Science Foundation Ireland sfi For what's next

CONNECT
Centre for Future Networks

Catalysing Impact
Our journey so far

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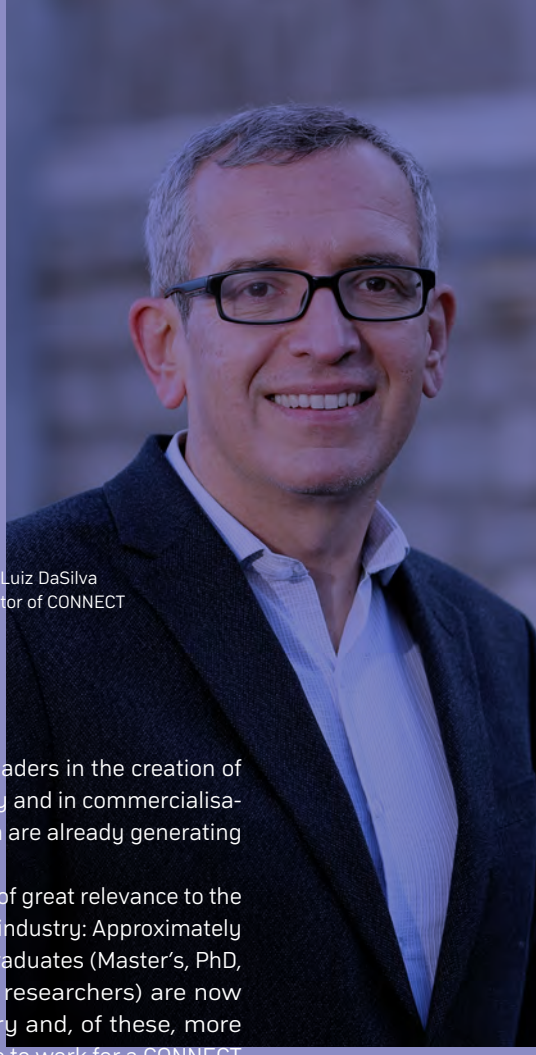
Gateways, an installation by CONNECT artist Fiona McDonald, at the Roscommon Arts Centre.

Foreword



Prof. Luiz DaSilva
Director of CONNECT

CONNECT, founded in 2015, is the Science Foundation Ireland research centre for future networks and communications. We envision a future of sustainably deployed, dependable networks that foster innovation in services, empower citizens, and improve quality of life. Research excellence is our first mission: it underpins all our achievements, our collaborations with industry, our ability to drive social and economic impact and our contribution to the creation of a diverse and highly qualified workforce.

To achieve this mission, we bring together leading researchers from 10 higher education institutions across the country while attracting further talent from around the world.

By working closely with our 40 industry partners, CONNECT is producing major research breakthroughs in communications and network technology. In this publication, we highlight some of these achievements in areas as diverse as network sharing, connectivity to flying platforms, the design of a new generation of power amplifiers for communications hardware, and revolutionary thermal management solutions for data centres. In addition, since our launch four years ago, we have become leaders in the creation of intellectual property and in commercialisation activities which are already generating employment.

Our research is of great relevance to the Irish and global ICT industry: Approximately 70% of CONNECT graduates (Master's, PhD, and post-doctoral researchers) are now working in industry and, of these, more than 40% have gone to work for a CONNECT industry partner.

CONNECT is an important asset to Ireland's economy: Of the many international researchers who have come from overseas to work with us, more than 40% have subsequently stayed to join the Irish workforce. We are also very proud of our homegrown spin outs and start-ups, which translate the science created in CONNECT into commercialisation success.

CONNECT is constantly growing: We have expanded to deploy and operate a nationwide IoT research infrastructure called Pervasive Nation, unique in the world, covering the majority of the population of Ireland and used by researchers and industry partners to prototype and deploy commercial IoT solutions.

We envision a future of sustainably deployed, dependable networks that foster innovation in services, empower citizens, and improve quality of life.

We have also established Smart Docklands, in partnership with Dublin City Council, to be an environment for innovation in smart communities, attracting foreign direct investment to Ireland and serving as a model for innovation and public-private partnership initiatives around the country.

