**Institution:** Queen's University Belfast

**Unit of Assessment:** UoA12

**Title of case study:** Natural Disaster-Tolerant Wireless System that Saves Lives

**Period when the underpinning research was undertaken:** from 2015 to 2019

**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: |
|---|---|---|
| Trung Q. Duong | Professor | 2013 – present |

**Period when the claimed impact occurred:** from 2016 to 2019

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

## 1. Summary of the impact

A Catastrophe-Tolerant Heterogeneous Telecommunications Network, a resilient and agile wireless communications system, was designed and implemented by the UoA. This provides seamless connectivity to relief authorities and workers when telecommunications infrastructure is significantly impaired.

Annually, central Vietnam is greatly affected by major storms that damage transportation, agriculture, and fishery, costing GBP1,900,000,000 in 2017.

The Vietnam Disaster Management Authority and one of the three biggest Vietnamese mobile operators have incorporated the system into their national disaster response plans.

## 2. Underpinning research

Physical destruction caused in Vietnam by various disasters such as floods, typhoons and storms to communication and power supply networks occurs on an annual basis. Commerical solutions for communication under these hostile conditions such as *Cisco's Network emergency response vehicle* have emerged. However, these are point solutions with short-range coverage and limited connectivity and are not applicable in disaster-prone countries with isolated widespread rural areas and large-scale disaster scenarios. There was therefore an urgent need to develop new approaches to overcome these limitations.

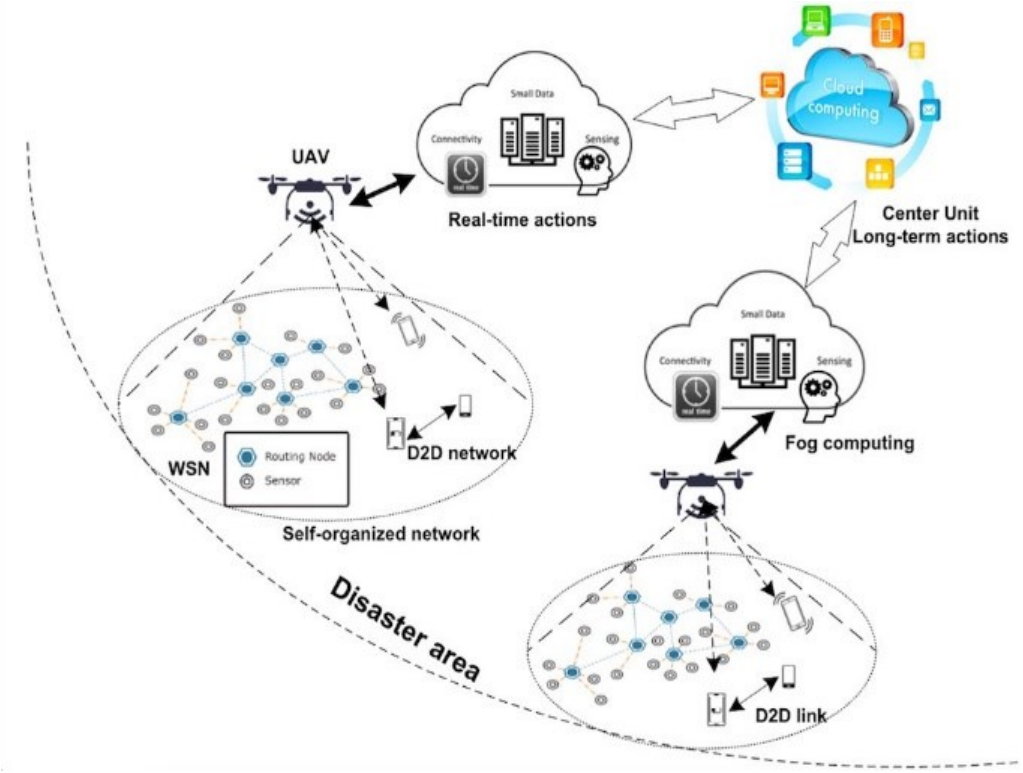
The 2016 *Newton Fund* supported research by Professor Trung Duong in collaboration with Vietnamese partners to develop an integrated heterogeneous wireless system (**IHWS**) that could overcome communications failures (e.g. network congestion) resulting from telecommunications networks that are severely damaged by natural disasters.

