Institution: Queen's University Belfast

Unit of Assessment: UoA12

Title of case study: Innovating High-Speed Network Processing of Future and Cloud Services

Period when the underpinning research was undertaken: from 2008 to 2016

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:
Sakir Sezer, Sandra Scott-Hayward	Professor Lecturer	1998 to present 2013 to present

Period when the claimed impact occurred: from 2011 to 2020

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

1. Summary of the impact

Ever-increasing internet bandwidth is required to support streaming and real-time content, as well as growth in internet connected devices. This requires a new generation of Internet routers to provide quality of service and secure content delivery.

Netronome, whose customers include the world's largest equipment vendors e.g. Dell, Cisco, is a world leader in high performance networking solutions. Netronome incorporated UoA research on high-performance management of internet traffic into its products, resolving the key challenge of tracking millions of simultaneous internet traffic flows.

Netronome's turnover consequently increased by over GBP[text removed for publication] per year with customers experiencing latency reduction and increased capacity per server node.

2. Underpinning research

Emerging highly cloud centric services, collecting information from and providing services to an expanding number of highly diverse and dispersed wireless and mobile communication devices, users and sensors, require communication networks that are dynamic, secure and deliver high Quality of Service. Such networks rely on smart network nodes built upon custom purpose processing known as Software Defined Networking (SDN) and Network Function Virtualisation (NFV) to achieve acceleration.

The UoA (from 2008 to 2016, Sezer, Scott-Hayward) developed research in lookup algorithms that provide fast memory-access, packet classification, parallel packet processing, and shared packet buffer architectures, akin to ultra–high speed phone book searching but across enormous volumes of internet traffic at exceptionally high speed.

The main research focus here has been the creation of highly parallel and pipelined custom integrated circuits and associated algorithms. The research has resolved key challenges of decomposing and scaling the highly data-dependent and memory-centric problem of lookup of multiple IP packet headers and tracking of millions of simultaneous IP traffic flows in a way that enables sustainable and scalable performance.

A software programmable hardware-based approach for fine-grain parallelisation was developed which resolved the latency and bandwidth related constraint of traditional software-based solutions of Open Virtual Switching (OvS) and Software Defined Networking (SDN).

The core innovations from QUB research that enabled these significant advances in Internet packet and flow classification technology, while extending this technology for Software Defined Networks are:

- US Patent: 13/929,809 **R[1],** this work showed that it is possible to manage network traffic data by performing parallel lookup operations on subfields of the network traffic data. A lookup result analyzer then determines whether additional inspection of the traffic data is required.
- Hybrid Packet Classification Architecture comprised of several configurable lookup algorithms that can be tailored (memory utilisation vs lookup latency vs lookup bandwidth) at runtime for various packet classification applications and traffic types **R[2 – 5].**
- Hardware accelerated exact match lookup for memory-efficient packet flow processing US patent 14/151,730, utilising the efficient use of embedded distributed memory technology, as intermediate lookup cache and external memory as the main storage for flow tables **R[6].**

3. References to the research

R[1] Traffic Data Pre-Filtering, US 13/929,809, Guerra, Yang, Sezer, Scott-Hayward
Applicant: Keissy Guerra, Belfast (GB); Sandra **Scott-Hayward**, Belfast (GB); Sakir **Sezer**, Belfast (GB); Xin Yang, Belfast (GB)
Patent No.: *US9,515,929 B2*
Date of Patent: Dec. 6, 2016
Assignee: Netronome Systems, Inc., Santa Clara, CA (US)

R[2] DDR3 Based Lookup Circuit For High-Performance Network Processing. Xin Yang, Sakir **Sezer**, John McCanny, Dwayne Burns. September 2009. *Proceedings of 2009 IEEE International SOC Conference (SOCC)*, pp. 351-354. DOI: 10.1109/SOCCON.2009.5398024

R[3] Optimized Packet Classification for Software-Defined Networking,
Guerra Perez, K., Yang, X., Scott-Hayward, S., **Sezer**, S., Jun 2014, *2014 IEEE International Conference on Communications (ICC).* Institute of Electrical and Electronics Engineers (IEEE), p. 859-864. DOI: 10.1109/ICC.2014.6883427

R[4] A Scalable Packet Sorting Circuit for High-Speed WFQ Packet Scheduling,
K. McLaughlin ; S. **Sezer** ; H. Blume ; X. Yang ; F. Kupzog ; T. Noll, IEEE Transactions on Very Large Scale Integration (VLSI) Systems (Volume: 16, Issue: 7 , July 2008) p. 781 - 791, DOI: 10.1109/TVLSI.2008.2000323

