EPSRC Centre for Doctoral Training in Communications

Annual Report 2019-20

Foreword

It is with great pleasure that we bring to you the latest report on the EPSRC Centre for Doctoral Training in Communications.

We have, since the launch of the CDT in 2011, recruited 9 cohorts of students. We are very proud of their achievements over this period in terms of innovation, publications, exploitation of research and transition to employment.

This report showcases a selection of student's recent achievements that we hope you will find informative and interesting. Despite the restrictions and challenges that we have all experienced since March 2020 due to the Covid-19 pandemic our students have continued to progress their research and demostrated innovative ways of working.

Please enjoy reading the report and do not hesitate to get in touch if you would like to learn more.

Professor David Bull
Director

Professor Mark Beach
Co-Director

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Recruitment

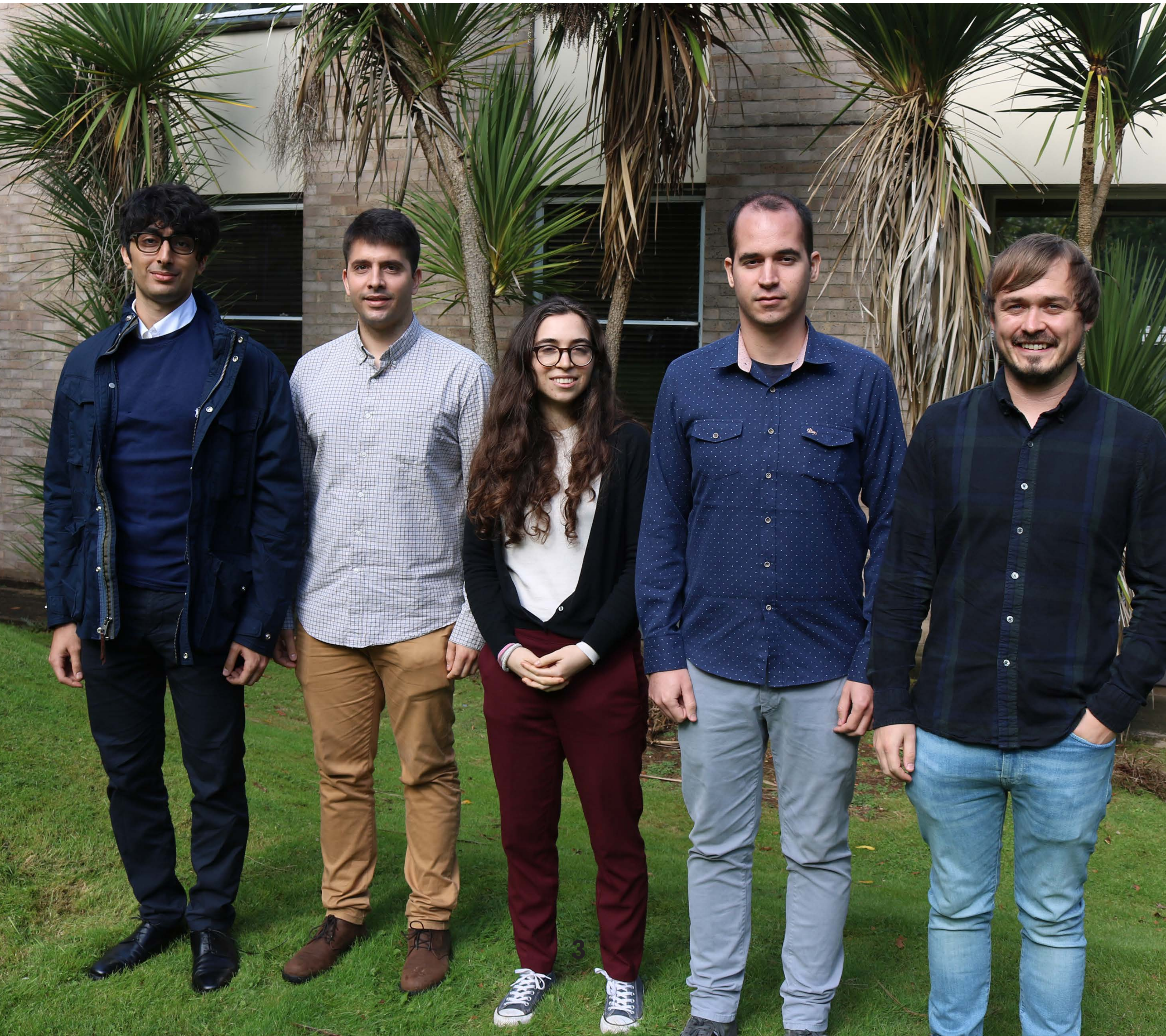
The Centre's mission is to produce graduates who are highly employable in either industry or academia - people who will become the future leaders in the sector.

