Institution: University of the West of Scotland		
Unit of Assessment: 11: Computer Science and Informatics		
Title of case study: Leading international 5G innovations and shaping global standards and policy		
Period when the underpinning research was undertaken: 2015 - 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:**
Jose Alcaraz Calero Qi Wang	Professor Professor	2013 - 2020 2008 - 2020
Period when the claimed impact occurred: 2015 - 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

University of the West of Scotland (UWS) plays a pivotal role in Europe's global leadership in 5G – a vital technology used across a wide range of crucial sectors, including energy, healthcare, security etc. UWS' ground-breaking research has led the development of Europe's 5G Golden Nugget innovation, and visions encapsulated within official White Papers. UWS' 5G network management and control solutions have been deployed in the 5G trial testbeds of several leading 5G industries. Furthermore, UWS' pioneering research has directly led to the development of the ITU (International Telecommunication Union) and ETSI (European Telecommunications Standards Institute) global ICT standards – essential to interoperability and innovation of international ICT systems. Further impact on national policies was achieved in the Scotland's AI Strategy.

2. Underpinning research

Research originality, rigor and quality: University of the West of Scotland's (UWS) Beyond5GHub team with the AVCN (Artificial-Intelligence, Visual Communications and Networks) Centre has been intensively researching 5G since 2014, leveraging UWS and industry partners' 5G testbeds, and producing internationally leading 5G innovations in enabling technologies and applications. The outstanding quality of the research was recognised by an international expert evaluation panel ("Exceptional results" in the official EU project evaluation report), and worldwide peer reviewers for leading journal publications (including 10+ IEEE transaction/journal papers).

Research outcomes and significance: Highlighted UWS outcomes include solutions for a novel autonomous network management framework to achieve 'self-organising' 5G networks. These solutions enable the automatic detection, and resolution, of a range of common network problems and fulfil essential network management tasks (traffic optimisation, service creation and infrastructure deployment and protection, etc.) that are currently manually addressed by network operators, resulting in substantial operating expenditure reduction. 5G real-time traffic 'self-optimisation' capability and multi-tenant-aware network monitoring are enabled by novel 5G-UHD **[3.1]** and 5G-QoE techniques to reduce up to 50% of bandwidth requirements for video traffic – which itself represents 80% of worldwide traffic – without compromising users' Quality of Experience (QoE), even when the network is experiencing cyberattacks or congestion. Moreover, UWS led the achievement of one of the six European 5G-PPP KPIs on the reduction of service creation time, decreasing from 90 hours to 90 minutes, by producing a novel on-demand one-click 5G infrastructure deployment solution **[3.2]** to automatically deploy and configure a new 5G edge network from bare-metal commodity computers in less than 40 minutes, significantly reducing both capital expenditure and operating expenditure. The pioneering self-organising framework was further applied to 'self-protection' against cyberattacks **[3.3].**

UWS has also focused on developing the cornerstone 5G technology 'Network Slicing', and successfully achieved massive (approximately 1,000,000 per 4 software switches) data-plane network slices **[3.4]** in super-fast networks (up to 100 Gbps) with guaranteed Quality of Service for multiple verticals over the same infrastructure, with significant reduction in capital expenditure and new business models enabled. The solutions were demonstrated in various use cases; for example,

saving lives by enabling 5G ambulance eHealth **[3.5]** for early stroke assessment during transit, and Smart Grid self-healing to protect critical energy infrastructure. To enable intuitive management of complex virtualised 5G networks, a novel augmented reality-based holographic network monitoring and management solution **[3.6]** was created, enabling visualisation of millions of 5G network nodes and multiple virtual network operators concurrently. Furthermore, UWS collaborated with other international 5G projects, including ANASTACIA on 5G-IoT security management **[3.3]**, and MATILDA on 5G Smart City lighting.

International research leadership: The above outcomes were achieved through several UWS-led international 5G projects, including two large EU Horizon 2020 Research & Innovation projects, SELFNET (Phase-1) and SliceNet (Phase-2). UWS technically led the projects, coordinating the R&D with global 5G players and beneficiaries including Orange, DellEMC, Altice ("Portugal Telecom"), Ericsson, IBM, EFACEC, etc.

