

Institution: University of Surrey		
Unit of Assessment: 12 Engineering		
Title of case study: Putting the UK in the driving seat in the race to 5G		
Period when the underpinning research was undertaken: 2008-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Rahim Tafazolli	Regius Professor of Electronic Engineering	February 1989 - present
Professor Ning Wang	Professor in Networks	November 2001 – present
Professor Pei Xiao	Professor of Wireless Communications	January 2011 - present
Period when the claimed impact occurred: 2013 - 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact (indicative maximum 100 words) <p>The 5G Innovation Centre (5GIC) has produced major impacts on the UK's 5G policy and put the UK in pole position in the race to 5G, worth £173 billion by 2030. £95 million from 26 major industrial partners and government was focused on UK research into 5G standards and roll out. Local Enterprise Partnerships (LEPs) were engaged to integrate 5G into regional economies and a network of over 300 Small and medium-sized enterprises (SMEs) created. 5GIC support was instrumental in Department of Digital Culture Media and Sport (DCMS) establishing a £200 million nationally co-ordinated programme of six regional 5G testbed facilities and trials, as part of over £1 billion of funding to boost UK digital infrastructure.</p>		
2. Underpinning research (indicative maximum 500 words) <p>From as early as 2000, Surrey academics – ahead of their time – had the vision of 5G as a flexible, software defined and context aware network.</p> <p>Basic research was conducted on enablers to realise this vision up to 2012. In 2012, the opportunity arose via national funding to set up a National 5G centre and testbed. We were successful with a bid to HEFCE for £13 million combined with a £26 million matching support from industry. Hence 5GIC was set up in a new building together with a campus wide small cell network to enable industry and academia to work together towards 5G. The formation of this unique centre was based on Surrey's critical mass of ground-breaking 5G orientated research and its close contacts with industry. Examples of the research were as follows:</p> <p>A new network architecture In [R1], specific virtual resource provisioning and control issues/strategies were proposed, and these contributed to the formation of the network slicing concept subsequently adopted in 5G. Also discussed are major technical challenges in achieving end-to-end service assurance based on unified virtual resources contributed from multiple autonomous operators. This paved the way to 5GUK which aims to provide end-to-end slice service from collaborative 5G operators.</p> <p>Low density signature (LDS) to Non-orthogonal Multiple Access (NOMA)</p>		

In [R2] the concept of changing the interference patterns seen by users via LDS was proposed and shown to increase loading by 250%. This was later named NOMA and is currently a strong candidate for inclusion into 5G standards as a multiple access scheme for Internet of Things (IoT), allowing larger numbers of IoT devices to efficiently use the available spectrum.

From 2013 to date, 5GIC has made additional key research contributions to the 5G architecture, examples of which follow:

Split control and user planes

The system architecture involving split control and user planes and a complete virtualisation of the system [R3] proposed and implemented by 5GIC has been adopted by 3rd Generation Partnership Project, 3GPP, the global standards body for 4G and 5G technologies.

A new radio air interface

A complete systematic approach to filtered-orthogonal frequency division multiplexing (f-OFDM) has been produced enabling it to be adopted as the 5G standard New Radio air interface [R4]. A multi-rate OFDM system was also proposed to enable integration of narrow band IoT with enhanced mobile broadband and radio access network slicing was proposed for the first time as an integral part of 5G.

Millimetre wave beam steering

A hybrid beamforming technique for use in massive multi-input multi-output (MIMO) systems which achieves the performance of an all-digital system but is less complex, cheaper and more energy efficient was produced [R5]. This practical implementation of beam steering in small millimetre wave cells, which originated in [R6] was demonstrated within the 5GIC testbed.

3. References to the research (indicative maximum of six references)

The quality of the underpinning research is evidenced through the publication of scientific papers in peer reviewed journals and conferences.