R[5] "Packet Prediction in a Multi-Protocol Label Switching Network Using Operation, Administration, and Maintenance (OAM) Messaging", US 14/264,003, Viljoen, Scott-Hayward
Applicants: Nicolaas J. Viljoen, Cambridge (GB); Sandra **Scott-Hayward**, Belfast (GB)
Pub. No.: *US 2014/0236873 A1*
Pub. Date: Aug. 21, 2014
Assignee: Netronome Systems, Inc., Santa Clara, CA (US)

R[6] "Dedicated Egress Fast Path for Non-Matching Packets in an OpenFlow Switch", US 14/151,730, Douglas, Toal, **Scott-Hayward**
Applicant: Netronome Systems, Inc., Santa Clara, CA (US)
Patent No.: *US 9,299.434 B2*
Date of Patent: Mar. 29, 2016

4. Details of the impact

Netronome is located in Silicon Valley, California, USA and employs over 200 highly skilled engineers. Netronome is a leading developer and vendor of high-performance networking solutions for cloud, data centre, service provider and enterprise communications products **S[1]**.

The above outlined innovations **R[1]-R[6]** have been translated in collaboration with Netronome into successful packet and network processing technologies that now underpin NFV/SDN enabled network and cloud products, providing programmable and secure multi-gigabit networking functions.

The impacts resulting are:

1. Technological Impact – Netronome has released NFV and SDN related products for Data Centre and Internet Security appliances with improved power efficiency and data throughout, thereby reducing overall processing latency.

2. Economic Impact – close research partnership enabled Netronome to be a market innovator in Network Flow Processor technology leading to an increased turnover of over GBP[text removed for publication] per year (associated with products for the NFV and SDN appliance market).

Netronome has been working with Queen's University Belfast Electronics, Communications and Information Technology Research Institute ECIT since 2011, in what has become an exemplar of University/Industry partnership. Netronome has invested over USD[text removed for publication] into ECIT research since then, **specifically targeting the advancement and commercial development of novel algorithms for accelerating network security processing and high-speed IP flow classification for Netronome's** [text removed for publication] **S[2]**. Netronome has been able to take full advantage of QUB's research facilities, PhD programmes, key skill sets and also research innovations in network and flow processing technologies.

Initial engagement with Netronome (2011) targeted the core competencies at QUB in lookup acceleration for packet and flow classification and flow processing. Follow-on engagements with Netronome (from 2013) were mainly focused on specific technological challenges, such as [text removed for publication]. This resulted in research contracts and a strong impact focussed partnership with Netronome.

Netronome's Chief Operating Officer (COO) said, *"From Netronome's perspective, the standout expertise of the research team led by Professor Sezer lies in their profound understanding of traditional technological constraints impairing performance and latency of high-speed search and lookup functions. The team has developed several*

novel search architectures overcoming such technological barriers… many of these innovations have been successfully optimized by [QUB] for Netronome's flow processor technology and deployed by the Netronome Agilio product family for a wide range of Network Security and SDN systems" **S[2]**.

The strength of this partnership has combined the research capability at QUB with the market leading products of Netronome, resulting in the world's first solution to the highly complex problem of creating a high performance, low cost, IP flow classification solution that is being applied to today's SDN products. **Netronome have stated that,** ***"Without this patented research and breakthrough at QUB, such a solution would not be possible"*** **S[2]**.

The Netronome COO has confirmed the reach of these products, and the benefit seen by Netronome*:* ***"Netronome's networking solutions incorporating (ECIT) innovations are being widely used by the world's largest network equipment vendors, delivering worldwide secure internet services. These technological advances have ultimately led to an increase in Netronome's turnover of over*** [text removed for publication] ***per annum"*** **S[2]**.

Key Netronome clients using the Agilio product family include Dell EMC, Ericsson, and Juniper Networks, sample customers are listed in **S[3],** with core technology partners in **S[4].**

The direct benefit for Netronome customers aligning with the core QUB research **R[4]-R[6]** are:

- Reduction of latency when compared with traditional Software based solutions
- Significant increase of traffic bandwidth per server node
- Effective utilisation of Datacentre computing (CPU) resources for application rather than for virtual switching.

As an example, Red Hat, a world-leading provider of open-source software solutions, partnered with Netronome to offer a new cloud and NFV infrastructure solution to boost efficiency for Red Hat's Enterprise Linux and OpenStack Platform users. A partner solution brief on Red Hat's website **S[5]** explains "***Netronome's programmable network flow processor delivers on-demand acceleration with traditional Ethernet services. By working with the open-source community to develop standard application programming interfaces for SmartNICs (network interface cards that offload processing tasks that the system CPU would normally handle), Netronome and Red Hat offer breakthrough efficiencies in data centre and cloud-based computing".***

5. Sources to corroborate the impact

S[1] Netronome website
S[2] Netronome testimonial letter
S[3] Netronome customers
S[4] Netronome technology partners
S[5] Red Hat Netronome Smart NIC