Four years into the lifetime of the centre, we have faced the challenge of mapping out the key research directions for the fast evolving landscape of communication networks. This is an industry that will face significant disruption over the next decade, from mission critical applications that will require stringent dependability guarantees from the network, to the need for radical new approaches to achieving sustainable deployment of network technologies. Our blueprint for this future involves identifying and addressing key research challenges in six areas that are poised for disruption: dependable networks, sustainable IoT, link performance, customized networks, data driven optimisation and management, and the new operators.

We will continue to firmly establish CONNECT as one of the leading research centres in the world by working closely with our industry partners to produce new breakthroughs for each of these challenges. Innovation and human capital are our key outputs, and we are committed to promoting gender balance and inclusiveness in ICT, and to contributing towards a technologically literate and scientifically well-informed population in Ireland. For all of us in CONNECT the first four years of our centre have been challenging, exciting, rewarding; and they have passed dizzyingly fast. And yet, there is no doubt that even faster change and bigger successes are in store for the next phase. We look forward to continuing this journey with our amazing network of partners.

Prof. Luiz DaSilva
Director of CONNECT
Chair of Telecommunications,
Trinity College Dublin

Our journey so far— a story of impact

Engaging with industry

8.6m

CONNECT researchers have secured over €8.6m in funding from industry partners.

17

17 licensed pieces of Intellectual Property

3

3 spinout companies employing 22 people (Danalto, ThinkSmarter and LiquidEdge).

24

Since 2015, CONNECT research has generated 24 patent applications

85

85 research agreements signed with 36 industry partners

Winning research funding

16.2m

CONNECT researchers have secured €16.2m in competitive funding chiefly from the EU's prestigious Horizon 2020 programme.

36/8

CONNECT is a partner in 36 European research projects, and leads 8 of these.

World leading science

800

CONNECT researchers have published more than 800 peer-reviewed publications since 2015.

1 in 4

1 in 4 of our investigators' papers appear in the top 5% of publications.

1 in 8

Almost 1 in 8 of our investigators' papers are co-authored with industry.

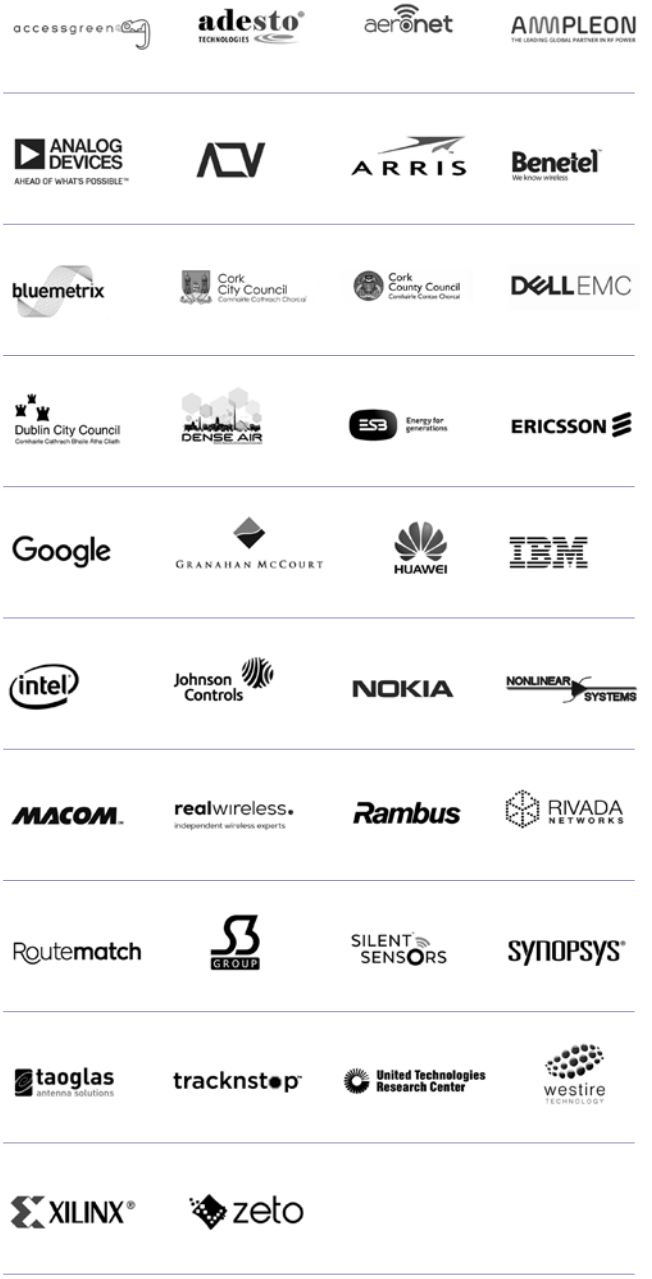
Half

Over half of our investigators' publications are international collaborations.

