Section A

The fields in this section are mandatory.

Institution: Durham University

Unit of Assessment: 12 General Engineering

Title of case study: Radio propagation for 5G wireless networks

Period when the underpinning research was undertaken: 2005 to present

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 Sana Salous	Professor of Communications Engineering	From 2003 to date

Period when the claimed impact occurred: 2017 to Dec 2020

Is this case study continued from a case study submitted in 2014? N.

Section B

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

Durham University has taken the lead in providing the research used by the International Telecommunications Union (ITU) and is ***the source of the sole dataset*** for the 73GHz frequency band ***and the residential model***. Professor Salous' research has contributed to the internationally agreed Recommendations for the fifth generation (5G) wireless communications in the built environment, and in the generation of new Recommendations around signal strength attenuation from outside to inside buildings.
These Recommendations have helped to determine the frequency allocation for 5G telecommunications systems which was decided at the World Radiocommunications Conference in 2019. This policy change has significant global impact on the telecommunications industry and its users.

2. Underpinning research (indicative maximum 500 words)

Professor Salous joined Durham in 2003 (as the first female professor in engineering at the University). Her major achievements include (a) **the development of a *unique architecture for frequency agile multiband* channel sounding equipment that has extended its range to the millimetre wave band**, and (b) t**he use of this equipment to obtain the characteristics of radio propagation in indoor and outdoor environments**. Her research is hugely relevant to current state of the art communication systems, following the unveiling and spread of commercial 5G wireless networks for mobile devices from 2019, which operate at these wavelengths.

Professor Salous' first contribution was pioneering the channel sounding technology necessary to fully explore ***wide bandwidths*** in the millimetre-wave spectrum. The requirements for high bandwidth and the ability to operate at different frequencies, means that wideband measurements using commercially available equipment have to be performed at quiet times. This impacts upon the quality of the data that can be obtained using this equipment, for the purpose of developing 5G. Most of the reported measurements tended to be undertaken in the evenings or at weekends when the environment is relatively stationary, rather than spanning the full temporal variation of the environment to include mush busier periods.

Following her arrival in Durham, Professor Salous further developed her frequency agile channel sounder technology from earlier work, into a Multiple Input (i.e. transmit), Multiple Output (i.e. receive) (MIMO) measuring device [R1]. Finally, a channel sounder MIMO architecture for the millimetre-wave band was developed and presented in [R2]. This latter work was funded by EPSRC [F1, F2], Ofcom [F3] and an EU grant [F4]. These advances paved the way for the design and development of a new type of radio channel measurement equipment using state-of-the-art digital and radio frequency (RF) techniques. The technology was developed to cover the range of frequencies to be allocated for 5G mobile radio networks, i.e. from below 6GHz up to 90GHz. The higher frequency range was agreed at the World Radiocommunications Conference in 2015. The new equipment developed at Durham University was used to perform propagation measurements which have directly led to the impact described below, i.e. the new propagation models used by industry and regulators, in [R3] and [R4]. Further details are given in the next section. Wideband measurements in typical indoor and outdoor environments were performed in suburban and residential environments. The Durham team used a unique waveform and the highest bandwidth compared with work by other groups. These studies provided key information to estimate channel parameters such as received signal attenuation (path loss) and wideband characteristics.

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

[R1] Salous, S., P. Filippidis; R. Lewenz; I. Hawkins; N. Razavi-Ghods; and M. Abdallah (2005), Parallel receiver channel sounder for spatial and MIMO characterisation of the mobile radio channel, IEE Proceedings – Communications (2005),152(6):912, http://dx.doi.org/10.1049/ip-com:20045346 Contextual information: 51 citations (Google Scholar), Q1 percentile journal in Scimago since 1999.

[R2] Salous, S., S. Feeney; X. Raimundo and A. Cheema (2016). Wideband MIMO channel sounder for radio measurements in the 60GHz band. IEEE Transactions on Wireless Communications 15(4): 2825-2832. http://dx.doi.org/10.1109/TWC.2015.2511006 Contextual information: selected output for REF2021, assessed as 4* by external readers in mock REF. 64 citations (Google Scholar), Q1 percentile journal in Scimago since 2003.

[R3] Raimundo, X.; S. Salous and A. Cheema (2018). Indoor Dual Polarised Radio Channel Characterization in the 54GHz and 70GHz bands. IET Microwaves, Antennas & Propagation 12(8):1287 http://dx.doi.org/10.1049/iet-map.2017.0711 Contextual information: 3 citations (Google Scholar), Q1/2 percentile journal in Scimago since 1999.

