Institution: University of Southampton

Unit of Assessment: 12 Engineering

Title of case study: 12-02 AccelerComm: hardware acceleration spin-out for 5G communications

Period when the underpinning research was undertaken: August 2013 – December 2020

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

Name(s):	Role(s) (e.g. job tile):	Period(s) employed by submitting HEI:
Rob Maunder	Professor	November 2007 – present
Taihai Chen	Research Fellow	June 2014 – June 2016
Lie-Liang Yang	Professor	December 1997 – present
Terrence Mak	Associate Professor	November 2015 – present
Shida Zhong	Research Fellow	June 2014 – September 2017
Matthew Brejza	Research Fellow	January 2017 – September 2017
Peter Hailes	Enterprise Fellow	October 2017 – December 2020

Period when the claimed impact occurred: March 2016 – December 2020

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

1. Summary of the impact

Professor Rob Maunder and his team at the University of Southampton have developed methodologies for the joint design of signal processing algorithms and their hardware acceleration for mobile communication. Since March 2016, the impact of this research has been as follows:

I1 Creation of a spin-out company AccelerComm Ltd to develop the research into commercial-grade hardware accelerator designs. AccelerComm now employs 33 people, has a valuation of over [text removed for publication] and offers 27 hardware accelerator design products protected by 5 granted patents and a further 32 patent applications.

I2 Deployment of hardware accelerator designs in 5G base-stations, test-and-measurement equipment, satellites and user devices world-wide, through 58 licenses of the AccelerComm products to [text removed for publication] organisations including National Instruments, [text removed for publication], generating [text removed for publication] of license sales booking for AccelerComm, plus royalty commitments that will be realised in future years.

I3 Contributing to the global standards that define 5G. Maunder led a consortium including Ericsson, LG Electronics, Orange, NEC and Sony that contributed to defining the hardware accelerated signal processing aspects of the global standard for 5G mobile communication.

I4 Facilitating 5G deployment. Research has led to open source simulation models that, in combination with AccelerComm's partnerships with hardware vendors Intel, Xilinx and Achronix, have contributed to the development of a global eco-system for open standardised hardware platforms for 5G base-station implementation, enabling the 'integration in a day' of hardware accelerators.

I5 Maunder informed part of the UK government's Future Telecoms Infrastructure Review, which sets the flagship policy for the roll-out of 5G in the UK, with the target of providing 5G coverage to the majority of the UK population by 2027.

2. Underpinning research

All deployments of state-of-the-art 5G mobile communications around the world depend on complex signal processing, which enables communication with high throughput (e.g. 20 Gbit/s), as well as high energy-efficiency, high spectral efficiency and hence high cost efficiency. In base-stations and mobile devices, this signal processing must be hardware accelerated, so that the processing throughput can keep pace with the communication throughput. Conventionally, this hardware acceleration is designed separately from the signal processing algorithms. However, achieving the required processing throughput can result in a poor signal-processing energy-efficiency and/or a high hardware cost, which overshadows the targeted high communication energy- and cost-efficiency, diminishing the environmental and economic advantages of 5G. Since August 2013, Professor Rob Maunder's research at the University of Southampton has developed methodologies for the joint design of signal processing algorithms and their hardware acceleration.

In this way, the throughput, energy-efficiency and cost-efficiency of both the transmission and the processing can be jointly optimised.

Funded by an EPSRC project [**G1**], Maunder built a research team to apply the above-mentioned research approach to error correction in mobile communications. This team has included five post-doctoral researchers and ten PhD students, who have co-authored 23 papers published in high impact IEEE and IET journals, which demonstrate the benefits of this methodology. For example, the application in turbo error correction codes demonstrated an order-of-magnitude improvement to processing throughput and latency, compared to the previous world record [**3.1**]. The Intellectual Property (IP) arising from this research led to the team forming the spin-out company, AccelerComm Ltd, in March 2016, as detailed in impact [**I1**] below.

