Institution:
Glasgow Caledonian University

Unit of Assessment:
11 - Computer Science and Informatics

Title of case study:
Pioneering Low Power Wide Area Wireless Network for Smarts Cities (Glasgow) and Remote Health Monitoring

Period when the underpinning research was undertaken:
December 2014 – ongoing

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:
Prof. Hadi Larijani,	Principal Investigator, Theme Leader	2000 - present
Dr. Ali Ahmadinia	Senior Lecturer, Audio and Electronic Engineering	2008 - 2016
Prof. Rohinton Emmanuel	Co-Investigator, Director BEAM research Centre	2008 - present

Period when the claimed impact occurred:
January 2015 – present

Is this case study continued from a case study submitted in 2014?
No

1. Summary of the impact

Hadi Larijani and his team's work demonstrated Low Power, Wide Area (LPWA) networking protocol (LoRaWAN) to be an effective and reliable method for smart sensor communication in Urban Environments [G1]. Following its first large scale study in a Scottish city, the Scottish Government subsequently acted and rolled it out across the country. The Centre of Excellence for sensing, imaging and Internet of Things (CENSIS) [C1] stated, that GCU "played an important part in a wider programme of activity led by CENSIS to establish a Low Power Wide Area Network (LPWAN, specifically LoRaWAN) testbed in Glasgow." Work with the companies Stream Technologies and Gas Sensing Solutions has led to a better understanding of the capability of LoRaWAN for smart sensors in cities and for fundamentally managing the power requirements for long-term use without intervention, contributing to the acquisition by multi-billion dollar company ARM and 20% increase in sales, respectively.

2. Underpinning research

Research in engineering applications of advanced machine learning and AI using Random Neural Networks (RNN) started in 2004 at GCU. This research has since involved more than 20 academics and research students. There are two research groups (Cyber Security, Networking, and Communications (CSNC) and AI + IoT Research Lab) that are part of the SMART Technology Research Centre.

Larijani's research contributions during this assessment period can be grouped in three main areas:

1. Smart building energy management systems using wireless sensors and IoT.
2. Accurate performance evaluation of low power wireless network (LoRaWAN).
3. Application of LoRaWAN for smart transport, disaster management, and telehealth.

Buildings consume 32% (24% for residential and 8% for commercial) of the global energy consumption, 19% of total energy related CO2 emissions and 51% of total electricity consumption. The smart building energy management system developed at GCU (hardware and software) was shown to save more than 30% energy and have the same thermal comfort [R1].

In 2014 a project with Gas Sensing Solutions Ltd. [G2], a Scottish gas sensing company showed that with LoRaWAN and cloud technologies, a suitable gas sensing solution could be developed so that sensors could communicate and their battery life extended, in some cases indefinitely (using Photovoltaic charging). This technology was further expanded by using Cloud infrastructure to manage cooling in buildings [R2]. The project determined whether random neural networks (RNN's) could provide necessary intelligent self-learning (ISL) and adaptive management capability for autonomous carbon dioxide/ humidity/ temperature wireless sensors within buildings – energy and indoor air quality demand control and management with minimal human intervention [R3]. Traceall Global Ltd bring significant experience in use and deployment of wireless sensor networks for buildings, logistics and healthcare applications.

In 2015 this work was also extended [G1] to the oil and gas sector and led to the study of security threats in LoRaWAN. This also resulted in a journal paper [R4] which reported on the use of LoRaWAN with security, and how can we implement security on these small devices. A pilot study was conducted in implementing edge security using Random Neural Networks and this led to the new KTP within IoT security. The main findings were that a multi layered approach for LoRaWAN and IoT security is required with elements of security embedded in the edge devices [R4]. Human safety using secure occupancy was reported in [R5].

More recently the LoRaWAN technology has been evaluated for disaster management [R6], and results have shown that due to its low power and wide area coverage it would be the ideal solution for post geological disaster implementation as a rapid response or as a backup for these eventualities.

Larijani and his team have generated nine journal publications in IEEE, ACM, and IET journals, one patent, and presented at 15 international conferences.