[R4] Raimundo, X.; S. El-Faitori, and S. Salous (2018) Multi-band outdoor measurements in a residential environment for 5G networks, 12th European Conference on Antennas and Propagation (EuCAP 2018). London, http://dx.doi.org/10.1049/cp.2018.0727. Contextual information: 6 citations (Google Scholar)

Key funding, all awarded to Professor Salous:

[F1] PATRICIAN EP/I00923X/1, EPSRC. This was a collaborative grant with Birmingham University and Queen Mary with overall value of GBP1.136,841 with Durham GBP125,009 (January to end of December 2011).

[F2] EPSRC impact acceleration account IAA (GBP118,039)

[F3] Ofcom contract Number 1362 on 'Long term measurements campaign and development of model(s) for mm wave bands (30-90GHz)'. GBP284,000

[F4] EU grant to use the frequency agile receiver of the sounder for spectrum sensing for sharing of the spectrum (subcontract from the EU funded CREW project for GBP98,481).

4. Details of the impact (indicative maximum 750 words). The 'Panel criteria', Annex A

Background

The announcement in November 2019 [E1] of additional frequency bands for 5G wireless networks by the international body responsible for regulating radio communications worldwide, is a significant impact of nearly two decades of research to which Professor Salous has made major contributions. The increasing demand anticipated in the 2000's for higher data traffic in wireless communication networks and the lack of available wide bandwidths in the sub-6GHz spectrum band, incentivised the research community, industry and regulators to consider alternative bands.

The millimetre-wave (mm-wave) band, up to 100GHz, has large, contiguous unallocated sections of the spectrum. These were seen as a home for future wireless communications capacity, which is now opening up wireless communication to advanced new applications in industrial automation, remote manipulation and support for the Internet of Things (IoT). A recent (October 2019) industry report [E2], estimates that the mm-wave band alone is likely to be responsible for 25% of the total economic value from the 5G network (equating to a USD565 billion increase in global GDP by 2034). Although, mm-wave communication offers the potential of high data rate, there are also challenges that need to be addressed. Some of these are primarily related to the undesired characteristics of the propagation channel in these bands. Millimetre waves suffer predominantly from high transmission loss and are susceptible to shadowing (e.g. blockage by humans or obstacles). It is the research findings of Professor Salous described above that have been used to determine propagation models for this part of the spectrum.

Impact on International Policy
Radio communications are regulated by the International Telecommunications Union (ITU), a United Nations agency based in Geneva, Switzerland. It is an intergovernmental public–private partnership organisation with 193 Member States, ~700 public (e.g. regulators such as OFCOM) and private sector companies (e.g. Samsung, Intel, Ericsson) and international and regional telecommunication entities. It coordinates global use of the radio spectrum and assists in the development and coordination of worldwide technical standards.

Standardisation work under the remit of the ITU is carried out by the technical Study Groups (SGs) in which representatives of the ITU's Telecommunication Standardisation Sector (ITU-T) develop Recommendations for the various fields of international telecommunications. These Recommendations are then adopted at the World Radiocommunications Conference (WRC).

Professor Salous' work on the development of the new channel sounding technology and the data generated using it, has fed directly into a number of ITU Recommendations:

ITU-R P.1411-10 provides guidance on outdoor short-range propagation over the frequency range 300MHz to 100GHz [E3-6]

- The data collected by Salous and co-workers provided **the entire data set for the residential model (0.8-73GHz) and the only data set for bands up to 73GHz** in the model leading to the parameters in Tables 4 (page 8) and 8 (page 14). [E3(i)]
- Other contributions by Professor Salous' team are incorporated into Tables 11 (page 30), 13 (page 33), 20 (page 37) and 21 (page 38) in ITU-R P.1411-10 and added text in Section 9 [E3(i)].

ITU-R P.1238-10 provides guidance on indoor propagation over the frequency range from 300MHz to 450GHz [E3(ii)]

- Contains several contributions derived from Durham data, e.g. tables 2, 4, 5 and an added Section (9.3).

E5 reports how the propagation data and models were derived and obtained for both Recommendations 1411 and 1238. Durham is directly cited in a number of places: Table 3 page 7, section 6.3.3.1 page 60 and 6.7.3 page 72.

ITU-R P.1407 describes the nature of multipath propagation and defines the appropriate parameters for the statistical description of multipath effects.

- Durham research forms the basis for Section 2 and the associated figures and the new Sections 4 & 5 and Annex 3. [E3(iii)]

ITU-R P.2109-0 provides a method for estimating building entry loss at frequencies between about 80MHz and 100GHz. [E3(iv)]
ITU-R P.2040 provides guidance on the effects of building materials and structures on radio-wave propagation. [E3(v)] Both these Recommendations are discussed in E7.