In September we welcomed the final cohort of Communications CDT postgraduates. Their studies are funded by EPSRC together with additional funding from industry which enables us to offer enhanced stipends to attract the very highest calibre students and opportunities. During the year the postgraduates undertook a number of taught units and assessments (see page 3 for details).

Students are attracted to the programme for many reasons including the opportunity to work with industry and secondments with companies in the UK and overseas.

Bristol is a hub for IT and the digital industries, with companies providing opportunities for training and employment. In 2017 the city was named 'the best place to live in Britain' by The Sunday Times which praised the city for being 'cool, classy and supremely creative' and reflects one of the reasons Bristol appeals to students as a study location.

The city will also be the host for the new creative media house *MyWorld* for screen-based media which will develop major new research and development (R&D) facilities and partnerships connecting regional and national partners with global tech giants. They will pioneer new digital formats and technologies. Together they will create innovative experiences across fiction, documentary, games, and live performance.



Taught Year

The first year of our programme combines taught material (mandatory units and an extensive choice of optional units), group and individual problem-based projects, and enterprise/innovation skills training as a foundation for PhD research in subsequent years.

The flexiblity of our programme enables students joining from varying academic backgrounds or who have been working in industry to enhance their knowledge. In the year of the Covid-19 pandemic postgraduates found their taught units for the Spring and Summer terms being converted to online teaching.

Group project

The unit introduces training in collaborative working, an essential skill for engineers who will work in teams and need to understand other disciplines and vocabularies, and also other cultures.

This year’s project was to investigate the feasibility of reducing battery size in a smartphone device, allowing for either a battery-less smartphone that runs solely through the implementation of energy harvesting, or a hybrid version with a smaller battery.

With smartphones’ increasing functionality and integration into people’s everyday lives, the reliance on battery life and charging times becomes ever greater. Smartphones progressively have higher resolution screens, faster and bigger processors, and increasing data rates spurned by new generations of broadband cellular networks. This increasing functionality comes at the cost of increasing power consumption. With smartphones still using 30-year-old lithium ion battery technology, large batteries and frequent charging are the current solutions to short battery life.

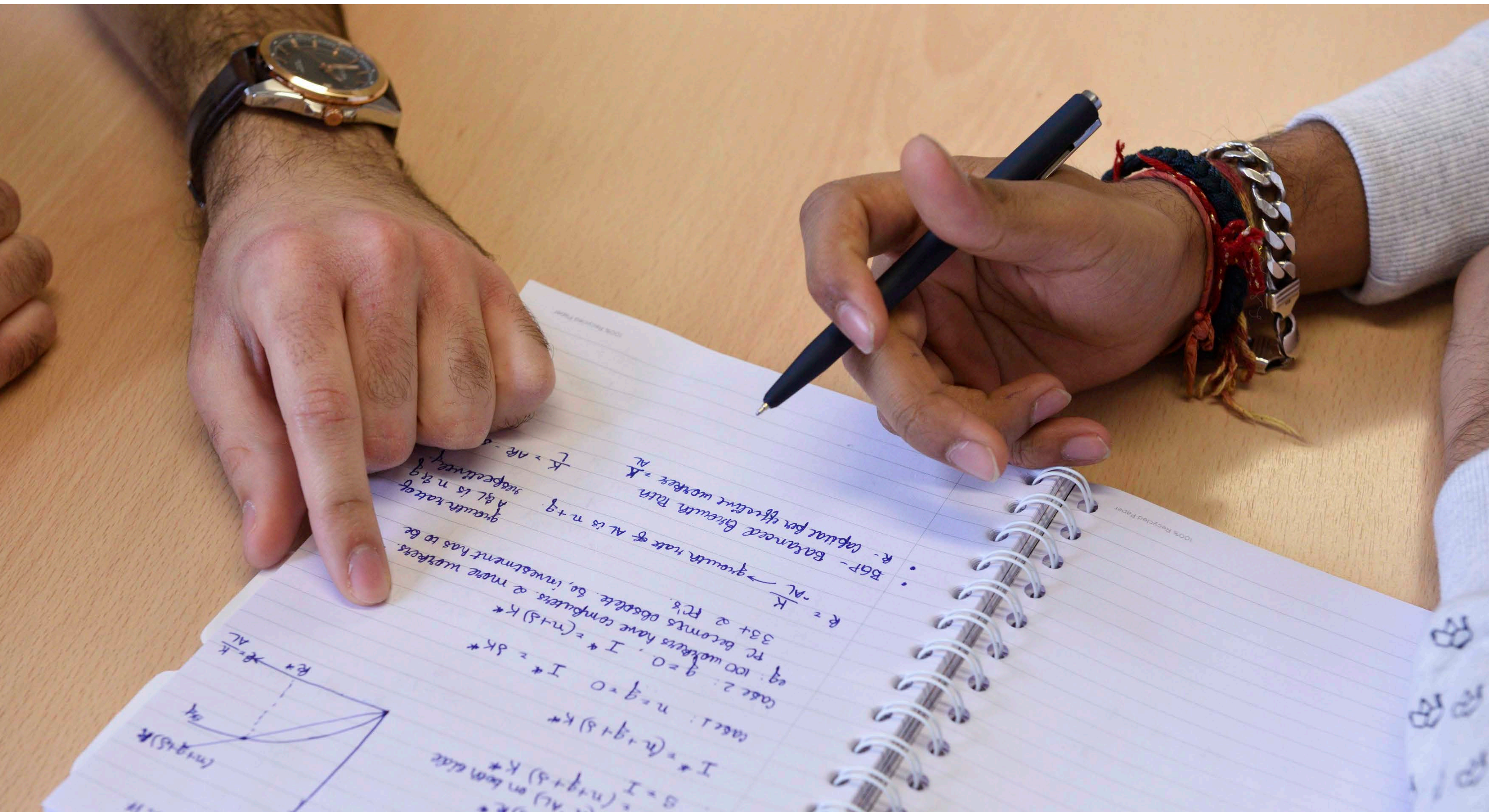
The project had the following objectives: investigate trends in smartphone technology with an emphasis on power consumption and charge intervals, a review of existing published work and investigate emerging technologies for power harvesting devices and methods. The postgraduates were then tasked with identifying the most promising avenues that will lead towards a no-battery or hybrid solution, along with any interventions required to realise this.