In addition to the research described above, AccelerComm's customer engagements of impact [**I2**] has also originated from a combination of research activities undertaken by members of the team. For example, [**3.2**] and [**3.3**] achieved the greatest degree of flexibility to support diverse standards, requirements and settings ever demonstrated for the hardware acceleration of turbo and Low Density Parity Check (LDPC) error correction codes, respectively. Meanwhile, EPSRC funded research [**G2**] led by Prof Lie-Liang Yang proposed a framework for combining all Non-Orthogonal Multiple Access (NOMA) mobile communication techniques into a single unified and generalised scheme for the first time [**3.4**]. This expertise has been transferred to AccelerComm through GBP127,000 of Knowledge Transfer Partnership funding [**G3**] and AccelerComm-funded collaborations, which has led to the development of hardware accelerator design products, as detailed in impact [**I2**] below.

Likewise, the team's research has also led to impacts in 5G standards [**I3**], deployment [**I4**] and government advice [**I5**]. For example, in collaboration with [text removed for publication], Dr Peter Hailes characterised the fundamental trade-offs between the various performance characteristics of hardware accelerated LDPC error correction codes, for the first time in [**3.3**] and [**3.5**]. This research influenced both [text removed for publication]'s and AccelerComm's contributions to the 5G standards, as well as to the development of open-source models of those standards, as detailed below. Furthermore, [**3.6**] demonstrated the first hardware accelerated turbo error correction codes that achieve the requirements of Ultra-Reliable Low Latency Communication (URLLC). This expertise has been transferred to AccelerComm through an Innovate UK project [**G4**] on Connected and Autonomous Vehicles, which has subsequently informed government policy, as detailed below.

3. References to the research

3.1 R. G. Maunder, "A fully-parallel turbo decoding algorithm", IEEE Transactions on Communications, vol. 63, no. 8, pp. 2762-2775, August 2015. https://doi.org/10.1109/TCOMM.2015.2450208

3.2 R. Al-Dujaily, A. Li, R. G. Maunder, T. Mak, B. M. Al-Hashimi, L. Hanzo "A scalable turbo decoding algorithm for high-throughput network-on-chip implementation", IEEE Access, vol. 4, pp. 9880-9894, November 2016. https://doi.org/10.1109/ACCESS.2016.2628801

3.3 P. Hailes, L. Xu, R. G. Maunder, B. M. Al-Hashimi, L. Hanzo, "A flexible FPGA-based quasi-cyclic LDPC decoder," IEEE Access, vol. 5, pp. 20965-20984, March 2017. https://doi.org/10.1109/ACCESS.2017.2678103

3.4 Q. Wang, R. Zhang, L.-L. Yang, L. Hanzo, "Non-orthogonal multiple access: a unified perspective", IEEE Wireless Communications, vol. 25, no. 2, pp. 10-16, April 2018. https://doi.org/10.1109/MWC.2018.1700070

3.5 P. Hailes, L. Xu, R. G. Maunder, B. M. Al-Hashimi, L. Hanzo, "A survey of FPGA-based LDPC decoders", IEEE Communications Surveys and Tutorials, vol. 18, no. 2, pp. 1098-1122, December 2015. https://doi.org/10.1109/COMST.2015.2510381

3.6 L. Xiang, M. F. Brejza, R. G. Maunder, B. M. Al-Hashimi, L. Hanzo, "Arbitrarily parallel turbo decoding for ultra-reliable low latency communication in 3GPP LTE," IEEE Journal on Selected Areas of Communications, vol. 37, no. 4, pp. 826-838, April 2019. https://doi.org/10.1109/JSAC.2019.2898654

Grants:

G1 EPSRC EP/L010550/1, GBP480,201, Highly-parallel algorithms and architectures for high-throughput wireless receivers, UoS, 2014-2017. PI: Maunder.

G2 EPSRC EP/P034284/1, GBP356,806, New Air Interface Techniques for Future Massive Machine-Type Communications, UoS, 2017-2021. PI: Yang.
G3 Innovate UK KTP 11036, GBP127,300, UoS/AccelerComm, 2018-2020. PI: Yang.
G4 Innovate UK 133560, GBP178,125, Feasibility study on polar codes for 5G URLLC, UoS/AccelerComm, 2018-2019. PI: Maunder.
G5 Innovate UK 900037, GBP499,741, ICURE Aid for Start Ups Cohort 4 - AccelerComm Limited, 2016-2018. PI: Maunder.

