocate white space according to local needs, while avoiding harmful interference with TV broadcast service. This 36-month project focuses on three main areas of application: wireless computer services, mobile broadband and public-safety applications.

The new system provides two services for accessing extra spectrum: an automatic spectrum trading market place, through which the quality and reliability of connections is guaranteed, and free, open-access 'commons' spectrum, whose reliability is dependent on the amount of traffic at any given moment.

"COGEU has implemented a proof-of-concept tool with which local and short-term spectrum licences are traded through an online auction mechanism," says Dr Marques, who is the coordinator of the project. "This allows small players to acquire local spectrum licences, which results in greater competition in the telecommunications sector."

"As with any other limited resource, proper management of the radio spectrum is important in maximising its value to the society."

To enable spectrum trading locally requires the accurate, real-time identification of available bandwidth locally, which COGEU's geo-location database does to an accuracy of 200 m, as well as mechanisms to ensure that no interference occurs to TV broadcast services.

"We have developed and made publicly available the first-ever TV spectrum geo-location database for Germany (the Munich area) and Slovakia (the Bratislava and Banska Bystrica area)," describes Dr Marques. "This database is regarded as a powerful tool to raise awareness among European regulatory authorities of the innovative and flexible use of spectrum."

BROADBAND FOR ALL

COGEU's technology provides the potential to extend quality broadband to even the remotest areas. "The trials have demonstrated that white space frequencies are suitable for providing broadband internet services to rural areas where the routing of cables or optical fibres is neither practical nor economical," points out Dr Marques. This corresponds with the Digital Agenda for Europe's objective of extending broadband access to all Europeans, everywhere.

But it is not just rural populations that are set to benefit. The crowded urban airwaves will also reap rewards as white space provides them with extra wiggle room. "In urban areas, such as Munich, COGEU has demonstrated that TV white space spectrum is suitable for indoor applications, such as 'super-WiFi' with extended coverage and capacity," says Dr Marques.

COGEU's technical solution and others that are likely to emerge require effective standards and regulations to ensure the maximum benefit is drawn from them. "Now is time for an appropriate EU regulatory framework and suitable industry standards," urges Dr Marques, noting that the consortium's partners are committed to helping draw up such standards.

'Cognitive radio systems for efficient sharing of TV white spaces in European context' (COGEU)
http://www.ict-cogeu.eu/

More info: COGEU is a Specific Targeted Research Project (STREP) funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

SKA AND MADONNA HAVE MORE IN COMMON THAN YOU THINK…

***A**fter three decades of mobile telephoning, we may have thought network crashes and dropped phone signals were a thing of the past. But little has changed at the cellular network architecture level. All we did from one generation of 'cell' phones, to the next is build more antennas so coverage more or less kept pace with new bandwidth and user demands, such as virtual gaming and video streaming. But sometimes 'keeping up' is not good enough.*

The biggest problem ahead for mobile wireless communications is interference as well as the spread of costly, power-hungry infrastructure to meet demand. "If we don't increase the capacity of wireless and backhaul systems, we'll experience more and more network crashes," predicts Dr Paulo Pereira Monteiro of Nokia Siemens Networks (PT).

But the answer, has been right in front of us for years, adds Dr Monteiro, who leads the EU-supported FUTON project: "We really needed to reduce cell size to increase capacity. That way we could increase the intensity of the antennas and ensure coverage where and when it's needed."

FUTON developed a simple and low-cost way of boosting wireless communications, using off-the-shelf components, to cope with increasing demands from latest-generation mobile devices like smart phones. Using a 'distributed antenna system' (DAS) and ultra-fast, radio-over-fibre delivery, they showed that, by centralising signal processing, base stations could then be downsized and placed discretely on lamp posts or in mobile set-ups.

Cellular base stations – containing radio antennas, transceivers and signal processors – have been the mainstay of mobile communications since the first commercial cellular networks went live in the 1980s. Used to transmit and process signals from mobile devices and connect them with the phone network, base stations and the underlying cellular architecture managed to keep up with the boom in number and speed of mobile devices, as well as the services and apps expected to run on them.

