# Engagement and Impact 2018

## Victoria University

## VIC09 (ST) - Impact

## Overview

**Title**

*(Title of the impact study)*

| |
|---|
| Smart Antenna to Smartphone |

**Unit of Assessment**

| |
|---|
| 09 - Engineering |

**Additional FoR codes**

*(Identify up to two additional two-digit FoRs that relate to the overall content of the impact study.)*

| |
|---|
| 10 - Technology |

**Socio-Economic Objective (SEO) Codes**

*(Choose from the list of two-digit SEO codes that are relevant to the impact study.)*

| |
|---|
| 89 - Information and Communication Services |
| 86 - Manufacturing |

**Australian and New Zealand Standard Industrial Classification (ANZSIC) Codes**

*(Choose from the list of two-digit ANZSIC codes that are relevant to the impact study.)*

| |
|---|
| 24 - Machinery and Equipment Manufacturing |
| 34 - Machinery and Equipment Wholesaling |
| 42 - Other Store-Based Retailing |
| 58 - Telecommunications Services |
| 69 - Professional, Scientific and Technical Services (Except Computer System Design and Related Services) |

**Keywords**

*(List up to 10 keywords related to the impact described in Part A.)*

Australian Telecommunications CRC

Nanoradio AB

Smartphone

Digital Signalling Processing (DSP) Algorithms

Wireless

Institute of Electrical and Electronics Engineers

WiFi

Multiple input multiple output, MIMO

IEEE 802.11n

**Sensitivities**

Commercially sensitive

Yes

Culturally sensitive

**Sensitivities description**

*(Please describe any sensitivities in relation to the impact study that need to be considered, including any particular instructions for ARC staff or assessors, or for the impact study to be made publicly available after EI 2018.)*

Please redact the following for publication:
•Delete Ericsson's name from section 2: Beneficiaries
•Delete the last paragraph in the sub-headed section "Market impact – public networks" of section 4: Details of Impact, beginning: "Nanoradio was not the only direct beneficiary of VU research knowledge. Long-time VU collaborator and original member of the ATCRC Ericsson…"

**Aboriginal and Torres Strait Islander research flag**

*(Is this impact study associated with Aboriginal and Torres Strait Islander content?*
*NOTE - institutions may identify impact studies where the impact, associated research and/or approach to impact relates to Aboriginal and Torres Strait Islander peoples, nations, communities, language, place, culture and knowledges and/or is undertaken with Aboriginal and Torres Strait Islander peoples, nations, and/or communities.)*

No

**Science and Research Priorities**

*(Does this impact study fall within one or more of the Science and Research Priorities?)*

No

# Impact

**Summary of the impact**

*(Briefly describe the specific impact in simple, clear English. This will enable the general community to understand the impact of the research.)*

Researchers led by Prof Mike Faulkner from Victoria University's (VU) College of Engineering and Science developed algorithms used in the first smartphones to incorporate multiple-antenna (MIMO) WiFi technology, marketed from 2010. The team helped develop the IEEE 802.11n standard published in 2009. It was the first to include MIMO, as have all since.

Any chipsets conforming to 802.11n sold by Swedish company Nanoradio from 2010 to 2012 contained algorithms and IP developed by an Australian team spun off from VU. The chips were the smallest available and had the lowest power consumption. They were included in Samsung, Sharp and Huawei smartphones. VU MIMO expertise also helped Tait Electronics of New Zealand establish itself as a global leader in narrowband spectral efficiency.

**Beneficiaries**

*(List up to 10 beneficiaries related to the impact study)*

Nanoradio AB, Sweden

Consumers who bought smartphone products containing 802.11n compliant WiFi from Samsung, Sharp, Huawei, and at least 12 other companies after 2010

Telecommunications industry (any product development using the MIMO technology application)

ATCRC industry partners (Ericsson, Sweden and TAIT Communications, New Zealand)

The IEEE 802.11n standardisation committee

Manufacturers who purchased Nanoradio chipsets containing energy efficient 802.11n standard WiFi for their products

