Institution: University of Kent

Unit of Assessment: 12: Engineering

Title of case study: Optimising Wireless Mobile Communication Technologies, Advancing Telecommunication Business Performance, and Informing International Standards

Period when the underpinning research was undertaken: 2006-2018

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Periods employed by submitting HEI:
Professor Jiangzhou Wang	Professor of Telecommunications	2005-present
Professor Nathan Gomes	Professor of Optical Fibre Communications	1989-2020
Dr Huiling Zhu	Reader in Communications	2006-present
Dr Philippos Assimakopoulos	Lecturer in Electronic Systems	2014-present

Period when the claimed impact occurred: 2014-present

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact (indicative maximum 100 words)

Kent's research on mobile communication has led to significant advances in distributed wireless transmission technologies, including user-selected algorithms in cloud radio access networks (Gomes, Wang, Zhu), indoor distributed antenna systems (Wang, Zhu), radio over fibre and optical fronthaul technologies, and the use of Ethernet in the fronthaul (Assimakopoulos Gomes). The team led the prestigious EPSRC NIRVANA and EU Horizon 2020 iCIRRUS 5G projects. Their combined research and expertise have been widely adopted by international telecommunications providers and vendors, including ThreeUK, BT, ADVA, and VIAVI. This has led to direct impacts on innovation and improved business performance through the design and delivery of new technologies. Kent's expertise has also been instrumental in the development of new IEC and IEEE standards and specifications for radio over fibre and fronthaul transport technologies.

2. Underpinning research (indicative maximum 500 words)

Advances in mobile communication technologies are essential to provide sufficient and reliable communication services to meet the demand on mobile network capacity from ever-increasing internet use. However, transmission quality can be adversely affected by the out-of-date and limiting infrastructure of mobile base stations, which are often too far from the mobile devices connecting with them.

Multi-antenna and cell densification is one of the key technologies in mobile communications. Because transmit power is limited, wireless transmission distance cannot be too large when the data rate is very high. In order to achieve a reasonable coverage area for each cell, antennas that are centrally attached to the base station in conventional mobile systems must be distributed throughout the entire cell, thus shortening the wireless transmission distance between mobile terminals and base station antennas. The use of this technology is of paramount importance in providing the services now demanded in wireless/mobile networks. However, the interconnection of these numerous and distributed antennas to the mobile operators' fixed networks is a significant challenge, requiring joint design of the wireless/mobile system and the fixed (usually optical fibre) system. By bringing together internationally leading expertise in wireless multi-antenna systems and resource allocation design (Wang and Zhu) and radio over fibre and optical fronthaul technologies (Gomes and Assimakopoulos), the Kent team placed itself in a unique position to address this challenge.

Radio over fibre and optical fronthaul technologies

In **2006**, Gomes defined how radio over fibre distribution networks for the support of indoor distributed antenna systems (DAS) could be designed **[R1].** In **2012**, he published a monograph in which he demonstrated the benefits that radio over fibre could bring by eliminating or mitigating the perceived barriers to the use of coordinated multipoint, a technique for the cooperative operation of geographically distributed antennas **[R2]**. Gomes's research highlighted the significant need for standardisation in this area, to support the development of future mobile/wireless systems **[R2]**.

Wireless multi-antenna systems and resource allocation

In **2013-15**, Wang and Zhu studied the spectral efficiency of an in-building DAS with frequency reuse **[R3, R4]**. They proposed a scheme that exploits the penetration loss of the signal through the floors, resulting in frequency reuse in spatially separated floors, which increases system spectral efficiency and also reduces co-channel interference, which was comparatively assessed against conventional co-located antenna deployment at the floor centre.

These research strands were bought together in **2017** when Gomes, Wang, and Zhu proposed a low-complexity user selection algorithm in a cloud radio access network (C-RAN) that showed much greater power savings than the previous method, with insignificant performance loss **[R5]**. The C-RAN, a development of the DAS concept, has become one of the key technologies in the international 5G international mobile standard (i.e. 3GPP).