4. Details of the impact

I1. AccelerComm Ltd: The underpinning research (particularly [**3.1**, **3.6**] and the corresponding Hardware Description Language (HDL) source code) led to the two patent applications on the hardware acceleration of channel decoding [**5.1**]. With the assistance of the University of Southampton incubator Future Worlds, Maunder and Dr Taihai Chen developed a pitch for this IP and was awarded GBP50,000 of SETsquared Innovation to Commercialisation of University Research (ICURe) funding in October 2015. This enabled them to meet and interview over 100 potential licensee companies and discuss their requirements from which they developed a business plan. They made a successful application for Innovate UK Aid for Startups funding **G5** and incorporated AccelerComm Ltd in March 2016 [**5.2**] to which the IP was assigned. They raised GBP500,000 of seed funding from IP Group [**5.3**] in December 2016 and recruited four of the postdoctoral researchers and students from Maunder's research team into full-time engineering positions. The ongoing collaboration between AccelerComm and the University of Southampton has resulted in a further 35 patent applications across Europe, USA and China, with five granted so far. Since the initial seed funding, AccelerComm has attracted a further GBP2,500,000 of investment from IP Group and Bloc Ventures in December 2018, as well as a further GBP5,800,000 of investment from IP Group, Bloc Ventures and IQ Capital in September 2020, with the company now valued at over [text removed for publication] [**5.3**]. AccelerComm now employs 33 individuals in Southampton and has a sales office in the USA allowing it to address the world’s largest market for mobile communications. Dr Tom Cronk (former management board member at Arm Ltd) joined the company as full-time CEO in May 2017 and Maunder has been employed as CTO for 4 days per week since April 2018. AccelerComm now offers a diverse range of 27 IP products, across the encoders and decoders of turbo, polar and LDPC channel coding, for application in base-station and mobile devices, and with implementation in software, FPGA and ASIC [**5.4**]. In recognition of its progress, AccelerComm has been selected in the EE Times Silicon 100 list of emerging electronics and semiconductor startups to watch [**5.5**].

I2. Licensing and product innovation: In addition to royalty commitments that will be realised in future years, AccelerComm has generated [text removed for publication] of license sales bookings, comprising [text removed for publication], demonstrating exponential growth. This has been achieved through 58 licenses of IP products to [text removed for publication], including several household name companies [**5.4**]. This has generated business performance impacts for these customers through the introduction of new products and testing processes, including the following highlights:

- In January 2018, AccelerComm sold an IP research license to one of the world's leading smart phone manufacturers. This partner confirmed that the AccelerComm polar decoding ASIC IP offers a significantly superior hardware efficiency than their own research solution [**5.4**]. Based on information published publicly by this partner, AccelerComm estimates that a 40% improvement in hardware and energy efficiency was found. This partner subsequently adopted this result as a benchmark for their productised solution, which has been now been deployed in their first 5G smartphones launched in 2019 and sold around the world.
- In February 2018, the FPGA manufacturer, Achronix announced a partnership with AccelerComm to apply the IP in their products enabling them to address new opportunities with 5G base-station equipment manufacturers. “The ability to instantiate AccelerComm’s industry-leading Polar Code IP in our eFPGA allows Speedcore-enabled ASIC and SoCs to be updated to support new standards. We see that the ability to flexibly reprogram a hardware accelerator for new requirements and emerging standards is going to be fundamental for cost-effective 5G deployments.” (Mark Fitton, Achronix senior director [**5.6**]).
- In June 2018, AccelerComm sold an IP commercial license to National Instruments (NI) for FPGA firmware. NI Director of Marketing, RF and Communications, James Kimery stated “Our

work with AccelerComm extends our platform toward 5G NR [3GPP New Radio] compliance which will enable researchers to build on 5G NR to explore application spaces critical to the 5G ecosystem" [**5.7**]. NI have integrated AccelerComm's 5G polar encoding and decoding IP with other FPGA firmware and software, in order to implement their [text removed for publication] product [**5.7**], exposing AccelerComm's 5G IP to NI's 35,000 customers world-wide. For example, NI's lead customer for this product, Spirent, have launched 5G test equipment incorporating the AccelerComm IP [**5.7**].