But this all-in-one 'transceiver and processor' approach is reaching its limits: technical (limited spectrum and crowded airwaves), economic (cost of installing and maintaining infrastructure and equipment), environmental (energy-consuming base stations) and social (people worried about unsightly antenna and base stations everywhere).

The 'hybrid' architecture proposed by FUTON uses high-speed, fibre-optic cables to transmit signals between 'remote antenna units' (RAUs) and a central unit where signal processing is carried out. The RAUs effectively replace base stations, providing radio coverage in each cell and converting radio signals into optical ones to be processed at the central unit.

"Our solution is a smart and economic way of collecting and processing signals in a centralised way," notes Dr Monteiro. RAUs are smaller, cheaper and simpler to install and maintain than fully-fledged base stations. They can be mounted on current infrastructure, so cost less to maintain and are less unsightly. With RAUs you can also uniformly distribute the radiated power, and thus optimise or control emissions more effectively in built-up settings.

NOT NEW BUT UNVERSAL

Using radio-over-fibre is not new – it has long been used to transmit cable television signals, for example – but the concept of centralised information and finding new ways to boost cooperation between antennas is new, according to the FUTON coordinator.

Because it enables signal processing from multiple RAUs to be carried out jointly, mobile devices would be able to communicate simultaneously with several antennas with perfect cooperation between them. Currently, signals from different base stations cause negative interference to your signal, but the ability to link with multiple RAUs would provide more bandwidth to more people in their area of coverage.

Take, for example, big events which place huge demand on established networks. What is needed is a smart, easy-to-manage mobile network which offers capacity on the fly. "I was at a Madonna concert and the density of calling caused several mobiles to crash. That meant no calls, no Twitter, and no YouTube uploads!" says Dr Monteiro. "Who'd think that after three decades of mobile technology advances, we would still have signal problems?

"But we've shown it's possible to mitigate the interference and increase capacity without installing heavy, costly, ugly infrastructure. FUTON has proved this is one way to deliver 1 Gigabit-per-second wireless broadband in a simple, cost-effective way."

From the findings and outcomes of this project not only telecommunication operators can benefit – FUTON will also provide a cost-effective solution to transport and handle the incredibly high bandwidth received by large antenna installations of the Square Kilometre Array. SKA is a huge distributed radio telescope consisting of different receiver element types covering a large frequency spectrum. The bandwidth produced by this telescope will exceed everything known today and probably for decades to come.

SKA is a global collaboration of 20 countries which seeks answers to fundamental questions about the origin and evolution of the Universe. Once operational, SKA will combine the signals received from thousands of antennas of different types, spread over a distance of more than 3000 km, to simulate a single giant radio telescope capable of extremely high sensitivity and angular resolution.

"Our DAS and RAU solution are being benchmarked for the elegant and effective way that it collects and processes data centrally," reveals Dr Monteiro, as evidence of the universal appeal of FUTON.

Mobile telecoms, and technology in general, are proven drivers of growth. Europe has a strong background in mobile developments – from the first-generation of GSM through to the latest LTE ('long-term evolution') of mobile communications – but other regions are rapidly rolling out 4G services and even leapfrogging previous generations. It is up to the current crop of scientists, engineers and researchers like the FUTON team to make sure Europe maintains its strong position for generations to come.

'Fibre-optic networks for distributed extendible heterogeneous radio architectures and service provisioning' (FUTON) *http://www.ict-futon.eu/*

GO FISHING WITH THE BEST 'NET' YOU CAN

It's not the size of the net or the depth of the sea where you fish that counts, but the right conditions and right net for the job. So say European researchers (not fishermen!) in optical networks and wireless technology. Their secret is to create not just any old 'network', but a Network of Excellence which drives and is driven by the spirit of its research community.