Enterprise

To ensure postgraduates have an appreciation of how research can be applied in the commercial world, all our students participate in a bespoke unit on Enterprise. This unit is unique to the CDT in Communications with case studies from the communications sector being used to illustrate concepts. Activities included studying business modelling, the analysis of business plans and finance, and seminars from speakers working in the communications industry. The assessment required the students to form small teams to create business plans that they pitched to a panel of industry experts and entrepreneurs.

Individual project

During the summer the cohort undertook an individual research project that produced the in-depth literature review for their PhD studies, giving them a ‘head start’ on their research.



Research & Training

Over the last 12 months our postgraduates have participated in numerous international conferences. In September Jonathan Thomas attended MLSS 2019 (Machine Learning Summer School) in Moscow where he developed an in-depth understanding of fundamental concepts within various areas of Machine Learning and had the opportunity to present his work at the MLSS poster session. Michael Wilsher presented his work on how 1-D soft random geometric graphs can be used to model vehicular networks at the Complex Networks and their Applications conference (Lisbon, December 2019). The conference brought together people working on both the theoretical as well as practical side of the field. He also presented his work at the International School and Conference on Network Science, NetSciX 2020 (Tokyo, January 2020). Several postgraduates attended the IEEE International Conference on Communications (June 2020) which was held virtually due to Covid-19. In September Mark Graham presented his work at the IEEE 57th Annual Allerton Conference on Communication, Control, and Computing (Illinois USA) and at the 4th Symposium on Spatial Networks (Oxford, UK).