Generate further income towards 6G: UWS has secured two new EU Horizon2020 5G Phase-3 projects, 6G-BRAINS (H2020-ICT-2020-2/101017226, EUR5,700,000) and 5G-INDUCE (H2020-ICT-2020-2/101016941, EUR6,000,000), from 2020 to 2022 to investigate advanced 5G towards 6G.

3. References to the research

3.1 Salva-Garcia, P., **Alcaraz-Calero, J., Wang, Q.,** Arevalillo-Herraez, M. and Bernal Bernabe, J., (2020) Scalable Virtual Network Video-Optimizer for Adaptive Real-Time Video Transmission in 5G Networks. *IEEE Transactions on Network and Service Management*, 17(2): 1068-1081. https://doi.org/10.1109/TNSM.2020.2978975.

3.2 Chirivella-Perez, E., **Calero, J., Wang, Q**. and Gutiérrez-Aguado, J., (2018) Orchestration Architecture for Automatic Deployment of 5G Services from Bare Metal in Mobile Edge Computing Infrastructure. *Wireless Communications and Mobile Computing:* 5786936. https://doi.org/10.1155/2018/5786936.

3.3 Zarca, A., Bernabe, J., Skarmeta, A. and **Alcaraz Calero, J.,** (2020) Virtual IoT HoneyNets to Mitigate Cyberattacks in SDN/NFV-Enabled IoT Networks. *IEEE Journal on Selected Areas in Communications*, 38(6): 1262-1277. https://doi.org/10.1109/JSAC.2020.2986621.

3.4 Matencio-Escolar, A., **Wang, Q. and Alcaraz Calero, J.,** (2020) SliceNetVSwitch: Definition, Design and Implementation of 5G Multi-Tenant Network Slicing in Software Data Paths. *IEEE Transactions on Network and Service Management*, 17(4): 2212-2225. https://doi.org/10.1109/TNSM.2020.3029653.

3.5 Wang, Q., Alcaraz-Calero, J., Ricart-Sanchez, R., Weiss, M., Gavras, A., Nikaein, N., Vasilakos, X., Giacomo, B., et.al, (2019) Enable Advanced QoS-Aware Network Slicing in 5G Networks for Slice-Based Media Use Cases. *IEEE Transactions on Broadcasting*, 65(2): 444-453. https://doi.org/10.1109/TBC.2019.2901402.

3.6 Sanchez-Navarro, I., Serrano Mamolar, A., **Wang, Q. and Alcaraz Calero, J.,** (2021) 5GTopoNet: Real-time topology discovery and management on 5G multi-tenant networks. *Future Generation Computer Systems*, 114: 435-447. https://doi.org/10.1016/j.future.2020.08.025.

Grants

3.A Wang, Q., Calero, J., Keshav, D.,"*SELFNET: Framework for Self-Organised Network Management in Virtualized and Software Defined Networks*" European Commission: Horizon 2020 5G-PPP scheme, Jul 2015 to June 2018, EUR6,866,496.

3.B Wang, Q. , Calero, J., "*SliceNet: End-to-End Cognitive Network Slicing and Slice Management Framework in Virtualised Multi-Domain, Multi-Tenant 5G Networks*" European Commission: Horizon 2020 5G-PPP scheme, June 2017 to June 2020, EUR7,979,030

4. Details of the impact

Develop Europe's 5G vision, innovation and trials

5G Infrastructure Public Private Partnership (5G-PPP) is the leading joint programme between the European Commission (EC) and European ICT industry, to deliver 5G architectures, technologies and standards – UWS research and influence has played an important role in shaping its decisions.

5G-PPP Technology Board (TB) has adopted the following 5G-PPP programme-level "Golden Nuggets" (flagship European 5G innovation achievements) – influenced by UWS research though UWS Board members **Alcaraz Calero** and **Wang**. These include: 5G PPP Phase 1 Golden Nuggets **[5.1]:** "Autonomic network management" **[3.1, 3.3],** "Automated physical and virtual infrastructure deployment" **[3.2],** and "Multi-level, multi-tenant-aware network monitoring" **[3.6];** and 5G PPP Phase 2 Golden Nuggets **[5.1]:** "AI-empowered cognitive network management & orchestration" **[3.5],** and "End-to-end multi-domain multi-tenants network slicing" [**3.4, 3.5].**

10 high-profile and widely-cited official 5G-PPP White Papers commissioned by the EC, and co-authored by UWS, have led the EC to adopt the vision on 5G Autonomous network management architecture **[5.2]** and 5G Software-Defined Networking (SDN) and Network Function Virtualisation (NFV) integration **[5.2]**, strategies on 5G innovations for new business opportunities, especially service creation and security **[5.3],** and network slicing trials for eHealth **[5.3].**

UWS was the only Scottish university in 5G-PPP, and one of the very few UK universities that technically led both Phase-1 (SELFNET) and Phase-2 (SliceNet) projects; thereby being positioned to influence Europe's 5G vision, strategies, innovation and trials, and bringing to bear world-leading UK academic expertise.