Fronthaul technology that can enable C-RANs for 5G and beyond networks is a significant challenge. The idea of using Ethernet in the fronthaul was proposed and tested through Kent's involvement in the EPSRC NIRVANA project (**2014-18**), for which Gomes was lead investigator, and the EU Horizon 2020 iCIRRUS 5G project (**2015-17**), on which Gomes was technical manager, with leadership in the wireless aspects coming from Wang and Zhu, and significant research work being undertaken by Assimakopoulos **[R6]**. NIRVANA and iCIRRUS were aimed at identifying the benefits and limitations of using Ethernet in the fronthaul of future mobile networks (5G and beyond), whilst also demonstrating such networks' usability. The iCIRRUS project, which involved eight industry partners, including Orange, VIAVI, and ADVA, as well as BT and Nokia in an advisory capacity, was the pioneering EU project in the important area of Ethernet in the fronthaul.

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

[R1] Das, A., Nkansah, A., **Gomes, N. J.**, Garcia, I. J., Batchelor, J. C., and Wake, D. (**2006**). 'Design of low-cost multimode fiber-fed indoor wireless networks'. *IEEE Transactions on Microwave Theory and Techniques* 54(8): 3426-3432. doi: 10.1109/TMTT.2006.877835.

[R2] Gomes, N. J., Monteiro, P. P., and Gameiro, A. (**2012**). *New Generation Wireless Communications Using Radio Over Fiber*. London: John Wiley & Sons. doi: 10.1002/978118306017.

[R3] Osman, H., **Zhu, H.**, and **Wang**, J. (**2013**). 'Achievable rate evaluation of in-building distributed antenna systems'. *IEEE Transactions on Wireless Communications* 12(7): 3510-3521. doi: 10.1109/TWC.2013.060513.121755.

[R4] Alade, T., **Zhu, H.**, and **Wang**, J. (**2015**). 'Uplink spectral efficiency analysis of in-building distributed antenna systems'. *IEEE Transactions on Wireless Communications* 14(7): 4063-4074. doi: 10.1109/TWC.2015.2416235.

[R5] Pan, C., **Zhu, H.**, **Gomes, N. J.**, and **Wang, J.** (**2017**). 'Joint Precoding and RRH selection for User-centric Green MIMO C-RAN'. *IEEE Transactions on Wireless Communications* 16(5): 2891-2906. doi: 10.1109/TWC.2017.2671358.

[R6] Gomes, N. J., Sehier, P., Thomas, H., Chanclou, P., Li, B., Munch, D., **Assimakopoulos, P.**, Dixit, S., and Jungnickel, V. (**2018**). 'Boosting 5G through Ethernet: how evolved fronthaul can take next-generation mobile to the next level'. *IEEE Vehicular Technology Magazine* 13(1): 74-84. doi: 10.1109/MTV.2017.2782358.

Grants

Since 2010, Kent has been funded by more than 20 grants in the field of mobile communications, with a total of more than £4 million from various funding sources, including EPSRC, EU Horizon2020/FP7, Royal Society, Royal Academy of Engineering, and industrial partners.

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

Since **2014**, the Kent team's collective research and expertise in mobile communication technologies have fostered widespread benefits across the sector. The team has a strong and longstanding history of collaboration with leading international telecommunications providers and vendors, including ThreeUK, British Telecom, ADVA, and VIAVI, as well as industry bodies such as the Institute for Electrical and Electronics Engineers (IEEE) and International Electrotechnical Commission (IEC). Through pathways such as their lead involvement in the iCIRRUS and NIRVANA projects, and via consultancy and specialist roles, the team's research has led to direct impacts on innovation and improved business performance through the design and delivery of new technologies. Examples are provided below.