The work won the prestigious 2017 Newton Fund Prize GBP200,000 awarded by the UK Government. At the award event **the British Ambassador to Vietnam, said: "International cooperation with a diversity of ideas, views and good practice plays a very important role in research and innovation".**

The system QUB (Duong) developed in association with Duy Tan University, Nong Lam University and Thuyloi University Vietnam acts as a Telecommunications Network that integrates conventional wireless sensor networks (WSNs), and mobile cellular networks (MCNs) in order to capture environmental events and provide information into disaster recovery agencies. This concept was embodied in the design approach articulated in the research paper **R[1].** The resulting solution this afforded offers a resilient, robust, flexible, and agile wireless communications design that can provide seamless connectivity. Theoretical

considerations related to providing a high quality-of-experience, even under critical conditions, such as destroyed telecommunication or electricity infrastructure was the subject of paper, **R[2].** These papers allowed the baseline system to be developed.

In mission critical communication systems that support disaster management workers, such as fire brigades, rescue teams, and emergency medical services, time is the critical factor and a maximum latency of a few milliseconds is required. A strict real-time deadline is therefore the most important requirement for such scenarios under a constantly changing environment. To tackle this issue, a real-time resource allocation algorithm was developed to maximise the energy efficiency, leveraging machine learning to jointly optimise the energy-harvesting time and the power control for unmanned aerial vehicle (UAV) communication at low latency, **R[3], R[4]**, **R[5]**. These papers set the basis under which a UAV communication layer could be added into the **IHWS**. This being a key component, since under hostile conditions in disaster scenarios, UAVs can remain airborne above the affected areas, acting as flying base stations in order to maintain connectivity. In **R[6],** an approach was developed wherein the UAV could automatically optimise its performance during operational deployment. The studies conducted in **R[1-6]** formed the basis for the complete Catastrophe-Tolerant Telecommunications Network architecture below.




Catastrophe-Tolerant Telecommunications Network

**3. References to the research**

**R[1]** N.-S. Vo, T. Q. **Duong**, and M. Guizani, “Quality of Sustainability Optimization Design for Mobile Ad Hoc Networks in Disaster Areas,” in Proc. of IEEE Global Communications Conference (GLOBECOM'15), San Diego, CA, Dec. 2015, pp.1-6. DOI: 10.1109/GLOCOM.2015.7417093

**R[2]** N.-S. Vo, T. Q. **Duong**, and M. Guizani, “QoE-Oriented Resource Efficiency for 5G Two-Tier Cellular Networks: A FemtoCaching Framework,” in Proc. of IEEE Global Communications Conference (GLOBECOM'16), Washington, DC, Dec. 2016, pp. 1-6; ***Best Paper Award*** DOI: 10.1109/GLOCOM.2016.7842185

**R[3]** T. Q. **Duong**, L. D. Nguyen, and L. K. Nguyen, "Practical Optimisation of Path Planning and Completion Time of Data Collection for UAV-Enabled Disaster Communications," in Inter. Wireless Communications & Mobile Computing Conf. (IWCMC 2019), Morocco; June, 2019. ***Best Paper Award.*** DOI: 10.1109/IWCMC.2019.8766511

**R[4]** M.-N. Nguyen, L. D. Nguyen, T. Q. **Duong**, H. D. Tuan, "Real-time Optimal Resource Allocation for Embedded UAV Communication Systems," IEEE Wireless Communications Letters (WCL), 8(1), Feb. 2019, pp. 225 – 228. DOI: 10.1109/LWC.2018.2867775

**R[5]** L. D. Nguyen, K. K. Nguyen, A. Kortun**,** T. Q. **Duong,** "Real-Time Deployment and Resource Allocation for Distributed UAV Systems in Disaster Relief," in IEEE Int. Workshop on Signal Proc. Advances in Wireless Communications (SPAWC), Cannes, France, July 2019. **(Invited Paper**) DOI: 10.1109/SPAWC.2019.8815522

**R[6]** T. Q. **Duong**, L. D. Nguyen, H. D. Tuan, and L. Hanzo, "Learning-Aided Real-time Performance Optimisation of Cognitive UAV-Assisted Disaster Communication," in Proc. of IEEE Global Communications Conference (GLOBECOM'19), Waikoloa, HI, USA, Dec.2019. ***Best Paper Award*** DOI: 10.1109/GLOBECOM38437.2019.9014313

## 4. Details of the impact

According to the Global Climate Risk Index, **S[1]**, Vietnam is among the 10 countries worldwide most affected by natural disasters and extreme climate events affecting over 4,000,000 people with economic losses estimated at over VND51,600,000,000,000 (GBP1,900,000,000).

