Institution: University of Bath

Unit of Assessment: Electronic & Electrical Engineering

Title of case study: Policing the Radio Spectrum to Protect Critical National Infrastructure

1. Summary of the Impact

Global Positioning System (GPS) devices are integrated into many modern electronic systems. The protection of these systems is vital to the daily operation of a nation's infrastructure and security. A new device and service for radio-frequency interference detection has been developed at Bath and is protecting GPS-reliant infrastructure from deliberate and accidental jamming. The system resulted from research into GPS signal processing. **Commercial impact** has resulted from the development of products and services operated internationally by a UK company. **Policy impact** has resulted from Ofcom's move towards making the possession of a GPS jammer illegal TEXT REDACTED. Economic and societal benefit has resulted from the protection against criminal jamming, ensuring the seamless running of transportation, telecommunications and emergency services that depend on GPS.

2. Underpinning Research

Key researchers: C Mitchell (now Professor, Bath 1999 to date) and R Watson (now Senior Lecturer, Bath 1998 to date), active in GPS research since 2001.

The problem addressed by the research is best described by example. In 2009 Newark airport in the US found some of its GPS related systems (in particular, Ground Based Augmentation Systems) were suffering from repeated interference. The problem was eventually traced back to a truck driver using a GPS jammer, but due to a lack of suitable detecting equipment this took six months to track down. Examples of the types of systems affected by GPS jamming include aviation, shipping, transportation of high-value or hazardous goods, banking transactions (which rely on GPS-derived timing), some mobile phone networks and emergency service communications. The protection of these systems in vital to the daily operation of a nation's critical infrastructure.

The research was first funded under an EPSRC Advanced Fellowship (GR/S49599/01, 2004-9) and involved making ionospheric scintillation measurements by GPS receivers [1] and methods for data analysis. Expertise in the detailed analysis of GPS signals was necessary to help eliminate anomalies in the measurements, in particular through examination of the carrier-to-noise ratios. Anomalous behaviour in the GPS system was being tracked by Bath's mathematical analysis that had been developed after recording GPS signals from a highly specialised receiver [2, 3]. Key to the approach was the development of statistical methods for differentiating between environmental effects and those resulting from anomalous interference. The Bath team's knowledge of the so-called 'normal' behaviour of the system allowed them to design and develop new algorithms that showed extraordinary sensitivity to any anomalous behaviour in the time series of the carrier-to-noise ratio [2]. Not only could they isolate anomalies but they could also discriminate between different causes and in some circumstances locations, thus distinguishing GPS jamming from natural environmental phenomena from malicious intentional criminal activity.

The underpinning research led to Technology Strategy Board (TSB) projects GAARDIAN and SENTINEL that enabled a continuation of the basic research and its extension in to applications (TSB/EPSRC grants TS/G002592/1; TS/I00257X/1, 2008-2012). Led by the founder and MD of the UK SME company, Chronos Technology, a consortium of academia and industry was formed to take the research outputs from Bath and to build them into a network that could provide a warning service across the whole of the UK. The SENTINEL consortium included as partners and research beneficiaries the General Lighthouse Authority (maritime navigation), Ordnance Survey (land-based surveying), National Physical Laboratory (timing standards), Thatcham (vehicle security) and the Association of Chief Police Officers (ACPO, national security interests). Within these TSB

projects Bath devised and developed sensors known as Interference Detection and Monitoring sensors (IDM) and a series of algorithms for interpreting the data from these were based on the need to identify and reject interference in GPS. **The IDM devices now allow the location of a GPS jammer to be identified in real time, protecting many systems that are vital to the daily operations of a nation's infrastructure and security**. **These GPS jamming detection devices are based upon fundamental research in GPS signal processing at the University of Bath.**

3. References to the Research

[1]* Mitchell, C. N., Alfonsi, L., De Franceschi, G., Lester, M., Romano, V. & Wernik, A. W. GPS TEC and scintillation measurements from the polar ionosphere during the October 2003 storm Jun 2005 In : Geophysical Research Letters. 32, 12, 4 p.L12S03 DOI: 10.1029/2004gl021644

[2]* Materassi, M. and Mitchell, C. N., 2007. Wavelet analysis of GPS amplitude scintillation: A case study. Radio Science, 42 (1) DOI: 10.1029/2005rs003415

[3]* Smith, A. M., Mitchell, C. N., Watson, R. J., Meggs, R. W., Kintner, P. M., Kauristie, K. and Honary, F., 2008. GPS scintillation in the high arctic associated with an auroral arc. Space Weather: The International Journal of Research and Applications, 6 (3), S03D01. DOI: 10.1029/2007sw000349.