[R1] N. Wang, Y. Zhang, J. Serrat, J. L. Gorricho, T. Guo, Z. Hu and P. Zhang, *A Two-Dimensional Architecture for End-to-end Resource Management in Virtual Network Environments*, IEEE Network, special issue on Wired and Wireless Network Virtualisation, Vol. 26, Issue 5, 2012, pp. 8-14 DOI: [10.1109/MNET.2012.6308069](https://doi.org/10.1109/MNET.2012.6308069)

[R2] R.Hoshyar, F.Watham and R.Tafazolli, *Novel low density signature for synchronous CDMA systems over AWGN channel*, IEEE Trans on Signal Processing Vol 56, No 4 April 2008. DOI: [10.1109/TSP.2007.909320](https://doi.org/10.1109/TSP.2007.909320)

[R3] Lake, G. Foster, S. Vural, Y. Rahulan, B.-H. Oh, N. Wang, and R. Tafazolli, *Virtualising and orchestrating a 5G evolved packet core network*, IEEE Conference on Network Softwarization (NetSoft), July 2017 DOI: [10.1109/NETSOFT.2017.8004215](https://doi.org/10.1109/NETSOFT.2017.8004215)
 “5G Mobile Core Network Slicing on an Orchestrated and Virtualised Infrastructure”
<https://www.softfire.eu/wp-content/uploads/SoftFIRE-White-Paper-on-Network-Slicing.pdf>

[R4] Lei Zhang, Ayesha Ijaz, Pei Xiao, Atta Quddus, and Rahim Tafazolli, *Subband Filtered Multi-Carrier Systems for Multi-Service Wireless Communications*, IEEE Transactions on Wireless Communications, vol. 16, no. 3, March 2017. DOI: [10.1109/TWC.2017.2656904](https://doi.org/10.1109/TWC.2017.2656904)

[R5] Mehdi Molu, Pei Xiao, Mohsen Khalily, Kanapathippillai Cumanan, Lei Zhang and Rahim Tafazolli, *Low-Complexity and Robust Hybrid Beamforming Design for Multi-Antenna Communication Systems*, IEEE Transactions on Wireless Communications, vol. 17, no. 3, pp. 1445-1459, March 2018. DOI: [10.1109/TWC.2017.2778258](https://doi.org/10.1109/TWC.2017.2778258)

U.K. patent “Beamforming in Multiple Input Multiple Output Systems” (reference number GB1617390.8) October 2016

[R6] Heliot F, Imran MA, **Tafazolli R**, *Energy-efficient Power Allocation for Point-to-point MIMO System over the Rayleigh Fading Channel*, IEEE Wireless Communications Letters, Aug 2012, vol. 1, issue 4, pages 304-307 DOI: [10.1109/WCL.2012.042512.120147](https://doi.org/10.1109/WCL.2012.042512.120147)

4. Details of the impact (indicative maximum 750 words)

Global adoption of 5G will create innovative new digital services based on ultra-secure, ultra-high-capacity real-time capability for wireless augmented and virtual reality. Applications in autonomous and intelligent transport, digital healthcare, robotic control and up to one million IoT devices per square kilometre will be worth £173 billion to the UK economy by 2030 [S1]. Although the UK played an active role in 2G (GSM) cellular standards, it fell behind in 3G and 4G. The goal behind 5GIC was to create a catalyst with our industry partners to help put the UK back into contention in the global race in research and development of 5G technologies [S2]. With 26 corporate members and over 300 SMEs, the 5GIC programme value now totals £95 million: £63 million from industry members and £32 million from government and regional bodies.

Creating an ‘innovation’ centre, where industry freely exchanged ideas with researchers, delivered a massive dividend. We were the only centre in the world to realise that 5G could not be rolled out on a single mmWave band but needed three bands that we called “5G pioneer bands” [S3]. A measure of our impact is the 30-fold increase in the value of one of the 5G pioneer bands changing the direction of 5G in Europe and leading to 5G reaching tens of millions more European consumers than would have been the case if 5G was solely a mmWave story [S4].

We have been one of the first in the world to demonstrate a fully operational 5G network [S5] and have contributed patents and technical papers to key 5G standards bodies. The UK Government ‘Future Telecoms Infrastructure Review’ in July 2018 [S6] cites the part played by the 5GIC 5G testbed (para 210) and the role that 5GIC had in the creation of these pioneer bands (para 218).

5GIC’s Impact on the National 5G Development Agenda

5GIC reached out to create collaborations across the UK regional Local LEPs [S7], connecting to the Midlands Engine and the Northern Powerhouse as well as individual companies such as McLaren, Bosch, Qinetiq and Airbus, all important potential future users of 5G technology. In 2016, the DCMS set up the national Future Communications Challenge Group, with 5GIC being one of the key contributors to the resultant report [S8]. The report recommended the creation of a national 5G Research and Development Hub which would support a series of large scale national 5G testbed demonstrators, each focusing on major applications for 5G in different sectors of the economy. A key goal was to help increase UK productivity by establishing a much more effective national mobile internet network [S8].