To help tackle this situation, multiple organisations in Vietnam have now adopted and implemented the QUB led integrated heterogeneous wireless system (**IHWS)** Catastrophe-Tolerant Heterogeneous Telecommunications Network:

Government departments and agencies:

The Ministry of Agriculture and Rural Development has disaster response responsibilities through the Vietnam Disaster Management Authority (VDMA); **its Minister said, "Your** (QUB) **research on Catastrophe-Tolerant Heterogeneous Telecommunications Networks has been incorporated into our disaster response plans". "It has played a significant role in saving life in Quang Nam Province - no death casualty in Dai Loc District since 2016 thanks to the warning system" S[2].**

Provincial municipalities:

In Central Vietnam, the **IHWS** is implemented in two closely located areas, Quang Nam Province and Da Nang City (1,300,000 inhabitants), here populations are particularly vulnerable to natural disasters and rapid urbanisation.

The Chairperson of Da Nang City explained that although efforts were made to enhance the capacity in disaster prevention and search and rescue, the number of casualties and damaged infrastructures had increased year after year. During 2005 to 2013, storms and flooding resulted in more than 100 deaths, 200 injuries, over 100 boats sunk, and 150,000 homes, transportation systems, agriculture, forestry and fishery damaged, generating an economic loss of VND8,500,000,000. (GBP300,000,000), **S[3].**

The **IHWS** was utilised in tracking and alerting of natural disasters (floods/storms/landslides), and in measuring and estimating environmental changes (carbon emission, city noise, water pollution). The implemented **IHWS** sensed and transmitted environmental quality levels; this information allowed the Quang Nam Province authorities to make better informed life-saving decisions.

Further, the IHWS was incorporated into Da Nang City's disaster response plans for the coastal areas, and the **Chairperson of Da Nang City commented, "Your IHWS provides reliable and fast information about storms, so that the DaNang Disaster Management Authority can quickly communicate with citizens when floods and storms happen, allowing us to make evacuation plans for the local community. ….. your IHWS played a vital role to evacuate people in Da Nang City living near the coastal areas (Son Tra district, 200,000 people). We have safely evacuated and rescued nearly 5,000 villagers and fishermen living alongside the Son Tra beach" S[3].**

Communications Service Providers

Vietnam's leading mobile operator Viettel (VTTEK) praised the value of IHWS **via its Head of 5G Research, "Through the existence of this project, VTTEK has the opportunity to support Vietnam and Binh Duong and Da Nang provinces in particular in natural disaster prevention and search and rescue" S[4].**

One of the three biggest Vietnamese mobile operators MobiFone has successfully implemented the IHWS. **Their head of product development said, "Since late 2016 your research in disaster communications has been embedded in mobile telecommunications solutions of MobiFone as part of our plan to cope with natural disasters. In November 2017 the coastal provinces from Quang Nam to Thua Thien Hue suffered a huge storm with extensive floods. Your disaster communications systems via our MobiFone network helped effectively announce early warning information to the community. Our network played a key role in evacuation missions and saving properties of poor farmers and villagers (approximately 1.2 million people). Without your disaster communications, such an effort would not have been possible" S[5].**

**Regarding the aftermath of the storm, he added, "The IHWS also provided vital information when most of telecommunications services were partly destroyed and not properly functional. Thanks to your disaster communication solution, our MobiFone telecoms system was able to maintain connection for more than 1 million subscribers in the affected region although the network infrastructure in these areas was not well equipped and severely damaged by the storm" S[5].**

## 5. Sources to corroborate the impact

**S[1]** Global Climate Risk Index 2017 by GermanWatch

**S[2]** Letter from the Vietnam Disaster Management Authority

**S[3]** Letter from the Chairperson of Da Nang People's Committee

**S[4]** Letter from Viettel Head of 5G Research, R&D Department

**S[5]** Letter from MobiFone Corporation