Improving ThreeUK's network quality and service optimisation

In March 2020, ThreeUK carried 35% of the UK's mobile data. Seven years earlier, however, in March 2014, ThreeUK was unable to provide high data-rate indoor wireless transmission within multi-floor buildings. To contribute to ThreeUK's technology development, in **2014-15** Wang was seconded to ThreeUK, and in that capacity he 'transferred novel multi-antenna transmission ideas and his latest knowledge and innovations of frequency reuse in indoor DAS to ThreeUK's technology' **[a]**. As ThreeUK's Head of Network Technology confirms: 'As a direct result of the project and Professor Wang's input and leadership, the following outcomes were achieved: first, we developed innovative solutions for different building mobile deployment systems […]; second, we identified and optimised two well-known indoor-channel models which resulted in an increase [of] accuracy […]; and, finally, we achieved extremely valuable conclusions regarding how to optimise the service' **[a]**. These outcomes and their application have led to the deployment of the technologies developed by the Kent team **[R3, R4]** and 'have led to higher network quality' **[a]**.

Enhancing British Telecom's 4G mobile network optimisation and business performance

The British Telecom Group operates three brands in the UK: EE, Orange, and T Mobile. EE's 4G mobile network is based on multiple input multiple output (MIMO) technology, which is optimised dynamically according to traffic load and accuracy of wireless channel state information estimation to achieve maximum system capacity. Since **January 2017,** Gomes, Wang, and Zhu have collaborated with BT, which has exploited Kent's cloud radio access technology **[R6]** and 'employed the innovative ideas and fundamentals of their work within [EE's] mobile operating service' **[b]**. BT's then senior manager of Network Strategy states that 'the implementation of their technology has enhanced the dynamic optimisation of our 4G mobile network and contributed to our improved business performance and position as the UK's leading mobile network operator' **[b]**. Specifically, 'their proposed low-complexity user selection algorithm is attractive for practical implementation. Their proposed algorithm was shown to achieve greater power savings than the traditional method, and the performance loss compared with the optimal approach is insignificant' **[b]**.

Informing ADVA's knowledge, technology solutions, and business strategy

ADVA is a telecommunications vendor and trusted partner of 18 of the world's largest

telecommunications operators, and serves hundreds of commercial and governmental organisations internationally. Through invitation by Gomes, ADVA was involved in the iCIRRUS project from its inception in **January 2015**. ADVA's Senior Vice-President confirms that 'From the outset the collaboration with Professor Gomes has brought numerous benefits to our company and contributed diversely to the advance of organisation innovation capacity in, and knowledge of, Ethernet fronthaul usage **[R6]**, whilst improving our business performance/activity in mobile transport networks, an area we recognise to be of high commercial significance' **[c]**. Furthermore, Gomes's expertise 'not only helped us [ADVA] advance our knowledge and understanding', but the collaboration resulted in joint publications, enabled ADVA to 'identify novel technology solutions', and helped ADVA 'to adapt its business strategy and invest in/expand its portfolio of network products' **[c]**.

Contributing to the development of VIAVI's business innovation strategy

VIAVI is a leading network service enablement (NSE) and test and measurement (T&M) company, headquartered in the USA, with revenues exceeding $1 billion per annum. VIAVI's business innovation strategy and knowledge of intelligent mobile access networks was informed by the expertise and research of the Kent team as a direct result of the corporation's involvement in the iCIRRUS and NIRVANA projects. As VIAVI's Chief Technology Officer highlights, the Kent team 'contributed to how we progressed our business innovation strategy, how we developed use cases and how we were able to articulate the value of our solutions to customers' **[d]**. In particular, the engagement 'identified how to gather metrics for intelligent operation for Ethernet fronthaul in a network **[R6]** using disaggregated RAN and device-to-device operations and their dependence on location intelligence in an extremely novel form' **[d]**. This knowledge enabled VIAVI 'to review our product roadmap and keep it abreast of developments', and enabled them to develop new product lines. These are significant contributions to a company that supports over 200 operators and service providers across seven continents **[d]**.