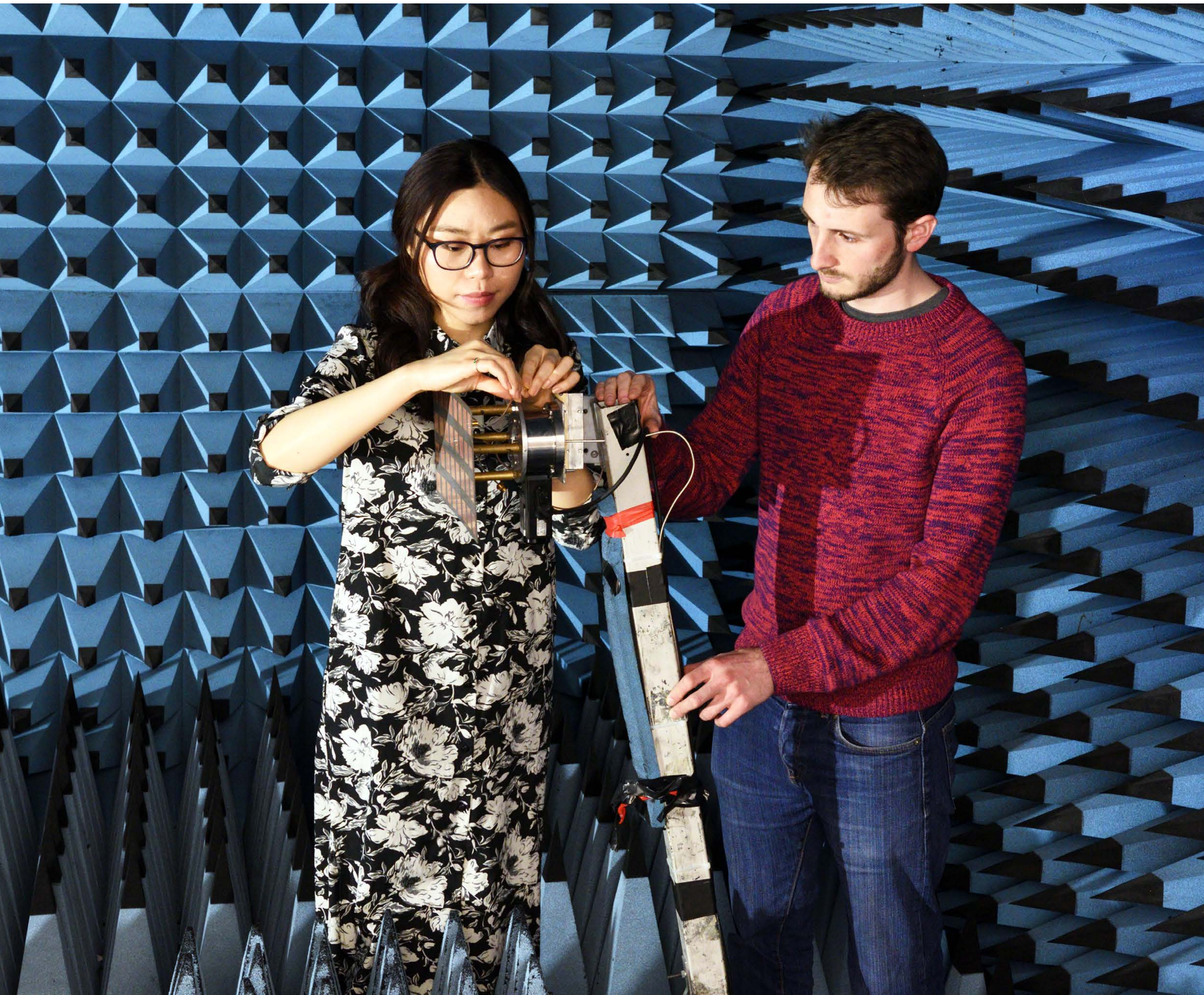
Postgraduates have also extended their technical and broadskills through participation in workshops and training course in person, and since COVID-19 have continued to enhance their knowledge by attending online events.

The University of Bristol Doctoral College skills courses proved popular amongst postgraduates with training opportunities including ‘Getting Started on a PhD’, ‘Supervision’, ‘Qualitative Data Analysis’ and ‘Project Management’.

The popular in-house ‘Poster and abstract’ workshop organised by our Director Professor David Bull, was hosted via Zoom.

Research seminars, hosted by associated research groups, began the year being in person but switched to virtual online as the country went into lockdown. Postgraduate have gained valuable skills in presenting in person, and virtually during the year.

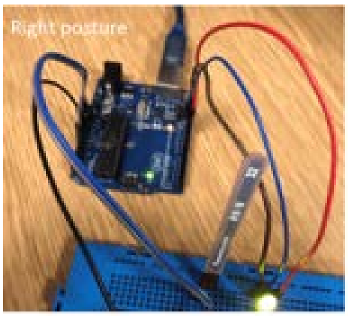
Our sponsoring companies have made training programmes availalbe online to the CDT and affiliated postgraduates. These include Introduction

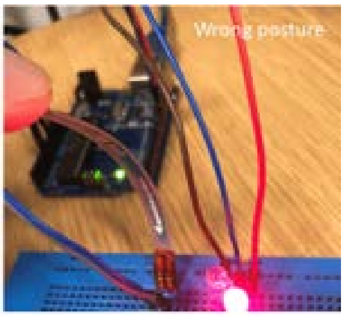


to measurements uncertainty' hosted by the National Physics Laboratory, National Instruments 'LabVIEW core 1&2'.

Team builidng and social events have continued with virtual coffee mornings and socials.