- In March 2019, AccelerComm sold an IP research license to one of the leading Mobile Network Operators in the USA. This customer is using this IP for FPGA polar coding to implement a test platform for the roll-out of their 5G network [**5.4**]. This is enabling them to evaluate and compare the performance of commercial base-stations offered by the leading equipment vendors, as well as supporting their contributions to the O-RAN standard of [**I3**].
- In October 2019, AccelerComm partnered with Xilinx, the world's leading FPGA manufacturer to develop software and FPGA IP to enable 5G error correction on the Xilinx T1 FPGA board, using the BBDEV standard discussed in [**I3**]. "AccelerComm's channel coding IP is an important addition to the [Xilinx T1] Zynq UltraScale+ RFSoC portfolio. This collaboration will help network equipment manufacturers get to market faster and deliver all-important latency and power consumption improvements in 5G networks" said Dan Mansur, vice president of marketing, Wired & Wireless Group, Xilinx [**5.8**]. AccelerComm is currently integrating this solution into the base-station equipment of a [text removed for publication] manufacturer.
- In October 2019, [text removed for publication] it was found that the AccelerComm software LDPC error correction IP is up to 3 times faster than the equivalent Intel IP for this purpose [text removed for publication] in the Intel FlexRAN software-defined basestation solution. By adopting AccelerComm's IP, Intel have been able to reduce the number of CPUs required to deploy FlexRAN [text removed for publication]. This reduces the costs of running a FlexRAN base-station [text removed for publication] as well as the environmental impact. Intel is now supplying and marketing the AccelerComm IP to its customers worldwide [**5.9**]. "Companies like AccelerComm who are using [Intel's FlexRAN reference software] are creating new paths to quickly commercializing solutions for various types of RAN deployments", said Cristina Rodriguez, VP and GM of Intel's Wireless Access Network Division [**5.9**].
- In January 2020, AccelerComm sold an IP commercial license to [text removed for publication] 5G base-station manufacturer. By integrating AccelerComm LDPC FPGA IP into its [text removed for publication] base-station product, [text removed for publication] saved several person-years of design effort and benefitted from improved system performance and reduced time to market, having now launched their product in [text removed for publication] international markets [**5.10**].
- In May 2020, AccelerComm sold an IP commercial license to a satellite company [**5.4**]. This customer has adopted AccelerComm LDPC error correction IP for an ASIC, which they will deploy in [text removed for publication] satellites and in terrestrial equipment around the world. This customer could have adopted any proprietary error correction solution, but AccelerComm convinced them of the performance and standards compliance advantages of 5G LDPC coding.

I3. Global 5G standards: Global investment in implementing and deploying 5G has exceeded USD12bn so far and is expected to exceed USD800bn by 2025 [**5.11**]. The standardisation of 5G began in May 2016, under the umbrella of the 3GPP organisation, which brings together telecommunications companies from around the world. During this process, the research of [**3.1**] was used to compare different types of error correction codes, receiving 39 citations among technical contributions made by Orange, ZTE, Samsung, LG Electronics, Xilinx, Interdigital, Ericsson, ZTE, Samsung, NEC, Nokia, Alcatel-Lucent Shanghai Bell, Verizon Wireless, Qualcomm and Huawei. Maunder presented 10 technical papers at the 3GPP meetings and led a consortium comprising AccelerComm, Ericsson, LG Electronics, Orange, NEC and Sony [**5.12**] presenting and defending way-forward proposals that drew upon [**3.1**] and [**3.3**]. These proposals recommended LDPC codes for channel coding in 5G, which was subsequently agreed in November 2016 and standardised across the global telecommunications industry [**5.12**]. This represents a very significant impact on 5G, because LDPC codes had not be used in any previous 3GPP standards and because channel coding is one of the most computationally complex components of 5G, which must be implemented in all compatible equipment and devices. The adoption of LDPC codes in 5G was also supported at 3GPP meetings by another consortium which included [text removed for publication], who were influenced by the findings of their collaboration with Hailes [**3.3**, **3.5**]. In the first half of 2020, AccelerComm collaborated with [text removed for publication] to define a [text removed for publication] standard for [text removed for publication] communication. AccelerComm demonstrated that polar coding offers significantly superior error correction capability than the legacy codes previously used in these applications [**5.13**].