4

4 of CONNECT's lead investigators are IEEE Fellows. Fewer than 0.1% of IEEE members are appointed Fellows annually.

Engaging with industry



CONNECT as a catalyst

Since launching in 2015, CONNECT has leveraged its expertise and partnerships with other research centres and collaborators, to lead several high impact programmes.

1. enable

2. Pervasive Nation

3. SMART DOCKLANDS
A Smart Dublin District

4. EDGE

1. **ENABLE** is a large multi-institute research programme, led by CONNECT in collaboration with the Insight and Lero SFI research centres, which connects communities with smart urban environments through the Internet of Things. 2. **Pervasive Nation** is a nationwide Internet of Things research infrastructure at the service of academic research and industry partners. 3. **Smart Docklands**, a partnership with Dublin City Council, provides entrepreneurs and SMEs with a platform for innovation in Dublin's docklands district. 4. The **EDGE** programme, a collaboration with AMBER and ADAPT SFI research centres, is training the next generation of ICT research leaders.

Economic Impact

CONNECT has attracted foreign direct investment from companies that would not otherwise have a footprint in Ireland. Our investigators have also brought several prestigious international conferences to Ireland since 2015, raising Ireland's profile on the international stage. CONNECT is centrally involved in organising the IEEE International Conference on Communications (ICC) in Dublin in 2020. The ICC attracts up to 3,000 delegates yielding a projected benefit of €4.5m to the Irish economy in business tourism spend alone. CONNECT has signed 85 research agreements with 36 industry partners, of which 12 are Irish. 19 of CONNECT's 36 industry partners are MNCs.

17

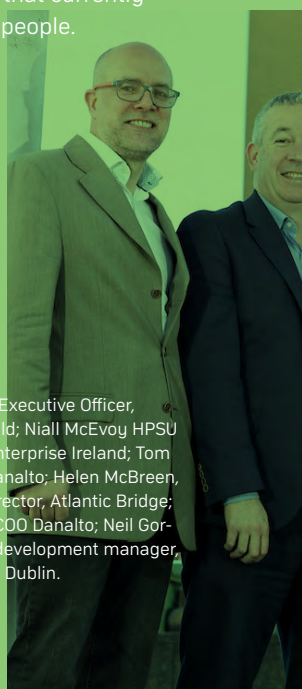
17 pieces of IP have now been licensed.

€6.7m

32 Enterprise Ireland Commercialisation Awards worth €6.7m have been granted.

3

We have now spun out 3 companies that currently employ 22 people.



Danalto Chief Executive Officer, David McDonald; Niall McEvoy HPSU manager at Enterprise Ireland; Tom Farrell, CTO Danalto; Helen McBreen, investment director, Atlantic Bridge; Albert Baker, COO Danalto; Neil Gordon, start-up development manager, Trinity College Dublin.

James Little, Scientific Advisor, and Brendan O'Brien, founder and CEO of ThinkSmarter.

ThinkSmarter

ThinkSmarter provides a cloud-based people movement and advanced footfall analytics software solution using WiFi and IoT sensors. ThinkSmarter was spun-in to Trinity College Dublin in 2018 when it licensed IP from CONNECT, and currently has a team of 15 employees across several countries. Customers include public and private enterprises in the retail, venue and smart city industries, with deployments in Ireland, UK, Austria, Spain, Israel, Qatar, Singapore and the USA.

Danalto

Danalto is CONNECT's most recent spin-out. It provides technology and managed services to ease and enrich the adoption of IoT by companies, and has licensed IP from CONNECT to help support this. The Danalto founding team were previously involved in leading Pervasive Nation – CONNECT's IoT testbed.

Danalto closed a successful funding round of €750,000 in late 2018, led by Atlantic Bridge's University Fund with Enterprise Ireland also participating through its High Potential Start-Up programme. Danalto is also part of a consortium which has been awarded funding from the Irish government's first Disruptive Technologies Innovation Fund.