The annual Bristol Doctoral College outreach event 'Research without Borders' became an online event with postgraduates being invited to submit novel ways of demonstrating research using pictures. Sarmad Ozan & Khalid Al Mallak entered 'Can you sit normally on your chair without slouching or leaning forward?'; a very important topic with most working from home in non office surroundings. The postgraduates had idenftified that working in an office or from home has the disadvantage of sitting for prolonged periods. They designed a device to assist with maintaining the correct posture which detects any improper lean to our posture while we are sitting to perform our work and notifies with a light indicator.





Final year postgraduate, David McEwan, undertook a 10-week secondment at Jump Trading between March and April 2020.During the secondment he performed many core RISC-V architecture experiments and designed a synchronous-multicore cycle-accurate execution-trace scheme then implemented a collection of prototypes. This involved work from the low-level of ISA, RTL, toolchain, and library, to the high-level software support and GUI/visualization. At the end of the secondment he gave a presentation with a series of demonstrations analyzing the company's existing codebase on an existing architecture on silicon and their newest architecture in pre-silicon simulations.

Our CDT Communications PhD researchers have A number of postgraduates have needed to adjust their PhD research projects due to Covid-19 as it was not possible to undertake experiments in the laboratory, those involving participants or the health of the postgraduates/their dependents had been affected by Covid. Where necessary EPSRC have provided additional funding for postgraduates in their final year to enable them to contine for a short period after their original end date. Similarly the University of Bristol funded extension for those with a UOB studentship and industry sponsors kindly provided the 'top up' funding to enable student to receive the enhanced stipend rate.

In June our labs at the University of Bristol began to reopen to researchers but with strict Covid rules and limited numbers being permitted access at any time. This was welocmed by all who had missed access to facilities and the opportunity to discuss ideas face-to-face with colleagues.

Postgraduates engaged with the shift to on-line conference delivery, with several students gaining experience through helping with the on-line delivery for IEEE PIMRC and supporting the conference organisers (including Professor Beach) and back room technical support of the live sessions. Peter James was our first researcher to present on-line at the EuCAP2020 conference in March on his work on a Three Port Circular Patch Antenna with Pattern and Polarisation Agility, animating and adding narration to his power point slide deck, by drawing on presentation skills gained during his talk year, and which showed how the radiation pattern of the antenna can be steered by combining different antenna modes. . Khalid Al Mallak was awarded second prize for his virtual poster at the 2020 UK URSI Festival in November for his on-going research on the Influence Vibration in Millimetre wave Communication Systems.

Sarmad Ozan has been perfecting the art of complex RF circuit simulations and parameter optimisation with his research addressing high dynamic range receivers and enhancing the linearity of low noise amplifiers (LNA). The front end electronics of a receiver, in particular the LNA, can be driven in to gain compression (usually expressed as the 3rd order intercept point, IP3) by the presences of large unwanted signals (known as blockers). Sarmad's enhanced cascode LNA applies feedforward correction of the distortion products through derivative superposition, achieving some 4dB uplift in IP3 and only a minor degradation of the noise figure.

Deep learning methods are increasingly being applied in the optimisation of video compression algorithms and can achieve significantly enhanced coding gains, compared to conventional approaches. CDT student Di Ma, with his supervisor Professor David Bull, has produced a body of work that is world leading in terms of video coding using deep neural networks.

This work includes a novel convolutional neural network (CNN) architecture, MFRNet, for post-processing

(PP) and in-loop filtering (ILF) in the context of video compression. This work is accepted for publication in a forthcoming special issue of the IEEE Journal on Selected Topics in Signal Processing.

The experimental results show significant and consistent coding gains over both anchor codecs (HEVC HM and VVC VTM) and also over other existing CNN-based PP/ILF approaches. Gains up to 21.0% are achieved (BD-rate VMAF) over HEVC HM.

In a second piece of work, we proposed a new Generative Adversarial Network for Compressed Video quality Enhancement (CVEGAN). Evaluation in the context of post-processing and spatial resolution adaptation (SRA) experimental results demonstrate significant coding gains based on perceptual metrics (up to 28% for PP and 38% for SRA compared to the anchor) over existing state-of-the-art architectures for both coding tools across multiple datasets.

In order to maximise the effectiveness of machine learning methods in video compression, representative video databases are needed for training. The BVI-DVC database has been accepted for publication in the IEEE Transactions on Multimedia (Ma, Zhang and Bull). BVI-DVC contains 800 sequences at various spatial resolutions from 270p to2160p and has been evaluated on ten existing network architectures for four different coding tools. This database produces significant improvements (up to 10%) in coding gain over other databases under the same training and evaluation configurations. This work has been adopted as the primary database by MPEG – JVET AHG11: Neural network-based video coding.