3. References to the research

- R1. Abbas Javed, Hadi Larijani, Andrew Wixted, "Improving Energy Consumption of a Commercial Building with IoT and Machine Learning'', IEEE IT Professional Journal, 20 (5), pp. 30-38, 2018. https://doi.org/10.1109/MITP.2018.053891335

- R2. Abbas Javed, Hadi Larijani, Ali Ahmadinia, Des Gibson, "Smart random neural network controller for HVAC using cloud computing technology", IEEE Transactions on Industrial Informatics, 13 (1), pp. 351-360, 2017. https://doi.org/10.1109/TII.2016.2597746

- R3. Abbas Javed, Hadi Larijani, Ali Ahmadinia, Rohinton Emmanuel, Mike Mannion, Desmond Gibson, "Design and Implementation of Cloud Enabled Random Neural Network based Decentralized Smart Controller with intelligent sensor nodes for HVAC", IEEE Internet of Things Journal, 4 (2), pp. 393-403, 2016. https://doi.org/10.1109/JIOT.2016.2627403

- R4. Ahmed Saeed, Ali Ahmadinia, Abbas Javed, Hadi Larijani, "Intelligent intrusion detection in low-power IoTs", ACM Transactions on Internet Technology (TOIT), Vol 16 (4), 2016. https://doi.org/10.1145/2990499

- R5. J Ahmad, H Larijani, R Emmanuel, M Mannion, A Javed, "Occupancy Detection in Non-residential Buildings–A Survey and Novel Privacy Preserved Occupancy Monitoring

Solution'', Applied Computing and Informatics, Elsevier, 2020. https://doi.org/10.1016/j.aci.2018.12.001

- R6. Ahsan Adeel, Mandar Gogate, Saadullah Farooq, Cosimo Ieracitano, Kia Dashtipour, Hadi Larijani, Amir Hussain, "A survey on the role of wireless sensor networks and IoT in disaster management", In: Durrani, T., Wang, W., Forbes, S. (eds.) Geological Disaster Monitoring Based on Sensor Networks, pp. 57-66. Springer Natural Hazards. Springer, Singapore (2019). https://doi.org/10.1007/978-981-13-0992-2_5

Grants Awarded:

- G1. (PI) H. Larijani, A. Ahmadinia, R. Ramirez-Iniguez (Total £150K 2014-2015). CENSIS (The Centre for Sensors and Imaging Systems and Gas Sensing Solutions– supported by SFC), "Low cost/ power consumption Random Neural Controller for enhanced sensor intelligence in Building Energy Management Systems, Tele-health and Oil & Gas applications.

- G2. (PI) H. Larijani, A. Ahmadinia, R. Emmanuel (Total £300K 2014-2015). TSB (Technology Strategy Board), "Feasibility of random neural networks as an intelligent self-learning platform for cost effective deployment of energy harvesting compatible wireless sensors applied to building management systems".

- G3. (PI) H. Larijani and A. Ahmadinia (Total: £145,000 Oct 2015- Sept 2017). KTP (Knowledge Transfer Partnership) (With Stream Technologies Ltd) Project Title: Radio-Frequency Identification (RFID) solution with energy harvesting for implementation in low power wireless sensors.

- G4. (PI) H. Larijani and O. Uthmani (Total: £161,000 Jan 2018- Sept 2020). KTP (Knowledge Transfer Partnership) (With Stream Technologies Ltd) Title of project: Real-time Security monitoring of IoT using Deep learning and Random Neural Networks.

4. Details of the impact

Impact 1. General policy to roll out the technology specific to application areas:

The research, development, and analysis of low power wireless networks (LoRaWAN network) for environmental sensing conducted by Glasgow Caledonian University has been instrumental in the development of Scottish smart cities.