SRS

SRS (Software Radio Systems) develops a range of SDR-based L1, L2 and L3 implementations for a range of wireless technologies, including LTE. Founded in 2012 by Dr Paul Sutton and Dr Ismael Gomez (postdoctoral researchers at CONNECT until 2017) SRS builds on CONNECT's history of software-defined radio (SDR) stretching back to 1999.

Their turnover for 2018 was up 300% on the previous year and they are now on track for further increases in 2019. SRS now have 8 employees in total: 4 in Ireland and 4 in Spain; 5 of whom came directly from CONNECT. SRS works with Enterprise Ireland as a "non-financial" HPSU.

SRS has been successful in securing funding from the European Space Agency, FP7, H2020 and the US Department of Commerce through the National Institute of Standards and Technologies. SRS also works with the US Deptartment of Commerce under the Public Safety Innovation Accelerator Program through the OpenFirst project, an open-source end-to-end LTE network for first responders. Their open-source srsLTE software suite is the leading project for LTE R&D globally.

Paul Sutton, founder of
Software Radio Systems (SRS)

Frank Smyth, co-founder and CEO, Pilot Photonics, with Jules Braddell, VP of Engineering.

Pilot Photonics

Pilot Photonics, a spin-out based in the Invent Centre at DCU, produces state-of-the-art photonic integrated circuits based on optical comb laser IP, which was funded through CTVR, CONNECT's predecessor programme.

Pilot produces the world's smallest and most versatile comb laser chips making optical combs suitable for use in high-volume applications such as communications, LIDAR and optical sensing for IoT.

Since 2017, Pilot has grown its team from two to eight people. In 2018 the company more than doubled its 2017 revenues. It has raised €1.3m of VC investment, and a further €700k of national and EU grants. Its largest customer is the European Space Agency from whom it has won contracts worth €900k including one contract for the development of a PIC comb source for use in atomic clocks. The company recently secured one of the Irish Government's first Disruptive Technology Innovation Fund awards for the development of a comb source for Terabit optical communication, ideas seeded in the CTVR and CONNECT programmes.

Scientific Impact

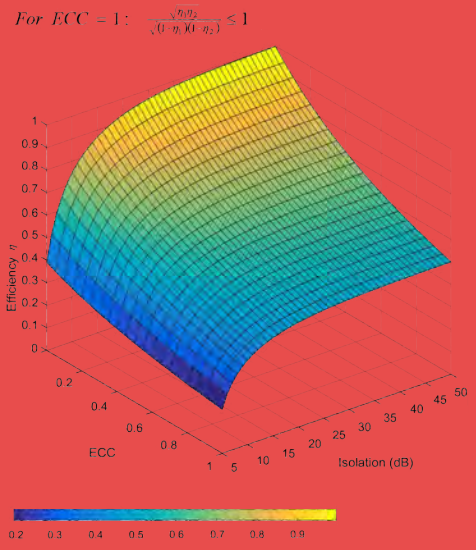
CONNECT has established a track record of scientific breakthroughs. Here are some advances in each of our six network research areas.

Dr Donna O'Shea, CONNECT Funded Investigator at CIT, at the launch of Cyber Ireland, a new national cyber security cluster.

Dr Ivan O'Connell, Tyndall National Institute, receives the 2018 SFI Industry Partnership Award

Industry Partnership Award

Ivan O'Connell, CONNECT Funded Investigator at Tyndall National Institute, receives the 2018 Science Foundation Ireland Industry Partnership Award for his research collaboration with Analog Devices. The award was presented by Professor Mark Ferguson (Director General, SFI), and Dr Orlaigh Quinn (Secretary General of Department of Business, Enterprise and Innovation) at the annual SFI Science Summit.



Breakthrough

Efficiency for a passive self-interference suppression circuit as a function of isolation and radiation pattern correlation. CONNECT researchers at TU Dublin are the first to formulate the efficiency limit of full-duplex antennas operating in the same spatial channel.

Cu-Diamond integrated heat spreader for cooling high-powered CPUs and GPUs

Converged networks

Heat is the number-one killer of electronic components and systems. A typical electronic stack consists of the PCB, the Si die, Thermal Interface Material (TIM1), a metallic Integrated Heat Sink (IHS), another TIM2 and the fluid-cooled heat sink. Every component in this stack, along with the interfaces between them, adds a resistance to heat flow causing the temperature of the Si die to increase proportionately.