5GIC led the first phase of this £176 million programme in a £16 million collaboration with the Universities of Bristol and King’s College London to deliver the 5GUK R&D Hub [S9] in March 2018, culminating in the world’s first demonstration of a 5G Network of Networks at the Barcelona World Congress of 2018, showcasing the UK’s 5G capability.

5GIC reach out to Regional Testbeds in Industry and the rural community

Following delivery of the 5GUK Hub, DCMS launched a £25 million competition for large scale 5G demonstrator testbeds. 5GIC worked with multiple partners in developing bids on an open collaboration basis to ensure that all the bids maximised potential for common approaches to the core technology. As a result, 5GIC is providing specialised core network services and research and development expertise to three of the largest DCMS Testbed and Trials programmes:

- **The Worcestershire 5G Consortium** – The country’s most comprehensive industrial 5G testbed trial with a team of 5G specialists and business experts pioneering the concept of ‘Industry 4.0’ [S10].
- **AutoAir** is making 5G technologies available for the validation and development of Connected and Autonomous Vehicles at the UK’s premiere vehicle proving ground at Millbrook.

- **5G RuralFirst**, led by Cisco and lead partner University of Strathclyde, will deliver testbeds and trials to exploit 5G benefits for rural communities and industries like agriculture, broadcasting, and utilities.

Many regional initiatives running today owe their existence to early, formative discussions at 5GIC. 5GIC has shaped and strengthened the UK's global position in the race for 5G.

"The first commercial 5G networks are now beginning to roll out and the pace of adoption will continue to accelerate significantly. 5GIC has played a very significant role in shaping the development of key aspects of 5G architecture, technologies and standards and ensuring that the UK is ready to adopt 5G at a pace which will improve the UK's position with international competition." Head of Group R&D Vodafone **[S4]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] CBI report 7th Dec 2018 Ready SET connect (p16)

<https://cbicdnend.azureedge.net/media/1167/cbi-ready-set-connect.pdf?v=20190418.4>

[S2] 5GIC staff and company members made significant input to and were responsible for the final editing of the Future Communications Challenge Group (FCCG) Report published in January 2017.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/582640/FCCG_Interim_Report.pdf

Letter of support from Professor Michael Short CSA Department of International Trade (PDF)

[S3] Supporting the European 5G initiative (spectrum) https://5g-ppp.eu/wp-content/uploads/2017/10/Euro-5G-D5.4_Spectrum_for_5G_v1.0.pdf

[S4] Letter of support from Head of Group, R&D Vodafone (PDF)

[S5] 5G UK Exchange debuts at Mobile World Congress 2018

<https://www.surrey.ac.uk/news/british-universities-debut-worlds-first-5g-end-end-network-mobile-world-congress>

[S6] UK Government 'Future Telecoms Infrastructure Review' July 2018 (p63-65, paras 210, 218)

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/732496/Future_Telecoms_Infrastructure_Review.pdf

[S7] Supporting regional SMEs

<https://www.surrey.ac.uk/news/5gic-provides-boost-regional-small-and-medium-sized-enterprises-smes>

[S8] Future Communications Challenge Group report Jan 2017

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/582640/FCCG_Interim_Report.pdf

DCMS report Dec 2017 – Next Generation Mobile Technologies: An Update to the 5G Strategy for the UK (p16)

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/677598/Next_Generation_Mobile_Technologies_An_Update_to_the_5G_Strategy_for_the_UK_Final_Version_with_Citation.pdf

[S9] DCMS Press release, March 2018, <https://www.gov.uk/government/news/25m-for-5g-projects-on-the-anniversary-of-the-uks-digital-strategy>

Announcing the winners of a £25 million competition to pave the way for a future rollout of 5G technology in the UK in which 5GIC is providing core 5G support to 3 of the 6 successful projects - Margot James, Minister of State for Digital and the Creative Industries, said:

“One year on from the Digital Strategy, we are delivering on our commitments to create a Britain fit for the future, with a thriving digital economy that works for everyone. The ground-breaking projects announced today will help to unlock 5G and ensure the benefits of this new technology are felt across the economy and wider society.”

[S10] Worcestershire LEP Industry 4.0 5G Test Bed Project

<http://www.wlep.co.uk/worcestershire-chosen-government-home-new-5g-testbed-putting-forefront-technological-innovation/>

Letter of support from Chair of Worcester LEP