Create global impact through international standardisation

Working with the International Telecommunication Union (ITU) and European Telecommunications Standards Institute (ETSI), UWS has led the standardisation in relation to six official standardisation Work Items, focusing on cognitive/intelligent management and control of Network Slicing – a key enabler in 5G for network operators and vertical businesses. Two of these Work Items have been approved as ITU Draft Recommendations **[5.4, 5.5]** ("The impact of interoperability and innovation enabled by the above work items extend beyond the current networks into foreseeable future", as acknowledged by ITU FG-AN Vice Chair)], one approved as ETSI POC (Proof-of-Concept) etc. **[5.6]** in collaboration with Orange, Altice, DellEMC, IBM etc. ITU is the United Nations' world-leading standardisation organisation for mobile telecommunications. ETSI, on the other hand, is responsible for establishing European and globally applicable ICT standards. Such exceptional achievements were particularly appreciated in the project final review **[5.9].**

Moreover, UWS influenced de-facto industry standards via open source projects: Open vSwitch (de-facto software-networking platform) benefited from UWS' enabling 5G-compatible processing capabilities **[5.6]**; OpenAirInterface (leading global 5G infrastructure platform) benefited from UWS' 5G topology management facility **[5.6].**

Impact on Europe's commercial 5G networks and vertical business trials

Orange Group's first commercial 5G network in Romania was launched on 5 November 2019, benefiting from UWS-led SliceNet and UWS development of mobile edge computing (MEC) (as acknowledged by Orange Development & Innovation Manager **[5.7]** and CEO **[5.9]**). UWS' 5G network slice solutions have been deployed in the 5G trial testbeds of leading European 5G industries including DellEMC (Ireland), Orange Romania, Altice (Portugal) etc.

Importantly, UWS developed Network Slicing trials for service quality assurance in eHealth, with DellEMC and Irish Ambulance Services, to reduce fatalities of onboard stroke patients by 25% **[5.3]** (as acknowledged by DellEMC Principal Research Scientist **[5.8]**), and in Smart Grid Self-Healing with the largest Portuguese energy company EFACEC, to reduce maintenance costs by up to 20% (as acknowledged by EFACEC Director of Technology and Innovation **[5.8]**). UWS

technologies were also applied to smart city lighting system in Bucharest with Orange Romania, to reduce energy costs by 77% (as acknowledged by Orange Development & Innovation Manager **[5.7]**). The UWS-led 5G autonomous network management solution was deployed in Altice, leading to the ETSI POC **[5.6]** (as acknowledged by Altice AI/Cognitive Solution Architect **[5.7]**).

Policy and wider impact

UWS' beneficial impacts, in terms of knowledge transfer to industries, have been further recognised through a highly prestigious national accolade: UK Times Higher Education (THE) Awards 2020 - Knowledge Exchange/Transfer Initiative of the Year Award **[5.10]**. "The judges applauded how the team had built on successive projects to demonstrate life-saving applications, commending the 'growing stature of the academic team and their work to create AI-based business solutions'." **[5.10].**

In recognition of its demonstratable world-leading expertise in 5G-AI **[5.10]**, UWS was invited as a Member of Scotland's AI Strategy - Developing AI & AI Enabled Services and Products Working Group **[5.10]**, to have helped the Scottish Government in defining its nationwide AI strategy for businesses and research through extensive consultation in 2020. The Scotland's AI Strategy has been recently launched **[5.10].**

5. Sources to corroborate the impact

5.1 EU 5G-PPP News/Reporting on Programme-Level Golden Nuggets (Phase-1 and Phase-2):

- EU 5G PPP Newsflash, "5G PPP Phase 1 Golden Nuggets", available at https://5g-ppp.eu/newsflash-august-2017/
- EU 5G PPP Periodic Reporting for Period 2 – SLICENET, available at https://cordis.europa.eu/project/id/761913/reporting/es