We have discovered a disruptive technology that can significantly drop the Si die temperature by eliminating some resistances whilst improving others, and is an all-in-one manufacturing process. Using a supersonic jet, a copper-diamond powder mixture is deposited directly on the Si die, eliminating TIM1, and a Cu-Diamond composite structure is additively manufactured, layer-by-layer, creating a high-conductivity low-coefficient of thermal expansion (CTE) IHS.

This is a potential step-change in thermal performance of electronic packages, allowing them to run faster and/or last longer, all whilst decreasing the number of processes in their manufacture, reducing cost and cycle times.

Prof. Anthony Robinson
& Dr Rocco Lupoi
CONNECT, Trinity College Dublin

A. Robinson and R. Lupoi, "Thermal structures for dissipating heat and methods for manufacturing thereof," Sep. 4 2017, European Patent Application No. 17189219.3

The first Gbps E-band link at 26 km to a ship and 16 km to a helicopter

Moving networks

In partnership with Aeronet, an Irish start-up, we have jointly led a project focussed on using E-band signals to communicate with moving targets, i.e., aircraft and ships. Range was the focus: with a 200 mW signal, the team has now demonstrated a Gbps link at a distance of 26km to a moving cruise ship off the coast of Florida, and a distance of 16 km to a low-flying helicopter travelling at 100 kmph at a height of 500m in Ireland.

A Gbps is 10 times what is commercially available and would allow full broadband speeds for everyone on board a large plane or cruise ship allowing, for example, the significant concurrent streaming of YouTube videos, uploading of images and gaming.

Patents have been filed, four of which have already been assigned, covering antenna design, network architecture, beam-switching technologies, authentication and security, and ship-system integration.

Prof. Ronan Farrell
CONNECT, Maynooth University

B. Russell and R. Farrell, “Antenna array for aeronautical communications,” Aug. 17 2017, WO Application CA3013982A1.

Molecular communications for bacterial suppression, wireless brain-machine interface, and DNA storage

Nano Networks

Molecular Communication in biofilm suppression

Biofilms contribute towards environmental contamination, as well as infections within the human body. This is big problem for people with implantable devices. We have utilised engineered bacteria to produce communication molecules that interfere with the biofilm-forming bacteria, avoiding the use of chemicals to control their formation. Engineered bacteria communication could counter other types of infections in the future.

Wireless optogenetic brain-machine interface

Today's brain implants are large and bulky, and often disruptive for a patient's lifestyle. We are developing miniature devices that can be seamlessly embedded into the brain, and which use light to stimulate a targeted population of neurons, genetically engineered to be sensitive to light at specific wavelengths. This research opens new applications ranging from countering neurodegenerative diseases as well as targeted neuroplasticity training, where new skills can be uploaded to the brain through brain stimulation.

DNA storage

The growth in the number of Internet users places increased stress on data centres. In recent years, researchers have investigated the storage of digital data in DNA. Our research investigates if encoded DNA can be stored in bacteria, making use of their properties such as swimming and DNA sharing among bacteria to create a physical library, capable of storing different types of data. This could lead to an automated mechanism for reading information from a library built purely from a biological system.

Dr Sasitharan Balasubramanian
CONNECT, Waterford Institute of Technology

D. P. Martins, K. Leetanasaksakul, M. T. Barros, A. Thamchaipenet, W. Donnelly and S. Balasubramaniam, "Molecular Communications Pulse-Based Jamming Model for Bacterial Biofilm Suppression," in IEEE Transactions on NanoBioscience, vol. 17, no. 4, pp. 533-542, Oct. 2018.

Pioneers of integrated magnetics-on-silicon for Power Supply on Chip (PwrSoC).

Low Energy Networks

Electronic devices need power supplies capable of converting electricity from the mains or batteries to the correct voltage needed to drive the sensitive electronic components. Optimising the efficiency of these power converters is critical, particularly at a time of growing global concern with energy saving.

Power converters are usually located alongside the electronic load (e.g., the microprocessor), making it difficult to maximise their efficiency. To integrate the power supply within the load would achieve the "holy grail" for power supplies, the PwrSoC.