In addition to direct engagement with some of the world's leading global telecommunications corporations, members of the Kent team have had a wider impact through contributions to international industry standards and specifications. Examples include:

Informing IEEE's knowledge and standardisation

In **2016**, IEEE 1914.1 Next Generation Fronthaul Interface (NGFI) Working Group set up a Task Force to facilitate the implementation of key 5G technologies from a fronthaul networking perspective, and to describe the required networking architecture to enable migration to 5G and Cloud-RAN/Virtual-RAN solutions. In **April 2016**, Assimakopoulos was appointed as a voting member of the Task Force and, through presentations, consensus-generating discussions, and the group's voting procedures, disseminated key findings **[R6]** from the iCIRRUS project **[e]** until the end of the project in **December 2019**. The Working Group's Chair asserts that 'the expertise and inputs from the iCIRRUS project, especially in the starting phases of the group's work, were extremely valuable in shaping the group's consensus' **[e]**. Similarly, they highlight that several main inputs, including in transport techniques and analysis of functional decomposition options in a disaggregated RAN, 'were important for a number of formative and informative sections in the [1914.1] standard', which was approved and publicised in **April 2020 [e]**. As the Working Group Chair confirms, the Group is **'**extremely grateful for our collaboration with Dr Philippos Assimakopoulos and, through him, with the University of Kent and the iCIRRUS project consortium over the initial phase of the group's work, and to the extent to which their research fed into and informed our group's knowledge' **[e]**.

6) Contributing to IEC standardisation

Gomes's high international standing and exceptional expertise in radio over fibre technology **[R1, R2]** led to his invitation to serve on Working Group 6 of the International Electro-Technical Commission's Technical Committee TC103. The Chair of Working Group 6 states that, 'as a result of Professor Gomes sharing his research expertise within the group, he has helped inform

our knowledge and contributed to the activities and outputs of the group in diverse ways, including to the development of the international standards and technical reports that the WG has published' **[f]**. In particular, in his twelve years working in the group, Gomes has provided strong technical input to two published international standards (**2016-present**), three technical reports (**2016-present**), and one publicly available specification (**2008-present**). As the Chair of Working Group 6 confirms: 'In addition to the published standards and technical reports, since **2014** Professor Gomes' research expertise contributed to the establishment and drafting of new work item proposals (standards and technical report proposals) on measurement methods of millimeter-wave Mach-Zehnder optical modulators and optical-to-electric conversion devices, and an antenna measurement method, 100-GHz spectrum measurement equipment, a foreign object detection radar system on airport runways, and a railway radio-communication system between train and trackside, all using radio over fiber technologies' **[f]**.

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

[a] Letter from the Head of Network Technology, ThreeUK, describing the impact of Wang's Royal Academy secondment to ThreeUK, the benefit of his expertise, and the influence of his research in improving the performance of the indoor DAS.

[b] Letter from the Senior Manager Network Strategy, British Telecom, identifying the impact of Gomes and Wang's research within the network operations of their mobile operating service and the implementation of their technology.

[c] Letter from Optical Networking SE, ADVA, describing the impact of Gomes's research and expertise, as well as of the iCCURUS project, on the company, its innovation capacity, and its knowledge of Ethernet fronthaul usage.

[d] Letter from the Chief Technology Officer for the EMEA region, VIAVI, describing the impact of the Kent team, and the iCCURUS and NIRVANA projects, in advancing their knowledge, business innovation strategy, and opportunities.

[e] Letter from the Chair of the IEEE standardisation committee, identifying the impact of the Kent team's research and expertise in advancing standards, shaping the group's discussions, and informing their knowledge.

[f] Letter from the Chair of the IEC standardisation committee, identifying the benefit of the collaboration with Gomes, the impact of his research, and its influence on IEC standards since 2014.