The recently completed EU H2020 Multidrone project was worked on by CDT student Stephen Boyle. This developed an intelligent, (semi) autonomous multi-drone platform for media production to cover outdoor events. In Multidrone, UoB recognised the need for a flexible drone training, pre-visualisation and planning tool, particularly critical for live events where there is only one chance to 'get it right'. An integrated system, based on Unreal Engine-4 (UE4), was created, capable of simulation based on reconstructions of real-world scanned environments. This supports both 3D environment creation and the incorporation of programmable foreground assets as filming targets. Stephen's work contributed to a workflow for the generation of actual background environments for simulation based on 3D reconstruction, terrain generation and activity simulation. The utility of this tool has been acknowledged for virtual production, shot planning, training and rehearsal for (multiple) drone operations, improving productivity, safety and the confidence of operators and directors, lowering risk, and ultimately enhancing the quality of viewer experience. This work has been continued through an EPSRC Impact Acceleration Award which will refine the tools and validate through a trial production partnering with BBC.

Dr Leo Laughlin, one of our alumni, together with several members of the CDT in Communications staff, has established a spin-out company 'ForeFront RF'.

In June 2020, the University of Bristol received the exciting news that an initiative, led by CDT Director, David Bull, had been awarded £30 million by the UKRI Strength in Places fund as part of a £46 million, five-year programme with a further £16m committed from some 30 regional, national and international collaborators. The MyWorld creative hub, which spans the Bristol and Bath region, builds on the successes of the CDT in Communications, Bristol Vision Institute and Bristol's Smart Internet Lab. It will position the South West as an international trailblazer in creative media technologies. MyWorld aims to create new jobs and inward investment by building on regional strengths in creative media production, technology and research. It will provide 1,000 square metres of new collaborative R&D facilities, fund innovative research and development projects, improve skills and exploit digital formats to create new experiences in fiction, documentary, games and live performance. It will enable the region's creative sector and technology organisations to collaborate and connect regionally, nationally and globally.

Photo by Kenneth Hanes from Pexels

Postgraduate Research Conference

Industry, academic and postgraduate research students attended our Annual Research Conference on the 27th September 2019.

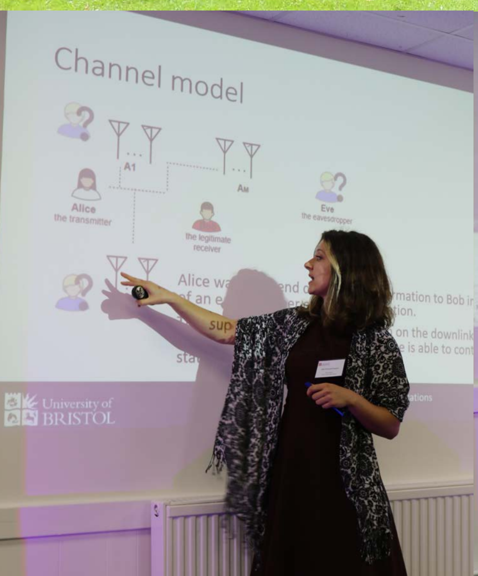
Our keynote speaker was Sylvia Lu, a member of the UK5G Innovation Network Advisory Board, member of the IET Communication Policy Panel, recognised in 2019 as one of the Top 50 Women in Engineering by the Women in Engineering Society, Tech Star 2017 winner and recognised for her work in the technology sector to help with promoting gender diversity in the sector. She spoke on the topic 'Thinking beyond the box – how to future proof your skills' and recomended to all present that the should "go beyond what makes you comfortable, break boundaries for a life beyond limits".

Postgraduates presented details of their latest research through posters, presentations and 3 minute pitches. The research topics included 'Reinforcement learning for network management applications', 'Detection of unusual behaviour in communication systems', 'Low cost novel phased array antennas', and 'Ray tracing optimisation techniques'

During the conference delegates had opportunities to network and discuss latest developments in the industry.

Roger Green,a current postgraduate, gave an insightful and entertaining presentation on the start-up company that he and others has established in the early 1990s - SynAppSys - and why although initially sucessful, it had failed, and the key lessons for others to note.

The CDT also welcomed back on of our alumnus Dr Wael Boukley Hasan who presented and answered questions on 'Research journey towards performance optimisation of sub-6GHz massive MIMO'.



