Institution: University of South Wales

Unit of Assessment: B10

Title of case study:
Developing frequency assignment techniques for British military communication systems

1. Summary of the impact

Between 1994 and 2000 Prof. Derek **Smith** developed algorithms that in the last 10 years have been incorporated into major communication systems used throughout the British Armed Forces. Previous systems were unable to reliably deal with the huge volume of data provided by modern intelligence, surveillance and reconnaissance assets, particularly suffering from interference between users. Since 2004, alternative systems (Bowman and Falcon) overcoming these deficiencies have been rolled out. Approximately 50000 radio sets using this technology have been manufactured and fitted to 15000 military vehicles, including the entire Royal Navy fleet and 75000 people required training in its use.

2. Underpinning research

Overview of problem

Modern communication systems involve the transmission and reception of huge volumes of data. While it is always important for data to be uncorrupted between the sender and the receiver, it is particularly problematic for military communication systems where the infrastructure has to be rapidly deployed and information sent on the network can be a life-or-death matter. Indeed, where there are a large number of users in close proximity to each other, for example in a combat situation, there is much competition for broadcast frequencies and data can undergo interference that renders the communication useless. Thus intelligent algorithms are required that efficiently utilize the range of broadcast frequencies available while simultaneously minimizing interference between users. **Smith**, along with others including **Perkins** and industrial partners, developed algorithms between 1994 and 2000 that have been incorporated into new communication systems utilised throughout the British Army, Navy and Air force from 2004 onwards.

General research

Smith has an extensive history of mathematical research in radio frequency assignment methods. In particular, in the period 1994-2010 alongside collaborators including Prof. S. Hurley (University of Cardiff), **Perkins** and with a number of postdoctoral researchers and postgraduate research students, considerable attention was focussed on developing algorithms for radio frequency assignment based on graph theoretic methods and meta-heuristic algorithms. The algorithms themselves were underpinned by evaluation work in graph theory and mathematical programming. Indeed, in excess of 30 papers were published on this work alone during the sixteen year period. While many of the algorithms developed gave leading results on standard benchmark problems, crucially they were developed in a way that made them suitable for immediate implementation.

Specific research

In the late 1990s, the Bowman net combat radio system was being developed for the British Army by BAE Systems and QinetiQ with funding from the Ministry of Defence Pathfinder programme and researchers at these companies realised that **Smith**'s work on radio frequency assignment would prove invaluable to the project. Hence, between February 1999 and March 2000 a postdoctoral research assistant (Dr Richard Taplin) was employed by BAE Systems and seconded to the University of Glamorgan (now USW) to develop the algorithms in a way that was suitable for Bowman. The initial frequency assignment algorithms were improved by the addition of the ability to handle issues involving radios that were cosited, including handling interference caused by intermodulation products, spurious emissions and spurious responses. These improved algorithms were both published in research papers and integrated into the Bowman communication system and the later Falcon communication system, both as currently used by the British Armed Forces. Further research students supervised by **Smith** and **Perkins** and with funding from BAE Systems have further refined aspects of this work in recent years and collaborative activity is planned to continue with General Dynamics, the manufacturer of the Bowman and Falcon radio systems.

3. References to the research

Publications

These papers motivated Smith's involvement with BAE Systems and QuinetiQ or arose from joint collaborative activity developing the algorithms that were implemented in Bowman & Falcon systems:

- S. Hurley, D.H. Smith and S.U. Thiel, F. A. Soft: A System for Discrete Channel Frequency Assignment, Radio Science, **32**(5), (1997), pp. 1921-1939. doi: 10.1029/97RS01866
- D.H. Smith, R.K. Taplin and S. Hurley, Frequency Assignment with Complex Co-Site Constraints, IEEE Transaction on Electromagnetic Compatibility, **43**(2), (May 2001), pp. 210-218. (ISSN 0018-9375). doi: 10.1109/15.925542
- R. Bradbeer, S. Hurley, D.H. Smith and G. Wyman, Improving Efficiency in Frequency Assignment Engines, IEEE MILCOM 2001: Communications for Network Centric Operations, CD-ROM Proceedings, October 2001. (CD-ROM Proceedings, ISBN 0-7803-7227-1, Softbound Proceedings ISBN 0-7803-7225-5). doi: 10.1109/MILCOM.2001.985758

Related Grants

- *Prior to 1999: (prior to BAE Systems/QinetiQ involvement)*
  - UK Radiocommunications Agency
  - ComOpt AB (a Swedish software company)
  - EPSRC
- *1999-2000: (BAE Systems/QinetiQ collaboration)*
  - Postdoctoral Research Assistant funded by BAE Systems/QinetiQ (under Ministry of Defence Pathfinder programme), British Aerospace Defence Systems (Land and Sea Systems) (purchase order M084353). Lead investigator was **Smith** with Professor Hurley (University of Cardiff), Mr. G. Wyman for BAE Systems and Mr. R. Bradbeer of QinetiQ.