Australian researchers and engineers employed by Nanoradio’s Australian office

Samsung Nanoradio Research, Sweden

Samsung, South Korea

**Countries in which the impact occurred**

*(Search the list of countries and add as many as relate to the location of the impact)*

| |
|---|
| Australia |
| Sweden |
| New Zealand |
| Japan |
| Korea, Republic of (South) |
| China (excludes SARs and Taiwan) |
| India |
| United States of America |
| Brazil |
| Russian Federation |

**Details of the impact**

*(Provide a narrative that clearly outlines the research impact. The narrative should explain the relationship between the associated research and the impact. It should also identify the contribution the research has made beyond academia, including:*
*- who or what has benefitted from the results of the research (this should identify relevant research end-users, or beneficiaries from industry, the community, government, wider public etc.)*
*- the nature or type of impact and how the research made a social, economic, cultural, and/or environmental impact*
*- the extent of the impact (with specific references to appropriate evidence, such as cost-benefit-analysis, quantity of those affected, reported benefits etc.)*
*- the dates and time period in which the impact occurred.*

*NOTE - the narrative must describe only impact that has occurred within the reference period, and must not make aspirational claims.)*

Researchers led by Prof Mike Faulkner from Victoria University's (VU) College of Engineering and Science developed algorithms used in the first wave of smartphones incorporating multiple-antenna (MIMO) WiFi technology, marketed from 2010.

Ideas for the algorithms were generated and tested as part of the Australian Telecommunications CRC (ATCRC) research program (1999-2006). VU was invited to join the ATCRC due to its strong industry links. Industry partners affiliated with the ATCRC/VU 'Smart Antenna' project (Swedish companies Ericsson and Nanoradio and New Zealand company Tait Electronics) were either existing VU contacts or sourced via VU industry networks.

VU research outcomes impacted the standardisation process, as well as public and private network markets.

Standardisation

Research of the ATCRC/VU Smart Antenna project resulted in a proposal to the International Standardisation Committee in 2004 to use MIMO technology in the next generation of wireless local area networks (IEEE 802.11n). The VU research team subsequently became part of the standards development process for IEEE 802.11n from 2003 to 2006. This standard, published in 2009, introduced multiple antenna technology that increased the average data rate from less than 100 to more than 400 megabits/second.

In the early 2000s, VU researchers were the first to identify and then present a solution [ref 6] to the problem of Doppler shift caused by movement of a wireless terminal. The solution was adopted as an option in the IEEE 802.11n WiFi standard, and remains a feature in many wireless standards to this day, including cellular fourth and fifth generation (4G, 5G) standards and proposals. It allows for improved transmission and reception in high-speed moving vehicles.

Subsequent and related inventions providing solutions to practical problems for MIMO and traditional system implementation were patented in 2006. They included "Channel estimation for OFDM systems" (refer to Additional

Indicator section), which has been cited at least 81 times (40 times since 2011), including references by multinational companies such as Qualcomm and LG.

802.11n represented a leap in wireless technology. It was the first standard to transmit parallel data streams concurrently from a single unit. Subsequent WiFi standards, including 802.11ac published in 2013, expanded on this MIMO feature and related technologies.

Market impact – public networks

Any chipsets that conformed to the 802.11n WiFi standard sold by Nanoradio to product manufacturers between 2010 and 2012 contained algorithms and IP developed by an Australian team that spun off from the ATCRC/VU team. These chips were included in smartphone models:
·Samsung GT-B7722u (2011), GT-B7732 (2011), GT-B7722i (2011) W6374 (VoIP phone) (2012);
·Sharp 945SH-G (2012), 002SH (2012), 004SH (2012); and
·Huawei T8301(2011)

From 2009 to 2014, the 802.11n standard was state-of-the-art technology, and manufacturers competed aggressively to deliver the next generation of WiFi into consumer goods, including smartphones, mobile phones, tablets, home WiFi routers, and business-based access points for WiFi distribution. Nanoradio offered 12 chips in their 2011 short-form catalogue, of which five contained IP derived from the ATCRC/VU project [ref 8]. At that time, Nanoradio had sales representatives promoting their product around the globe.

From 2006 to 2009, several companies globally were working on next-generation 802.11n WiFi ready to be designed into products to be sold between 2009 and 2014. Nanoradio's chips were the smallest and had the lowest power consumption of any device on the market, which saw it, and its VU research team to become leaders among the handful of companies getting WiFi into smartphones.