PhD Projects commenced 2019

Moonas Ahmad

Power amplifier architectures for mmWave communications

The next generation of communication systems will make use of mm-Wave spectrum to achieve high data rate demands due to crowding of frequency bands below 6 GHz. Multiple mm-wave frequency bands are being allocated for future communications (e.g., 24/28/37/39 GHz). To achieve Gb/s data rates, mm-Wave communication systems will use spectrum-efficient modulation schemes (e.g., 64- and 256-QAM) and MIMO techniques. High order QAMs scheme waveforms have high peak-to-average power ratios (PAPRs) thus putting strict linearity requirement on power amplifier. Also, mm-Wave devices should be energy efficient in power back-off (PBO) to extend the battery life. This means that power amplifiers (PA) for mm-Wave application should be both linear and energy efficient which is hard to achieve due to trade-off between these two parameters.

But Gb/s data rates and >400MHz bandwidth target for mm-Wave communication entails additional challenges for PA design techniques. The signal processing for Digital Predistortion (DPD) will be complex and consume high dc power. Envelope tracking (ET) PAs will require high-speed supply modulators with wide dynamic range. Outphasing PAs require the generation of highspeed outphasing signals, demanding significant baseband overhead. Instead PA architecture such as Stacked-transistor, Doherty and switch-mode seems more suited for mm-wave system. Thus, the design approach will be to utilise Doherty PA architecture where Stacked-FETs will be used to implement main and auxiliary PAs to enhance efficiency and DPD techniques will be employed to increase linearity.

Faya Algatini

Micro- countermeasures for severely constrained IoT wireless embedded devices*

Most Internet of Things devices are resource-constrained in terms of power and memory. To communicate despite such constraints, the 6LoWPAN/RPL/TSCH stack synchronously routes compressed IPv6 packets in multi-hop wireless networks to and from a border router which acts as a gateway to the Internet. Although RPL performs adequately as a routing protocol for multi-hop wireless networks, it presents vulnerabilities which adversaries exploit to drain the aforementioned resources or disrupt routing paths. To counter such attacks, scholars have used countermeasures such as an Intrusion Detection System (IDS) to detect attacks and report them to an Intrusion Response Systems (IRS) which filter out their traffic and maybe create new policies to prevent this from happening in the future. There are different types of an IDS such as a signature-based or anomaly-based. As for IRS, it can be perceived as a firewall and maybe as a prevention system. Both countermeasures can be categorized in terms of deployment as centralized, decentralized or hybrid. The goal of this project is to develop an outlier detection via machine learning IDS and game-theoretical IRS which both are fully decentralized. First, implement and analyze most known RPL attacks and their combinations in Contiki-NG. Second, choose features and construct a training set for the machine learning algorithm. Finally, create perfect information extensive form games against attackers by calculating their payoffs, constructing game trees and finding Nash's Equilibrium via backward induction.

Obada Alia

Physical layer network security for the future internet

With the improvement of quantum computers, the current public encryption algorithms will be considered outdated; hence a new technology is required to secure the internet. Quantum Key Distribution (QKD) provides an unconditional secrecy based on the principles of quantum mechanics, and found to be the essential element in many cryptography applications. QKD protocols are divided into continuous-variable QKD (CV-QKD) and discrete-variable QKD (DV-QKD) protocols and a comparison in terms of performance, applications, and limitation is made. Two of the main limitations of QKD are that fact that the current available protocols only support end-end transmission and the relatively short effective range of transmission comparing to other security methods. Integrating QKD with the classical channels (co-existence) in a mesh-topology network is proposed with which to enhance the quality of the transmission and to provide a multi-hop connectivity using trusted nodes. The proposed solution has been integrated into a fully meshed metro network where a dynamic quantum channel is co-existed with four classical channels in the 5GUK Test Network. The results show the possibility of having such a network revealing the resource allocation and rerouting advantages for QKD networking.

Sebastian Kudera

Atmospheric ducting and over the horizon propagation

Atmospheric ducts, which are caused by the rapid decrease in the refractive index of the lower atmosphere, can trap the propagating signals. The atmospheric duct trapping effects can be used as a means of communication for links beyond-line-of-sight (b-LoS). In this work, the effects of atmospheric ducts on RF propagation when it takes place over water in the context of developing Smart City infrastructure are studied. Main characteristics of ducts are analysed, and it is found that due to its high rate of occurrence and strength the most promising type of duct is evaporation duct. Even the strongest ducts trap radiowaves at propagation angles only to within 1°. Drawbacks of atmospheric duct are overviewed. Ducting is found to create radar holes, inter-symbol interference and co-channel interference. To overcome those problems, optimal transmit and receive beam patterns should be designed and orthogonal frequency division multiplexing (OFDM) can be promising for the ducting layer if the channel creates high delay spreads. This work introduces the state-of-the-art methods for wave propagation modelling, the Parabolic Equation (PE) method, and the Ray-Optics (RO) method. The assumptions of the derivation, the advantages, and drawbacks of the PE and RO methods are discussed. A basic limitation of the RO model is that it assumes a horizontally homogeneous refractive environment and must be used over a flat surface, while parabolic methods cannot be used in estimating delay spreads and angle of arrivals. Therefore, characteristics of the channel can be estimated with hybrid models. Deep learning methods look