I4. Facilitating 5G deployment: While the 3GPP standards for 5G global telecommunications precisely define *what* 5G base-stations and mobile devices must do in order to communicate with each other, the standards do not provide any detail on *how* to do it. In order to educate the global telecommunications industry about how to implement the error correction codes of these standards, Maunder has published the corresponding research conducted at the University of Southampton (exemplified by [**3.1**, **3.3**, **3.6**]) in the form of open source simulation models [**5.14**]. These open-source models have been adopted by 175 researchers and industry experts around the world, in order to form the basis of their own simulation models and to confirm the standards compliance of their products. These models have contributed to the OpenAirInterface, which is providing an open-source reference solution for complete base-stations and mobile devices. Furthermore, AccelerComm has contributed to the standardisation of the O-RAN Alliance, Data Plane Development Kit and [text removed for publication] interfaces between hardware and software base-station components, and has adopted these standards so that AccelerComm products can be integrated into customer products within one day of design effort [**5.8**, **5.9**].

I5. Influence on Government Policy Debate: Based on his experience of 5G standardisation and his research on Connected and Autonomous Vehicles (CAVs) [**3.6**], Maunder advised the UK government's Department of Digital, Culture, Media and Sport and the Office of Communication (OfCom) on 5G roll-out as part of an academic panel in November 2017 and individually in March 2018. More specifically, Maunder's advice contributed to the Future Telecoms Infrastructure Review policy paper [**5.15**], which sets the target of providing 5G coverage to the majority of the UK population by 2027. In particular, Maunder highlighted the challenges of and potential solutions for motivating Mobile Network Operators (MNOs) to invest in deploying the road-side infrastructure required to provide the underpinning URLLC access for CAVs throughout the UK. This contributed to the recommendation of introducing light-licensing models to encourage co-operation between MNOs, as detailed in paragraph 221 of [**5.15**].

5. Sources to corroborate the impact

5.1 R. G. Maunder, A. Li, I. Perez-Andrade, “Fully Parallel Turbo Decoding”, US10439645B2, granted October 2019; R. G. Maunder, M. Brejza, L. Xiang, “Detection circuit, receiver, communications device and method of detecting”, GB2559616A, filed February 2017.
5.2 Companies House filing, March 2016, (hyperlink); AccelerComm website (hyperlink).
5.3 Letter from Dr Lee Thornton, Investment Director, IP Group.
5.4 Letter from Dr Tom Cronk, CEO, AccelerComm.
5.5 EE Times Silicon 100 list, July 2020, (hyperlink).
5.6 Achronix press release, AccelerComm, February 2018, (hyperlink).
5.7 National Instruments press release, AccelerComm, June 2018, (hyperlink);
[text removed for publication] Spirent interview, AccelerComm, March 2019, (hyperlink).
5.8 Xilinx press release, AccelerComm, July 2020, (hyperlink).
5.9 [text removed for publication] Intel press release, AccelerComm, March 2020, (hyperlink).
5.10 Letter from [text removed for publication], CTO for [text removed for publication].
5.11 Gartner, “Forecast: Communications Service Provider Operational Technology, 2Q20 Update”, July 2020, (hyperlink); GMSA, “2020 The Mobile Economy”, (hyperlink).
5.12 Letter from [text removed for publication] 3GPP RAN1 Delegate, [text removed for publication];
Discussion of R1-1610604, Section 8.1.3.1, Report of 3GPP RAN1 #86bis, (hyperlink).
5.13 Letter from [text removed for publication], Principal Scientist, [text removed for publication].
5.14 Github repository, (hyperlink).
5.15 DCMS, "Future Telecoms Infrastructure Review", July 2018, (hyperlink).