| **Institution:** Queen's University Belfast |
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| **Unit of Assessment:** UoA12 |
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| **Title of case study:** Hardware Accelerated Processor for Network and Cloud Security |
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| **Period when the underpinning research was undertaken:** from 2006 to 2011 |
|---|

| **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 | Professor | 1998-present |

| **Period when the claimed impact occurred:** from 2013 to 2020 |
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| **Is this case study continued from a case study submitted in 2014?** N |
|---|

## 1. Summary of the impact

Custom processors for high-performance pattern matching have been commercialised through QUB start-up, Titan IC Systems Ltd. which grew its revenue to over GBP [text removed for publication] at June 2019.These processors, used for malware and network intrusion detection have enabled hardware acceleration for products in the Cyber Defence and Enterprise Security markets. Titan IC's customers include cybersecurity, government and data analytics markets. Titan IC license product to [text removed for publication]% of the top five Network Interface Controller (NIC) vendors who together supply [text removed for publication] of this market. Titan IC was acquired, in 2020, by the US company *Mellanox* a leading supplier of end-to-end Ethernet interconnect solutions.

## 2. Underpinning research

Cybercrime threatens users, digital economies and society. Network and cloud security must be capable of delivering high performance in terms of throughput and low inspection latency without compromising security and integrity of applications and services. State-of-the-art security technologies are reliant on the offload and acceleration of computationally expensive functions, such as pattern matching. The detection of obfuscated cyberattacks, i.e., those where the hacker disguises their activity, requires sophisticated pattern matching techniques. To address this, a description language called 'regex' that searches mathematically mapped sequences of characters (regular expressions: a special text string for describing a search pattern) to define a search pattern is universally adopted as a description language to specify unique signatures for known cyber-attacks. Unfortunately, the method is slow especially when huge data sets are to be searched using conventional computing platforms. Therefore, hardware acceleration is required.

Before the UoA research described below was conducted by Professor Sezer, based at QUB's Center for Secure Information Technology (CSIT), traditional acceleration methods widely used for parallel signal processing were limited by the data-centric and data-dependent nature of regex processing. Previous academic and industrial research had failed to develop a hardware accelerated regex processor that was capable of outperforming traditional software-based solutions. Research at QUB successfully targeted and resolved this challenge.

1. Sezer introduced a hardware based programmable circuit that can decode any arbitrary length of input data without being constrained by decoding fan-out i.e., the number of gate inputs that the output of a logic gate drives. This enabled superior parallelism that is scalable and capable of supporting throughput rates of up to 40Gb/s, **R[1]**.

2. Sequences of characters can contain repetitions of character sequences. This means regex can have multiple valid search paths. By assuming there are enough parallel processing resources available, Sezer devised an algorithm whereby multiple paths can be searched in parallel permitting significant acceleration and reduction of inspection latency, **R[2]**.

3. Software optimised regex processing depends on data based on a 4Kbyte page size. QUB investigations showed that for 4Kbyte cached regex processing most input data lookups failed during the first or second lookup cycle. Our investigation of various cybersecurity related signatures identified that a page size of 64Kbytes overcomes this problem**, R[3]**.

4. A dedicated compiler was also created to translate text based on regular expression into computer code that can be executed on QUB's custom-purpose processor architecture, **R[4]**.

The above research underpins the key features and performance advantage embodied in the Titan IC Regular eXpression Processor (RXP) technology.

## 3. References to the research

**R[1]** Design and implementation of a field programmable CRC circuit architecture, Toal, C., McLaughlin, K., **Sezer**, S. & Yang, X. , IEEE Transactions on Very Large Scale Integration (VLSI), Vol. 17, No. 8, Aug. 2009, pp1142-1147, DOI: 10.1109/TVLSI.2008.2008741

**R[2]** Sorting Apparatus and Method, US Patent *US20090182714A1*, 2006, Inventors **S.Sezer**, K McLaughlin, Assignee Titans IC Systems Ltd.

**R[3]** High performance multi-engine regular expression processing, Thianantha Arumugam, Sakir **Sezer**, Dwayne Burns, Vishalini Vasu; IEEE International System on Chip Conference (IEEE SoCC2011), Sept. 2011. DOI:10.1109/SOCC.2011.6085117

**R[4]** An Approach for Unifying Rule Based Deep Packet Inspection" A. Munoz, S. **Sezer,** D. Burns, G Douglas, IEEE International Conference on Communications (ICC2011), Kyoto, Japan, June 2011.  DOI: 10.1109/icc.2011.5963095

## 4. Details of the impact

Titan IC Systems Ltd delivers accelerated search and analytics within high-speed networks and big data worldwide and is a spin-out (incorporated 2007) from QUB *CSIT*, the Centre for Secure Information Technologies at Queens University Belfast.