We have developed "magnetics-on-silicon" solutions for PwrSoC. Using electroplated copper windings in combination with thin film soft magnetic cores, magnetics-on-silicon technology enables inductor and transformer components to be miniaturised to such an extent that they effectively disappear onto silicon wafers, in a manner similar to what CMOS technology has done for the transistor. It offers many benefits: reduced CO2 emissions through more efficient power supplies; increased battery lifetime in portable and automotive applications; reduced costs and size by reducing the number of components; and enhanced system reliability through reduced noise due to the reduction and/or elimination of interconnect parasitics.

This has established Ireland as a global hub for education, research and innovation in advanced power supplies. Ireland now hosts what can be described as the first global PwrSoC cluster with Irish-based companies such as Analog Devices, Bourns Electronics, ON Semiconductor, Tokyo Electronics Magnetics Solutions, UBLOX and US start-up Endura Technologies, all exploring R&D in the PwrSoC space.

Prof. Cian Ó Mathúna
CONNECT, Tyndall National Institute

C. Fernandez, Z. Pavlovic, S. Kulkarni, P. McCloskey, and C. Ó Mathuna, "Novel high-frequency electrical characterization technique for magnetic passive devices," IEEE Journal of Emerging and Selected Topics in Power Electronic, vol. 6, no. 2, pp. 4137-4145, June 2018.

Stochastic, optimisation-based model extraction as a low complexity alternative for digital pre-distortion of RF power, resulting in 98% reduction in computational complexity

Dense Networks

This solution is a low complexity alternative to the conventional Least Squares (LS)-based approaches for digital pre-distortion of RF power amplifiers. In existing digital pre-distortion (DPD) systems, to extract the coefficient values for the DPD models, LS-based algorithms are typically used. The LS algorithm offers high accuracy and fast convergence but comes with a high implementation cost in terms of hardware resources, as it requires complex matrix multiplication and inversion operations. High implementation complexity is particularly undesirable for applying DPD in small-cell base stations since these stations operate at much lower power levels than those in conventional larger cells. The power efficiency and implementation costs of all components in the transmitter chain, including DPD, must be carefully managed.

To reduce the computational complexity, we have identified that the Simultaneous Perturbation Stochastic Approximation (SPSA) can be used as a good alternative to the LS algorithm for DPD model extraction. SPSA is an optimisation algorithm based on stochastic searching. The key idea of SPSA is that instead of conducting differential calculation, the loss function gradient is estimated by using measurements on the loss function.

A main advantage of such algorithms is that they do not require the detailed knowledge of the functional relationship between the parameters being adjusted (optimised) and the loss function being minimised. If the SPSA algorithm in DPD is used, in contrast to the conventional approach, the DPD model does not need to be reconstructed in the model extraction unit. Instead, the coefficients are perturbed/tuned according to the error and optimum coefficients with multiple iterations are found.

Prof. Anding Zhu
CONNECT, University College Dublin

N. Kelly and A. Zhu, "Direct Error-Searching SPSA-Based Model Extraction for Digital Predistortion of RF Power Amplifiers," in IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 3, pp. 1512-1523, March 2018.

First derivation of mathematical expressions to quantify the performance of a mobile network with a combination of radio access infrastructure and spectrum sharing among multiple operators.

Shared Networks

A conventional mobile network is run by a carrier that owns the equipment and holds a license for some portion of the radio spectrum. The fundamental performance characteristics of such a network, such as the download speeds, are well-understood and can be characterised mathematically. Yet, when two or more mobile carriers share part of their spectrum or radio equipment (or both) these same expressions and models no longer apply. The reason is simple: sharing changes spatial patterns of mobile network deployments.

We are the first to characterize these spatial patterns, showing that these same patterns can be observed in real mobile networks throughout major European cities. From this, we were the first to derive mathematical expressions that quantify the fundamental performance of these shared mobile networks. We can now show, for example, that radio equipment and spectrum sharing cannot be simply substituted for one other, as there is a trade-off in the coverage and speeds these two types of sharing bring.
This research influenced initiatives spanning policy-shaping, industry collaboration, and academic publications. It also informed a study prepared for the European Commission DG Communications Networks, Content & Technology by Tech4i2, Real Wireless, CONNECT at Trinity College Dublin, and InterDigital. CONNECT's main contribution was the study on spectrum needs for 5G, which evidenced the need for new mechanisms enabling more flexible spectrum-use to meet the capacity and service availability objectives of the technology.