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Networks of Excellence, or NoE, are medium-sized research projects co-funded by the European Commission as part of its Framework Programme for research (FP7). These projects are "designed to strengthen scientific and technological excellence on a particular research topic through the durable integration of the research capacities of the participants". So far so good.

But unlike the Integrated Projects which have yielded measurable technological breakthroughs, NoEs often struggle with missed targets and misdirected emphasis on 'tangibles'. Not everyone agrees with this, and there are several projects which prove the exception can actually make the rule.

MAKE NO BONES ABOUT IT

Take, for example, the 'Building the future optical network in Europe' (BONE) project which with as little as €3.8 million from the EU has built a dedicated community of some 600 researchers and 49 partner organisations eager to innovate in optical networking.

The funding acts as "seed money" to set up and trigger new collaborations, researcher exchanges and to nurture ideas, says Professor Peter Van Daele, BONE's coordinator from IBBT-IMEC-Ghent University (BE). Thanks to a spirit of cooperation and shared vision, the partners have tackled many challenges facing the development of better, faster, safer optical networks needed for 'broadband' rollout, the future internet, and to meet Europe's Digital Agenda targets.

"If the European Commission wants to support innovation, long-term investment in creating a community of experts scattered all over Europe is needed. NoEs are an ideal tool for this," says Professor Van Daele. They provide a nurturing environment, a spirit of free-thinking and even a "touch of beautiful chaos", he says. Then the community can refine the ideas and "search for method in the madness to unleash true innovation", he says.

And through its outreach activities, including mobility actions, workshops and exchanges, academic and industrial partners spread all over Europe can help researchers (especially young scientists) disseminate their results, papers, and new ideas. With the greater awareness that comes from this Europe-wide, it also reduces duplication of research, and helps to consolidate and foster EU industry-research relationships.

LEADERSHIP TAKES VISION

Another over-achieving NoE is Newcom++. Among the many technological breakthroughs emerging from Newcom++'s ecosystem is a new class of channel codes for the reliable transmission of data over wireless networks. So-called Polar Codes, they hold the promise of a large increase in bandwidth, allowing mobile devices to dramatically increase the speed of data transmission. Developed by Newcom++ partner Erdal Arikan of Bilkent University in Turkey, this groundbreaking work – described as the "Holy Grail for secure wireless information transfer" – was recognised with a Best Paper Award from the Information Theory Society.

Newcom++ partners have worked on many more innovative ideas and technologies that go far beyond fourth-generation (4G) and long-term evolution (LTE) mobile and wireless communications. "What happens after next-generation has been our key


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driver," says Professor Marco Luise of DSPCOLA-University of Pisa (IT) and Newcom++ project manager-director. For example, Newcom++ researchers at the Polytechnic University of Turin (IT) worked on advanced decoding algorithms for multiple-input and multiple-output (MIMO) technology in which both the transmitting and receiving devices have multiple antennas to improve communications.

And like BONE, Newcom++ also focused on the education and training needs of young researchers in the field via exchanges, online collaboration, and knowledge-sharing opportunities. And perhaps the crowning achievement of the project is the new Newcom++ Vision Book: *Perspectives of Research on Wireless Communications in Europe and the Satellite and Terrestrial Radio Positioning Techniques* published by different teams involved in the project.

Like the technology, the "after-next-generation" NoE has also been planned for. "We used our experience and the critical momentum in the group to spin-off a new network – with a slightly different vision and consortium but equal passion to maintain Europe's stronghold in wireless communications," says Prof. Luise. This permanent structure will be boosted by the creation of the multi-cite European Lab for Future Wireless Internet (EU-WIN) at Eurocom Nice, CTTC in Barcelona, and CNIT at the University of Bologna.