5.2 EU 5G-PPP White Papers on 5G Architecture and Vision:

- EU 5G PPP Architecture Working Group (including Q. Wang and J. Alcaraz Calero), "5G PPP View on 5G Architecture, Version 3.0", Jun 2019, available at https://5g-ppp.eu/wp-content/uploads/2019/07/5G-PPP-5G-Architecture-White-Paper_v3.0_PublicConsultation.pdf.
- EU 5G PPP Software Networking Working Group (including J. Alcaraz-Calero and Q. Wang), "Vision on Software Networks and 5G", Jan 2017, available at https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP_SoftNets_WG_whitepaper_v20.pdf.

5.3 EU 5G-PPP White Papers on 5G Businesses and Trials:

- EU 5G PPP (including Q. Wang and J. Alcaraz-Calero), "5G Innovations for New Business Opportunities", 5G PPP White Paper, Feb 2017, available at https://5g-ppp.eu/wp-content/uploads/2017/03/5GPPP-brochure-final-web1-with-Author-credits.pdf.
- EU 5G PPP Trials Working Group (including J. Alcaraz-Calero and Q. Wang), "The 5G PPP Infrastructure -Trials and Pilots Brochure", Sept 2019, available at https://5g-ppp.eu/wp-content/uploads/2019/09/5GInfraPPP_10TPs_Brochure_FINAL_low_singlepages.pdf.

5.4 International Standard on 5G Cognitive/Intelligent Network Slicing Management:

- Draft Recommendation ITU-T Y.ML-IMT2020-E2E-MGMT "Machine learning based end-to-end multi-domain network slice management and orchestration", July 2020. Members Only Access. (Please refer to Testimonial from ITU Focus Group on Autonomous Networks (FG-AN), 2021.)

5.5 International Standard on 5G Cognitive/Intelligent Network Slicing Control:

- Draft Recommendation ITU-T Y.ML-IMT2020-VNS "Framework for network slicing management enabled by machine learning including input from verticals", July 2020. Members Only Access. (Please refer to Testimonial from ITU Focus Group on Autonomous Networks (FG-AN), 2021.)

5.6 Other International Standardisation by Leading SliceNet Work Package (WP) on Standardisation as WP Leader and UWS Open Source Software for De-facto Industry Standards**:**

- Standardisation contributions to ETSI POC etc.: https://slicenet.eu/slicenet-poc-contributions/.
- De-facto industry standard open source projects contributions to Open vSwitch: https://slicenet.eu/slicenet-repository-of-opensource-software-components-developed-in-the-project/.
- De-facto industry standard open source projects contributions to Open Air Interface: https://openairinterface.org/ and https://gitlab.eurecom.fr/oai/openairinterface5g.

5.7 5G Telecom Operators' Testimonials:

- Testimonial from Orange Romania, 2021.
- Testimonial from Altice Labs (Portuguese Telecom), 2021.

5.8 5G Vertical Businesses' Testimonials:

- Testimonial from Dell Technologies, 2021.
- Testimonial from EFACEC Serviços Corporativos, SA, 2021.

5.9 Media Coverage:

- Orange begins 5G services with roll-out in Romania, available at https://www.computerweekly.com/news/252473634/Orange-begins-5G-services-with-roll-out-in-Romania, 7th Nov 2019.
- Exceptional results reported from the European Commission at SliceNet's final review, available at: https://5g-ppp.eu/exceptional-results-reported-from-the-european-commission-at-slicenets-final-review/, Jul 2020.

5.10 Policy and Wider Impact Including THE Awards:

- Winner of Times Higher Education (THE) Awards 2020 -Knowledge Exchange/Transfer Initiative of the Year Award, Nov 2020, available at https://www.the-awards.co.uk/2020/en/page/2020-winners.
- UWS Beyond5GHub 5G-AI demos, available at http://beyond5ghub.uws.ac.uk/.
- Scotland's AI Strategy - Developing AI & AI Enabled Services and Products Working Group, available at https://www.scotlandaistrategy.com/working-groups.
- Scottish Government news on launching the Scotland's AI Strategy: https://www.gov.scot/news/unlocking-the-potential-of-artificial-intelligence/
- The Scotland's AI Strategy. https://www.scotlandaistrategy.com/news/scotlands-ai-strategy-launched