This research was instrumental in our engagement with Rivada Networks in the design of an open-access wholesale market that bundles spectrum and network infrastructure.

Prof. Luiz DaSilva
CONNECT, Trinity College Dublin

J. Kibilda, N. J. Kaminski, and L. A. DaSilva, "Radio access network and spectrum sharing in mobile networks: A stochastic geometry perspective"," IEEE Transactions on Wireless Communications, vol. 16, no. 4, pp. 2562-2575, April 2017.

Human Capital Impact

63%

63% of our research trainees have gone to work with Industry.

30

CONNECT researchers come from 30 countries around the world.

7 in 10

7 in 10 CONNECT trainees remain in Ireland, contributing to a highly skilled workforce.

CONNECT provides its researchers with a comprehensive training programme in key transferable skills such as communication, commercialisation, and networking.

EDGE (an EU Marie Skłodowska-Curie Action programme) led by CONNECT has attracted world class researchers to Ireland. EDGE has now launched a 'Female Leadership Development Programme' to empower and support female STEM researchers. Our researchers are challenged to position their research in the context of wider social, political and environmental challenges. Our Writer in Residence, Dr Jessica Foley, leads Engineering Fictions – a creative writing workshop to support transdisciplinary communication in the contexts of ICT research and industry.

108

108 Master's, PhD and post-doctoral researchers have been trained at CONNECT, providing highly skilled talent for academia and industry.

1 in 4

1 in 4 of our trainees have gone to work for one of our industry partner companies.

100%

100% of our postdocs working in Industry are in positions relevant to their CONNECT training.

Societal Impact

CONNECT supports Social Innovation Fund Ireland (SIFI) via our Social Entrepreneur in Residence, Deirdre Mortell. This helps us to develop a broader understanding of how tech can address today's societal challenges. CONNECT has been heavily involved in supporting SIFI's flagship *ThinkTech*, a Tech for Good Fund worth €1 million sponsored by Google.org and the Irish Government.
CONNECT also supports SIFI's *AI for Good*, with one of our artificial intelligence experts, Dr Irene Macaluso, serving as an external expert in the development of this initiative.

Engage

CONNECT engages with dozens of Transition Year students each year via outreach programmes at Tyndall National Institute in Cork.

Communicate

Our researchers have communicated their work on RTÉ, BBC, The Irish Times, and multiple other media outlets.

Inspire

CONNECT engages with the public at festivals around the country and throughout the year, e.g., National Ploughing Championships, Cork Science Festival, Fota Mad Scientist, Culture Night.

Pervasive Nation

Pervasive Nation is CONNECT's nationwide IoT research infrastructure. With 40 base stations around the country, Pervasive Nation offers a Low Power Wide Area Network (LPWAN) called LoRa, which is available for academic research and testing by industry.

Pervasive Nation supports urban and rural applications, enabling programmes such as Smart Docklands in Dublin, and projects such as the proposed innovation hub at Valentia Island in County Kerry. Pervasive Nation is used by a wide variety of organisations, from large multinationals to charities such as Alone. Pervasive Nation is funded by Science Foundation Ireland.

Smart Docklands

Smart Docklands, a partnership of CONNECT and Dublin City Council, provides a unique platform for innovators and entrepreneurs to develop new and innovative solutions that will transform our cities. With its density of new builds, global tech companies and range of connectivity options, Smart Docklands is bridging the academic, industry and community sectors in forging a connected, smart future for Dublin's docklands district. In particular, it is engaging residents' groups as key stakeholders in the creation of the city's digital future. In 2018 Smart Docklands publicly trialled Ireland's first autonomous shuttle bus.

+353 (0)1 896 4889
info@connectcentre.ie
www.connectcentre.ie
twitter.com/connect_ie
linkedIn.com/company/connect-centre

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European Regional
Development Fund

CONNECT Centre
Dunlop Oriel House
34 Westland Row
Trinity College Dublin
The University of Dublin
Dublin 2

+353 (0)1 896 4889
info@connectcentre.ie
www.connectcentre.ie
twitter.com/connect_ie
linkedIn.com/company/connect-centre

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