'Building the future optical network in Europe' (BONE), 'Network of excellence in wireless communication' (Newcom++)

More info: BONE and Newcom++ projects were funded by the EU's Seventh Framework Programme (FP7), Future Networks activities

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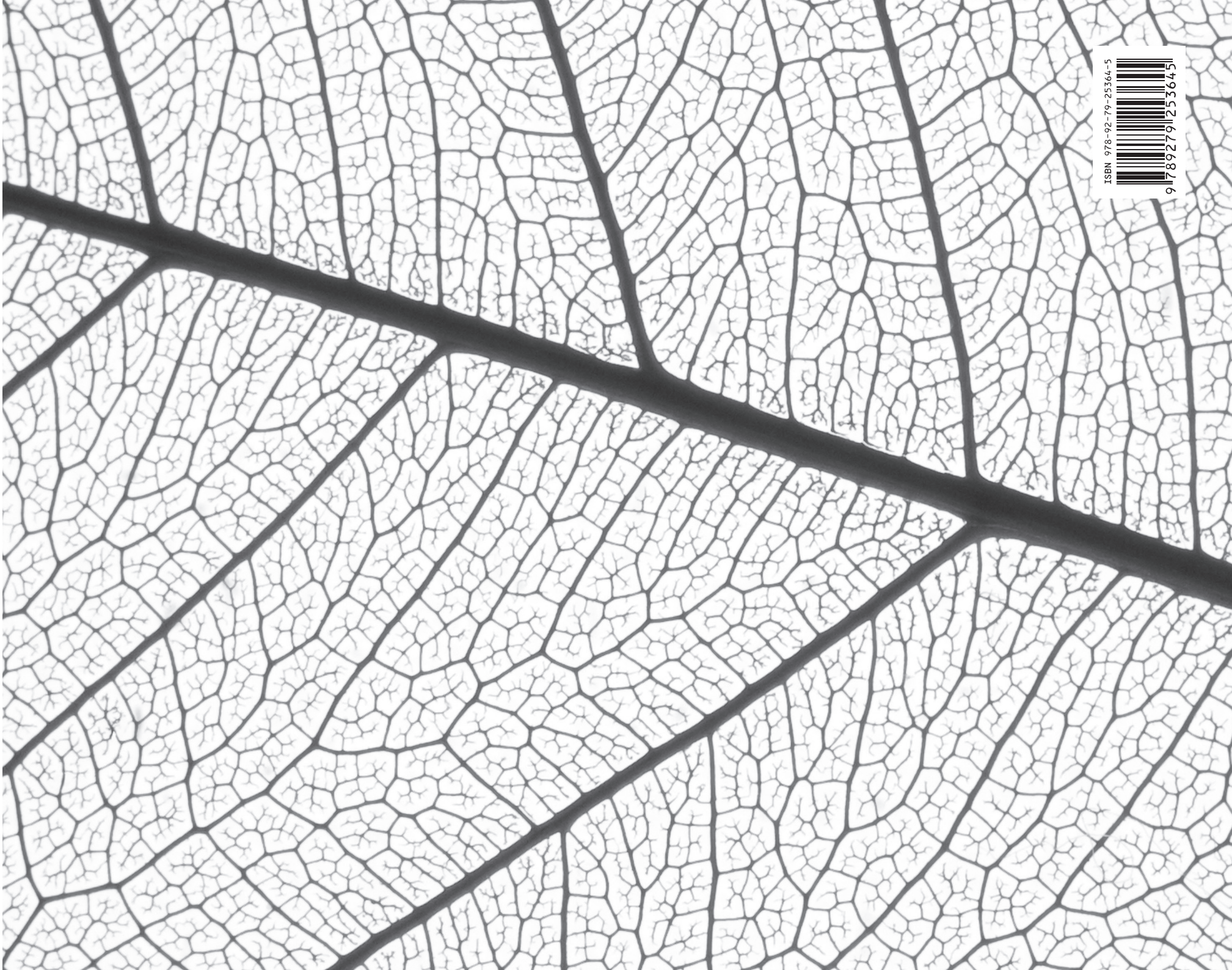

ISBN 978-92-79-25364-5