[4] The underpinning research was undertaken with grants from the EPSRC (GR/S49582/01, GR/S49599/01, 2004-2009). The fundamental signal processing research, that proved to be vital to the subsequent SENTINEL project, was developed further by Mitchell and Watson under EPSRC grant (EP/F013264/1, 2007-2008).

*denotes references that best indicate the quality of the research.

4. Details of the Impact

Economic impact has resulted through the development of a new product range and service from Chronos Technology Ltd, a UK SME. Chronos supplies and develops a range of bespoke timing products for time and frequency synchronisation in power and telecom networks and is a specialist provider of technical solutions for telecom synchronisation applications [a]. Under project SENTINEL, a new sensor product and a service for Interference Detection and Monitoring has been developed [b]. This is the first such system capable of detecting dangerous anomalies occurring in GPS signals in real time. The devices or sensors are known as Interference Detection Monitors (IDM) and are linked together into the SENTINEL system. SENTINEL has now been deployed in many locations across the UK to quantify the nature and extent of GPS jamming and assess its impact on TEXT REDACTED. Alarm signals provided by SENTINEL are reported in near real-time and can be made available to the appropriate law enforcement authorities or security agencies.

TEXT REDACTED. Details of the products can be found on the Chronos Technology website [a] or by searching for SENTINEL or CTL-3510 and CTL-3520.

TEXT REDACTED. Six jobs have already been created in a new division, including a dedicated technical sales manager for the new products. Sales enquiries are currently being received from many different countries.

Testimonial from the MD of Chronos Technology:

"Collaboration with The University of Bath within the SENTINEL project has enabled Chronos to adapt basic academic research related to GPS anomaly detection into a focused operational system to detect and analyse GPS Jamming and Interference on a 24x7 basis."

Thus, quoting the REF guidelines, "*A new business sector has been created"* and *"potential future*

losses have been mitigated … in safety or security critical situations."

Policy impact has resulted from the SENTINEL project because it has provided an important input into the evidence base to support the policy change by Ofcom, and has helped enable the Ofcom board to support and prioritise the case for legislative change that would make possession of a GPS jammer illegal [c].

The SENTINEL project has been reported up to Ministerial level in UK Government, including the Cabinet Office, on a Government GPS Vulnerability briefing and has been cited in the House of Lords by the (then) counter terrorism Minister (Baroness Neville-Jones) as the UK response to the risk of terrorist jamming of GPS signals. TEXT REDACTED.

In response to a question in the UK House of Lords asking what steps the Government plans to take to reduce the vulnerability of global navigation satellite systems to terrorist attacks Baroness Neville-Jones, Minister of State, Home Office, replied*: "Her Majesty's Government are taking steps to counter interference with GPS systems. These measures include Project SENTINEL which aims to provide the capability to detect and locate the source of GPS interference, warn critical users and enable law enforcement agencies to take action when criminal activity is involved."* [d]

In addition, policy and service impact has occurred through the impact of SENTINEL research TEXT REDACTED. The on-going protection of critical national infrastructure and commercial services from malicious attack has been enhanced [c, e].

Thus, quoting the REF guidelines, "*policy debate has been stimulated or informed by research evidence"* and *"risks to the security of nation states have been reduced."*

5. Sources to Corroborate the Impact

a) Chronos Technology Limited: http://www.chronos.co.uk

b) Chronos Technology/University of Bath License Agreement

c) TEXT REDACTED

d) House of Lords Hansard, Question asked by Lord Patel of Blackburn, 16 Mar 2011: Column WA68 http://www.publications.parliament.uk/pa/ld201011/ldhansrd/text/110316w0001.htm

e) Further References can be found on the Chronos website: http://www.chronos.co.uk under SENTINEL or products CTL-3510 and CTL-3520.