Sarmad Ozan

Frequency agile and resilient RF technologies

Millions of devices are susceptible to cyber-attacks due to the vulnerabilities in the Radio Frequency (RF) technologies used. Nowadays, society relies primarily on services provided by the Critical Infrastructures (CIs) such as health, transportation and public safety which can severely be affected in terms of functionality and stability if an adversary intent to degrade wireless connectivity by some means such as jamming. Therefore, it is desirable to have an agile and secure receiver architecture that works in different bands and can be adaptable to different standards. Carrier aggregation (CA) is a known technique to combine multiple component carriers (CCs) across the accessible spectrum, to improve network performance, but is problematic in implementation. This project addresses how wireless communication receiver RF technologies works and how it can be made resilient to attack by reviewing the advances in RF technologies including low-noise amplifiers, mixers, and filters; also how to avoid the overload on the receiver components from strong RF signals and non-linearity. Further, these devices need to be tuneable in frequency thus offering in the RF front-end making it adapt quickly to blocking signals from adjacent channels and allow multiband reception of the signal. Today's challenges are presented in terms of secure RF design with a connection to the spectrum allocations and regulations, and how the RF technologies can comply with these regulations.

Ioannis Papoutsidakis

Towards Massive, Ultrareliable and Low-Latency Wireless Communications

At the moment, the 5th generation of wireless networks (5G) is deployed around the world and several limitations of the system are exposed. For instance, only Enhanced Mobile Broadband (eMBB) of the three designated service classes is implemented and ready to be used. These shortcoming result to an emerging interest for the future wireless networks that must be innovative and at the same time cover the weaknesses of previous generations. In this work, a vision for the 6th Generation (6G) wireless networks is presented based on new technological trends and applications. The potential service classes for 6G, that can accommodate new applications, are presented and open research problems are discussed. We focus, especially, at a service class that connects 5G and 6G research, namely Ultrareliable and Low-Latency Communications (URLLC). The fundamental tradeoffs between rate, reliability, and latency are considered in the context of short packet communications and a new converse bound to the non-asymptotic achievable rate is developed for arbitrary channels. Additionally, the latency performance of potential new transmission schemes such as Non-Orthogonal Multiple Access (NOMA) is examined.

Simon Wilson

Secure dynamic spectrum access

"Secure By Design" initiatives are intended to ensure that wireless systems are built on secure foundations and include the ability to field-update the radio physical layer. Such security and agility will enable spectrum allocation through Dynamic Spectrum Access (DSA), a technique for improving spectrum usage based on instantaneous need in space and time, rather than fixed licensing. DSA has attracted much attention, with many administrations keen to promote its development and uptake, but will require secure sharing protocols and flexible, agile radios as well as robust detection mechanisms to identify unused spectrum. It is therefore timely to extend further wireless physical layer security research, to identify threats and find solutions that can be retrospectively applied to existing systems, and to influence the next generation of wireless standards, all the while raising awareness of potential problems. The initial approach to be taken in the Secure DSA project will be to: understand the vulnerabilities of sharing protocols by analysis of current and potential dynamic access protocols; identify the key features of robust detection mechanisms to identify unused spectrum; evaluate the security of protocols employed to manage spectrum sharing; establish a novel methodology to simulate potential economic benefits of DSA; develop a range of sensitivity tests; and undertake a cost-benefit analysis of DSA protocols.

Our Current & Past Collaborators

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Graduates

Congratulations to our postgraduates who have graduated in the last twelve months and who are now working in industry or academia around the world.

Michael Baddeley

Nakrop Jinaporn

Sam Young

Oliver Norman James

The Team

Professor David Bull

Director

Professor Mark Beach

Co-Director
Year 1 Tutor

Dr Simon Armour

Admissions Tutor, Taught Programme Director & Year 1 Tutor

Professor Kevin Morris

Group Project Co-ordinator

Professor Oliver Johnson

Years 2-4 Tutor

Dr Ayvandi Ganesh

Admissions Co-ordinator

University of BRISTOL

EPSRC Centre for Doctoral Training in Communications,
Merchant Venturers Building, Woodland Road, Bristol, BS8 1UB
Tel +44 (0)117 954 5395 Email cdt-communications@bristol.ac.uk

bristol.ac.uk