At January 2019, Titan IC had grown to a team of [text removed for publication] staff, of which [text removed for publication] are directly involved in engineering and product development, including 9 at PhD level. Titan IC secured investment of over GBP[text removed for publication] from local investors and one strategic investor. The company has also secured over GBP[text removed for publication] in grant funding from Invest NI for [text removed for publication] large R&D projects and grew its revenue from products to over GBP[text removed for publication] for year ending June 2019.

**The CEO of Titan IC Systems, said," The establishment of the company in 2007 was a direct result of research carried out by Professor Sezer and his team in the Network Security Group at the Centre for Secure Information Technologies (CSIT). This research**

**led to a number of technology breakthroughs and patents which enable our high-speed string matching, Regular Expression (REGEX) processing and offload acceleration. The company was able to leverage these** (QUB Sezer Developed) **underlying technology components to bring to market its RXP Accelerator technology, widely regarded as the industry-standard for high-speed complex pattern matching, real-time Internet traffic inspection, and the detection of malware using regular expressions. In addition to the critical underpinning technology, the company continues to benefit from its relationship with CSIT, with several consultancy and research engagements being delivered in recent years. A number of our key staff were also recruited from the research team at CSIT, including 8 PhDs." S[1].**

The company has won a number of awards for its work, for example in October 2019, Titan IC's strong growth was acknowledged as ranking 28 out of the 50 fastest growing technology companies in Ireland. It also won the Innovative New Technology Award in association with Google, and the Deloitte Technology Fast 50 Cyber Security Award, **S[2]**.

The company's core technology, RXP, is a highly sophisticated hardware engine that offloads RegEx processing.

RXP is regarded as the industry-standard for high-speed complex pattern matching, real-time Internet traffic inspection and the detection of strings, keywords and malware using regular expressions (RegEx). The Regular eXpression Processor (RXP) technology is based on the QUB research identified in section 2.

RXP is currently worldwide the only hardware-accelerated regex processor for the cybersecurity market. The developed RXP technology has gained significant deployment in the form of offload accelerators embedded on Peripheral Component Interconnect Express, PCIe cards, a common interface for graphics cards, hard drives, ethernet hardware connection etc., and also as an example on the *Amazon Web Services AWS-F1 system*, developed to deliver agile, complete cloud solutions. At January 2020, RXP was the worldwide preferred choice of technology for internet traffic inspection, making it the equivalent of the GPU for the gaming market, for the internet security market.

**The RXP product has many major tier-1 customers in US, UK, Europe and Asia, S[3]** within the semiconductor, cybersecurity, government and data analytics markets with Titan IC Systems Ltd licensing the RXP semiconductor IP to major security solution providers, including **Trent Micro, Cisco, S[4], Looking Glass, Valtix, Silicom.** In addition, Titan IC systems Ltd. has successfully licensed to three of the top five Network Interface Controller (NIC) vendors **Mellanox,S[5]/Cavium/Marvell,** (together these companies supply approximately [text removed for publication]% of the Cloud Network Interface Controllers).

Commenting on the decision to license RXP technology**, The Senior Vice President of Silicon Engineering at Mellanox explained**, "**...., we chose to add the innovative RXP from Titan IC to our IPUs (Intelligent Processing Units) because of its massively parallel RegEx processing capabilities and performance benefits." S[5].**



Titan IC RXP ACCELERATOR **S[6]**

Titan IC was acquired in March 2020 by the major US company Mellanox, a leading supplier of end-to-end Ethernet interconnect solutions, making Titan IC the centre of advanced network intelligence research and development for Mellanox.

**The President and CEO Mellanox Technologies said, "Our customers will benefit from the deep analytics and enhanced security that will be delivered by the integration of our best-in-class Ethernet and InfiniBand products and world-leading deep packet inspection and analytics technologies from Titan IC." S[7].**

**5. Sources to corroborate the impact**

**S[1]** CEO Titan IC Letter
**S[2]** The 2019 Deloitte Technology Fast 50 Awards.
**S[3]** Titan IC Partners
**S[4]** Titan IC committed to work with Cisco and the Open Source Snort community
**S[5]** Titan IC Accelerates Pattern String Matching Mellanox
**S[6]** Titan IC RXP ACCELERATOR
**S[7]** Titan IC Acquisition by Mellanox