  This grant initiated the development of frequency assignment algorithms that have been used in Bowman and Falcon communication systems.
- *2000-current: (BAE Systems)*
  - 2002-2003 – Postdoctoral Research Assistant seconded for Frequency Assignment Methods for Frequency Hoppers (BAE Systems purchase order 47002477). This work contributed to frequency hopping aspects of Project Bowman.
  - 2003-2004 – Postdoctoral Research Assistant seconded for CDMA (BAE Systems purchase order 46001008). This work contributed to frequency hopping aspects of Project Bowman.
  - 2004-2007 – EPSRC Case studentship. (BAE Systems purchase order 47003909).

  All three of these projects were supervised by **Smith** and **Perkins**.

4. Details of the impact

BAE Systems

The frequency assignment system developed in the research described above was presented to leading figures in UK military communications research at a seminar in February 2000. It was clear that the approach was a considerable advance on existing military frequency assignment systems. The system was subsequently selected to form the basis of the frequency assignment system in project Bowman and its incorporation was eased since Dr. Taplin was a BAE Systems employee and returned to work at BAE Systems at the end of the project. In application, the system was found to be remarkably error free. The experience of using the system in Bowman led to its use in a further military communication system, known as Falcon. BAE Systems developed the Bowman management system and leveraged this experience to design Falcon's management software.

Application in Bowman

The Bowman communication system is a combat net radio system used for tactical communications at platoon level and upwards by the British Armed Forces. It was phased into use starting in 2004 and fully

rolled out in 2008, replacing the aging Clansman analogue radio system. Bowman delivered a step change in capability over the Clansman family of radios through its security, data capability, reliability and resilience against electronic warfare attack. It is a tactical communications system integrating digital voice and data technology to provide secure radio, telephone, intercom and tactical internet services in a modular and fully integrated system. The key aspect of **Smith**'s algorithms in Bowman is that a large number of operators can simultaneously send and receive communications (i.e. the capability and reliability of the system has been substantially improved). Over the assessment period, Bowman has been operated by soldiers from every part of the British Army as well as specialists from the Royal Corps of Signals. Furthermore, the Bowman communication system is currently being rolled out across elements of the Royal Netherlands Navy.

Application in Falcon

The Falcon communication system came into service in 2010, replacing the near 30-year old Ptarmigan system, with a new generation tactical communications system. It delivers secure voice and data over an internet protocol system. Falcon is currently being fielded by the Royal Signals and the Royal Air Force. Falcon replaces aging asynchronous transfer mode equipment used in Ptarmigan with a scalable application that can be configured rapidly to meet the needs of an expeditionary force. It connects with other digital communications technologies in the British military and coalition allies. Falcon also uses manpower more efficiently than Ptarmigan; the highly automated system requires 50 to 75 percent fewer personnel to operate. **Smith**'s algorithms have made valuable contributions in maximizing data transfer and reducing interference between users.

Financial impact

Those close to the project asked to estimate the financial benefit see such requests as intrusions into commercial confidentiality. However, all parties recognize that the work was essential: Bowman would have taken a different path if the spectral use had not been improved. Hence the project is viewed as highly worthwhile and certainly provided a benefit to the economy which should be seen in the light of the total costs of the two projects. The Bowman family of digital radios, and the associated Combat Infrastructure Platform project, constituted a £2.4 billion project while Falcon was over £200 million. **Smith**'s frequency assignment engine is critical to the operation of both Bowman and Falcon. The effectiveness of a frequency assignment system that minimizes interference, while at the same time allowing efficient use of the radio spectrum has huge commercial benefits; this is particularly important in the light of continuing pressure to release military spectrum for civil use. In civil use, the radio spectrum now has an enormous commercial value (e.g. the auction of spectrum for third generation mobile telephones raised over £22 billion for the UK government).

Reach and significance

The Bowman communication system is expected to continue in service until approximately 2026 and is currently fitted to over 15 000 military vehicles, the entire Royal Navy fleet and carried by dismounted soldiers resulting in close to 50 000 radio sets. Additionally, 75 000 personnel required training in their use. *General Dynamics*, the radio set manufacturer, has a global workforce of almost 100 000 people. Smith's work has an extensive reach that will continue for at least the next 10-15 years. While it is not easy to determine the significance of the work to the entire Bowman and Falcon projects, all parties see **Smith**'s algorithms as an essential component and the entire project would have taken a very different route in their absence.

5. Sources to corroborate the impact

- Background on Bowman communication system including its use by British Armed forces and Royal Netherlands Navy: http://www.generaldynamics.uk.com/solutions-and-capabilities/bowman-command-battlespace-management

- Testimonials on how Bowman fared in the combat zone from end-users: http://www.generaldynamics.uk.com/about-gduk/customer-success#bowman-quotes-and-video

- Background on Falcon communication system, including its improvement over previously-used

communication systems:
http://www.afcea.org/signal/articles/templates/SIGNAL_Article_Template.asp?articleid=1031&zoneid=52

- Further details on Falcon communication system and how it improves on previous technologies:
http://www.baesystems.com/product/BAES_019993/falcon

There are five corroborative sources who are able to assess the impact of Smith's work on Bowman and Falcon comprising past and present employees of *BAE Systems* and *QinetiQ*.