GCU research has helped companies to develop smart solutions in cities for environmental sensing (air pollution) [C1], traffic management, building energy management [C2], intelligent lighting, and for the rural areas of developing countries. The first KTP project between GCU and Stream Technologies [G3] led to a pilot project in Glasgow in collaboration with Strathclyde University, Glasgow University, and CENSIS. As a direct result of these projects the Scottish Government has rolled out LoRaWAN networks across Scotland and an IoT network infrastructure for environmental sensing, disaster recovery and smart cities has been developed. The UK government is now funding similar initiatives.

For specific projects and applications:

Stream Technologies published two White papers for their customers highlighting the benefits of LoRaWAN. GSS solutions was able to implement their sensors for Schneider Electric. In Stream's White paper [C7] "the results encouraging in the assessment of the LoRaWAN technology. For 'set and forget' sensing where two-way communication is not a requirement and where occasional missing packets are not an issue, the uplink success rate in a multi-gateway environment is very good." The (CEO) of Stream in an interview with IoT Now [C8], stated, "with Glasgow Caledonian University we are exploring the concept of harvesting energy from

broadcast sources such as television and radio transmissions and the irony hasn't escaped us that we're looking to use energy from one radio source to power another. How cool is that?"

Impact 2. Creating new business, improving the performance of existing businesses from Stream Technologies testimonial [C6]:

Gas Sensing Solutions Ltd.: The project with GSS [G2], using Cloud infrastructure to manage cooling in buildings [R3] led to increased sales of GSS by over 8% [C9], and they are now entering the market of smart sensors. The AI developed by GCU and tested in real world environments has been a major contributing factor to this development.

Stream Technologies: Work in collaboration with GCU through the two KTPs [G3, G4] established Stream Technologies as a key player in the LPWA IoT sector [C3, C4]. It led to the creation of a Glasgow and subsequently Scottish LoRa network and consortium, which cemented the company's role in the growth of Scottish IoT via pilot projects, bootstrapping IoT Scotland and the validation of Geolocation on LoRa networks [C3, C4, C5], as well as the invalidation of RF power harvesting as a usable power source of LPWA. As a result of their expertise in LoRa developed through the KTPs (as well as cellular and satellite connectivity), Stream Technologies was acquired by ARM in June 2018. The combination of Stream's technology with Arm's Mbed IoT Device Management Platform will provide a basis for a combined physical and software platform. ARM claimed that customers would see a number of key benefits from the Stream acquisition and integration with ARM's Mbed IoT Device Management Platform, including:

- Single pane of glass that provides customer visibility and management capabilities throughout the device's lifecycle – deployment, connectivity, provisioning, management, and updates.
- eSIM orchestration that communicates and connects policies enabling zero touch onboarding that drive efficiencies and scale of IoT connections.
- Global aggregation across network types and flexible wireless connectivity options that can be optimized across devices, regions, and use cases that are deployed.
- Simplified billing and reconciliation through APIs and automated controls that can charge based on any event for increased flexibility.
- Connect and manage any device regardless of network type to steer reliable and trusted data, seamlessly push new updates and features, and optimize quality-of-service and latency for troubleshooting.

In the 2020 acquisition of ARM by Nvidia, the company was valued at $40bn (£31.2bn), an increase of $10bn over its value in 2016, prior to the acquisition of Stream Technologies.

5. Sources to corroborate the impact

- C1. Supporting statement from CENSIS.
- C2. Herald Scotland, "Scottish sensor system aims to tackle office air quality issues", Monday 16 March 2015.
- C3. CENSIS media release, "Glasgow pioneers Internet of Things connectivity with new LoRa network", The Scotsman, 5 July 2016.
- C4. IoT Now, "Glasgow pioneers Internet of Things connectivity with new LoRa network", 14 July 2016.
- C5. The National, "Glasgow to get boost from Internet of Things", 6 July 2016.
- C6. Testimonials from CTO, Stream Technologies.

- C7. LoRaWAN Performance in Generic IoT Scenarios – White Paper, Stream Technologies.
- C8. IoT Now Dec/Jan 2015/16, 5 (5), pp. 8-11.
- C9. Testimonial by ex-CEO Gas Sensing Solutions (GSS).