In fact, Nanoradio forged a supplier relationship with Samsung, which according to the market research portal Statistica, had in 2012 become the largest supplier in the world with 30.3% of the smartphone market.

Investment news website Crunchbase reports that venture capitalists invested US$91million in Nanoradio between 2005 and 2010. When Samsung finally acquired Nanoradio in July 2012, it can be assumed the purchase price exceeded this amount.

Nanoradio was not the only direct beneficiary of VU research knowledge. Long-time VU collaborator and original member of the ATCRC Ericsson continued to derive benefit after its departure from the CRC in 2001. It received radio propagation data from VU's early MIMO measurement campaign and Faulkner was a vital link for the company to stay abreast of developments in WLAN technology. This ultimately led to a patent for Ericsson, "Low complexity inter-carrier interference cancellation" (US7706428B2), which has received 103 citations, including references by multinational companies like Qualcomm, Samsung and Huawei [ref 3].

Market impact – private networks

Tait Electronics of New Zealand established a collaboration with VU under the ATCRC in 2002 to gain access to Faulkner and his team's expertise in MIMO development. Doug McConnell, Chief Technology Officer at MiMOMax Wireless Ltd (MWL), recalls: "This collaboration was an important ingredient to our MIMO development program for point-to-point and point-to-multipoint networks. Our success in this program led to the establishment of MWL in 2007 as a separate entity under the Tait group of companies to exploit rapidly evolving advanced wireless technologies."

Building from this initial research foundation, MWL has established itself as a global leader in narrowband spectral efficiency, and has grown the business to service a large international customer base.

Backwards compatibility

By 2012, the industry was moving towards the next WiFi standard 802.11ac. While new algorithms were developed, all products after 2014 needed to be backwards compatible with existing and previous standards. The new design team at Samsung would have used the algorithms developed by VU to achieve this.

**Associated research**

*(Briefly describe the research that led to the impact presented for the UoA. The research must meet the definition of research in Section 1.9 of the EI 2018 Submission Guidelines. The description should include details of:*
*- what was researched*
*- when the research occurred*
*- who conducted the research and what is the association with the institution)*

The ATCRC/VU Smart Antenna project studied the application of Multiple Input Multiple Output (MIMO) antenna systems in wireless communications.

The team included Prof Faulkner, Dr Leyonhjelm, 3 post-doctoral researchers, 2 engineers, and 9 PhD students. They began investigating MIMO technology by undertaking multiple antenna propagation measurements and capacity analysis. After proof-of-concept, the team moved into development. Each PhD student researched a specific problem, such as timing synchronisation [9], channel estimation [7], MIMO tracking [5], bit-loading [2] and signal peak reduction [1,4].

The students provided performance/complexity alternatives enabling quick decision-making and risk reduction, as time to market became important. Key development milestones include:
·2002: Simulation and hardware platform development
·2003: First test-bed of a MIMO system in the Southern Hemisphere. Collaboration with ACREO (Swedish equivalent of CSIRO) for chip development
·2004: Proposal submitted to Standardisation Committee for IEEE 802.11n
·2005: ACREO withdraws. Nanoradio AB approaches ATCRC/VU for baseband development: 1. Digital Signalling Processing algorithms, 2. System model of physical layer
·2006: Nanoradio sets up Australia office. VU consults to Nanoradio to provide continuous support to commercialisation: 1. Completed physical layer simulation model for 802.11n standard, 2. Completed physical layer algorithms and simulation down to bit level.

**FoR of associated research**

*(Up to three two-digit FoRs that best describe the associated research)*

| |
|---|
| 09 - Engineering |
| 10 - Technology |

**References (up to 10 references, 350 characters per reference)**

*(This section should include a list of up to 10 of the most relevant research outputs associated with the impact)*

1.G. Hill and M. Faulkner, “Comparison of low complexity clipping algorithms for OFDM”, The 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 2002, pp. 227-231 vol.1. (23 citations: Google Scholar).

2.J. Gao, M. Faulkner "On implementation of bit-loading algorithms for OFDM systems with multiple-input multiple-output," IEEE Vehicular Technology Conference VTC Fall, Vancouver, Canada, 2002. (33 Citations: Google Scholar).