- Measurements carried out by Professor Salous' team at Durham in collaboration with Ofcom's propagation team were submitted to the data pool used to generate the Recommendations. In ITU-R P.2109-0 Section (23) e.g. 23.1 and 23.3 directly credit Durham University. [R3] is cited in section 23.6. [E7]

In addition, Durham's research has contributed to all sharing studies contained in Recommendations: P1144 P.[BEL], P.[Clutter_Loss], P.619, P.2041, P.1409, P.452, P.2001 [E4]

Professor Salous has acted as a Contributor to Correspondence Group CG 3K-6 (led by Samsung and then the Electronics and Telecommunications Research Institute ETRI Korea) responsible for the 5G model approved by SG3 in March 2017 and updated in 2019. Study Group 3 is responsible, inter alia, for studying international telecommunication/ICT policy and economic issues and tariff and accounting matters (including costing principles and methodologies), with a view to informing the development of enabling regulatory models and frameworks. The main providers of data were NTT Docomo (the largest mobile operator in Japan), ETRI Korea (Government funded Research Centre), Intel USA and Durham University. [E8]

At the most recent World Radiocommunications Conference in 2019, the ITU agreed the new bands for 5G based on these Recommendations [E1]. Already, auctions have been held in a number of countries for commercial use of the new bands. For instance, in the US Verizon is using 28GHz and AT&T is using 39GHz.

Contribution to SEAMCAT
It is essential for the optimal use of the radio spectrum that radio compatibility is ensured between different frequency ranges. SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool) is a statistical simulation model which was developed within the framework of CEPT (European Conference of Postal and Telecommunications Administrations). SEAMCAT is an open source software tool which is free of cost and allows users to effectively simulate interference scenarios between different radio communication systems

The models underpinned by Durham research as described above in ITU-R P.1411 (https://ecocfl.cept.org/display/SH/A.17.14.2+ITU-R+P.1411-10 and ITU-R P.2109 https://ecocfl.cept.org/display/SH/A17.18+ITU-R+P.2109-0 are implemented in SEAMCAT as reported in several ECC reports and outlined in an email from the Swiss Federal Office of Communications [E9, E10].

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

[E1] The ITU official announcement of frequency bands in the millimetre wave band in November 2019.

[E2] Reports from industry body, the Global System for Mobile Communications, the GSMA: "*Impact of mmWave5G*", October 2018 and July 2019

[E3] Compilation of ITU Recommendations described in the impact narrative

(i) ITU-R P.1411-10
(ii) ITU-R P.1238-10
(iii) ITU-R P.1407
(iv) ITU-R P.2109-0
(v) ITU-R P.2040

[E4] Email from the Head of RF Propagation, Ofcom, UK

[E5] ITU R-REP-P.2406-1-2019 *Studies for short-path propagation data and models for terrestrial radiocommunication systems in the frequency range 6GHz to 100GHz.*

[E6] Salous, S., Lee, J., Kim, M.- D., Sasaki, M., Yamada, W., Raimundo, X. & Cheema, A.A. (2020). *Radio propagation measurements and modeling for standardization of the site general path loss model in International Telecommunications Union Recommendations for 5G wireless networks*. Radio Science 55(1): e2019RS006924.

[E7] *Compilation of measurement data relating to building entry loss*. Report ITU-R P.2346-3

[E8] Liaison statement from Study Group 3 regarding new models

[E9] SEAMCAT tool, website and associated ECC reports:

(i) ECC Report 302 "*Sharing and compatibility studies related to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) in the frequency band 5925-6425MHz*," May 2019 (applies both ITU-R P.1411-9 and ITU-R P.2009-0),
(ii) ECC Report 303 "*Guidance to administrations for Coexistence between 5G and Fixed Links in the 26GHz band ("Toolbox")*", July 2019 (applies both ITU-R P.1411-9 and ITU-R P.2009-0)
(iii) ECC Report 307 "*Toolbox for the most appropriate synchronisation regulatory framework including coexistence of MFCN in 24.2527.5GHz in unsynchronised and semi-synchronised model*", March 2020 (applies ITU-R P.2109-0)
(iv) Addendum to ECC Report 200 "*Additional co-existence studies between SRDs/RFIDs and E-GSM-R in the 900MHz frequency band*," May 2020 (uses ITU-R P.2109)
(v) ECC Report 314 "*Co-existence between Future Railway Mobile Communication System (FRMCS) in the frequency range 1900-1920MHz and other applications in adjacent bands*," May 2020 (applies ITU-R P.2109)
(vi) ECC Report 316 "*Sharing studies assessing short-term interference from Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) into Fixed Service in the frequency band 5925-6425MHz,*" May 2020 (applies ITU-R P.2109)
(vii) SEAMCAT website

[E10] Email of support from Radio Communications Engineer, Swiss Federal Office of Communications