3.M. Faulkner, L. R. Wilhelmsson and J. Svensson, "Low-complex ICI cancellation for improving Doppler performance in OFDM systems," IEEE Vehicular Technology Conference, Montreal, Que., 2006, pp. 1-5. (67 citations) (Also patented, see US7706428B2 ‘Low complexity inter-carrier interference cancellation’ (103 Citations: Google Patents).

4.Patent: US7376197B2. Berangi R., Faulkner, M., Signal peak reduction circuit for non-constant envelope modulation signals (66 Citations: Google Patents)

5.L Gor, M Faulkner, “Power Reduction through Upper Triangular Matrix Tracking in QR Detection MIMO Receivers”, IEEE Vehicular Technology Conference, Montreal, Canada, Sep 2006. (8 Citations: Google Scholar) (Also patented, see: WO2007035993A1. Faulkner M, Gor L, “Channel tracking for MIMO receivers”, 2007 (17 Citations: Google Patents)

6.G. Lebrun, J Gao, M. Faulkner, “MIMO transmission over a time-varying channel using SVD”, IEEE Trans. Wireless Communications, Vol.4, No.2, pp.757-764, 2005. (173 citations: Google Scholar).
First presented at IEEE Global Telecommunications Conference (Globecom 02), Taipei, Taiwan, pp. 414-418, 2002. (26 Citations: Google Scholar)

7.I Tolochko and M Faulkner, “Real time LMMSE channel estimation for wireless OFDM systems with transmitter diversity,” Pro IEEE 56th Vehicular Technology Conference, 2002, pp.1555-1559, vol.3. (28 Citations: Google Scholar) (Also Patented: US20070110172A1. Faulkner M, Tolochko I., Channel estimation for OFDM systems (81 Citations: Google Patents)

8.Nanoradio AB 2010, Short form catalogue 2011: Always on WiFi, Eddy Wireless, last accessed 13 June 2018, <https://eddywireless.com/yahoo_site_admin/assets/docs/shortform2011.70160844.pdf>

9.K Wang, M Faulkner, J Singh, I Tolochko, ‘Timing synchronization for 802.11a WLANs under multipath channels’ Proc. Australian Telecommunications and Networking Conference, ATNAC, 2003. (49 Citations: Google Scholar)

# Additional impact indicator information

**Additional impact indicator information**

*(Provide information about any indicators not captured above that are relevant to the impact study, for example return on investment, jobs created, improvements in quality of life years (QALYs). Additional indicators should be quantitative in nature and include:*
*- name of indicator (100 characters)*
*- data for indicator (200 characters)*
*- brief description of indicator and how it is calculated (300 characters).)*

Name

Patent citations – no. times patents invented by VU research team members have been referenced

Indicator Data

7 patents with a total of 312 cites, including Channel estimation for OFDM systems (US20070110172A1, 81 cites); Low complexity inter-carrier interference cancellation (US7706428B2, 103 cites)

Indicator Description

Patent citations map the progress of the knowledge contained within the patent document and offers a measure of its technological significance. Subsequent patent citations of VU-invented patents thus confer a value status to the original patent and its affiliated products. (Source: Google Patent)

Name

Nanoradio – Product list containing Nanoradio Devices

Indicator Data

Nanoradio secured 20 design wins from seven companies in 2010. That is, seven product manufacturer companies purchased Nanoradio chips containing VU IP to be incorporated into 20 products.

Indicator Description

Business stats presented in: Nanoradio 2010, “Nanoradio at a Glance”, Corallia, last accessed 20 June 2018, <http://www.corallia.org/images/stories/documents/Corallia-InternshipDay-Nanoradio.pdf>. Chips containing VU IP were Nanoradio’s key value proposition. Products would be in market from 2011

Name

Nanoradio – Device sales, past and present growth rates

Indicator Data

Nanoradio’s feasible sales estimation for 2011 was to sell 10 million devices/chips with projected income in excess of $100 million, representing compound growth of over 300% pa since 2009.

Indicator Description

Source: Nanoradio 2010, “Nanoradio”, Corallia, last accessed 20 June 2018, <http://www.corallia.org/images/stories/documents/17.nanoradio.pdf>. Applied market knowledge of chip prices at the time (~US$8-15 each) to estimate projected income. Other data presented within document