Institution: Lancaster University

Unit of Assessment: UoA 11: Computer Science and Informatics

Title of case study: Impact of QoS research on the global TETRA radio standard

1. Summary of the impact

Lancaster University's pioneering research on Quality-of-Service (QoS) architecture has led to significant impact on the development of TETRA (Terrestrial Trunked Radio) – the digital radio standard used by emergency and public safety services globally. The route to impact was via UK projects on Mobile and Emergency Multimedia. It involved the transfer of QoS technology and know-how to HW Communications Ltd (HWC), a Lancaster-based SME. HWC became instrumental in developing the outcomes of our collaboration in TETRA's *Multimedia Exchange Layer* (MEX) standard and its specification for TETRA II (or TETRA Enhanced Data Services, TEDS) – a new version of TETRA that enables multimedia data services. MEX was adopted as a new clause in the TETRA II release in 2010. The impact is that vendors of TETRA equipment manufactured after 2010 can implement MEX in their products, thereby leveraging Lancaster's pioneering QoS research to enable applications to obtain the best possible level of service in a standardised way – which is absolutely crucial for the public-safety and related applications for which TETRA is being used.

2. Underpinning research (indicative maximum 500 words)

The research underpinning this case was conducted in the 1990s. At the time it was a novel challenge in computer networking to support applications with different traffic requirements (e.g., real-time video, telemetry, messaging) over wireless communication networks. Lancaster's work on this problem had two lines of research at its root, from 1993-95:

1) In the Communication Systems Department, one of the founders of HWC, Prof. Bahram Honary, led work on the lower networking layers on combined source and channel coding. Channel state data is extracted at the physical layer, and the radio notifies higher layers to enable applications to adapt to available channel capacity [1]. This enables the QoS requirements of applications to be managed depending on channel state. Feedback from the radio to the application, using cross-layer information, is now built into TETRA II (TEDS) in the MEX layer.

2) In the Computing Department, Prof. David Hutchison and colleagues conducted pioneering work on QoS management, principally in the middle and upper network layers. This research, carried out under EPSRC grant GR/H77194/01, led to the groundbreaking contribution of an integrated cross-layer QoS architecture (QoS-A), published in a seminal article [2]. A key insight developed in this work is the idea of QoS mapping, i.e. how QoS requirements at an application level could be specified and then mapped down onto the lower layers. QoS-A introduced architectural components that handle application-level QoS, and multiplex best effort and QoS-based traffic, concepts that underpin the TETRA MEX layer.

From 1996 to1998, the two strands of research came together in the "Mobile Multimedia" EPSRC/DTI LINK project (GR/K82024/01, 1996-1998) led by Hutchison and Davies (then a Lecturer in the Computing Department) in collaboration with Honary and HWC, and with Philips Telecom (later known as Simoco).The project investigated QoS support for distributed multimedia applications over heterogeneous and mobile networks, and specifically TETRA [3]. It developed a cutting edge experimental infrastructure that was the first to study TETRA as a carrier for multimedia (the first version of the standard had just been published, in 1995). The project was instrumental in extending the QoS-A work for operation over wireless networks. Such networks are characterised by limited capacity and fluctuating performance/connectivity, making it essential that environmental changes are not hidden in protocol layers but propagated to the application, to facilitate adaptation [4].

From 1998 to 2001, the University and HWC collaborated on multimedia communication for emergency services over wireless TETRA networks. Honary and HWC led a DTI project on "Emergency Multimedia" (EMM) with Simoco as TETRA technology partner, and subcontracted to

Davies' group in the University. The research group was granted three months of exclusive access to one of the first publicly deployed TETRA networks in the UK, and developed a tele-medics application demonstrated with Langdale and Ambleside Mountain Rescue (LAMR). This was the first work to demonstrate multimedia over TETRA "in the wild", underpinned by QoS management software to map the different requirements of real-time video, telemetry, digital photos, GPS and interactive messaging.

The key outcomes of the described research leading to the impact were:

1) Novelties in cross-layer QoS management, mapping and filtering first established in pioneering architecture work and evolved through projects in mobile environments;
2) Distinctive know-how of building infrastructures that support multimedia applications with diverse traffic requirements over wireless networks, including over TETRA;
3) Software implementation of QoS support functionality including priority management and multiplexing of applications over TETRA networks.

3. References to the research (indicative maximum of six references)

[1] Honary, B. & Darnell, M. (1993) "Extraction and application of channel state data in digital communication schemes". Proceedings of Symposium on Communication Theory & Applications (ICSTA), Ambleside.
Abstract of conference presentation by the two founders of HWC, available on request; describes QoS-related research within HWC on propagation of channel state to applications, leading to collaboration with Prof. Hutchison in a LINK project on QoS for mobile multimedia applications.

[2] Campbell, A., Coulson, G. & Hutchison, D., (1994) "A Quality of Service Architecture", ACM SIGCOMM Computer Communication Review 24 (2), 6-27.
Journal article authored by Hutchison's group, with 565 citations to date. Introduced QoS management, mapping and filtering concepts and architectural work at the root of this case.

[3] Shearer, E.H.S. (1995) "TETRA – a Platform for Multimedia". In IEE Colloquium on Mobile Computing and its Applications, pp. 5/1-4.
Abstract of an IEE colloquium contribution in which our collaborators Philips Telecom presented the idea of Multimedia over TETRA supported by a QoS architecture.

[4] Yeadon, N., Davies, N., Friday, A. & Blair, G., "Supporting Video in Heterogeneous Mobile Environments", ACM symposium on Applied Computing (SAC 1998), 439-444.
Conference paper, international and peer-reviewed, authored by Davies' group. Describes support for video over wireless networks in which Lancaster was first to explore multimedia over TETRA.

4. Details of the impact (indicative maximum 750 words)

Pathways to impact

Long-standing collaboration with HWC. Our partnership with HWC is a major route to impact (on TETRA, and other areas of communication systems research). With regards to QoS research, the collaboration culminated in subcontracting the University for EMM software development. The code was released to HWC in October 2001. It includes Mux/DeMux software for QoS mapping and multiplexing of application, written by Friday (an RA in Davies' group) in collaboration with Indika Samarakoon of HWC [A]. The TETRA MEX layer standard specification evolved from Mux/Demux and the precursory research.

Collaboration with Philips Telecom / Simoco. The joint work with Simoco gave Davies' group access to early TETRA technology and enabled application of their QoS research for operation over TETRA. It also led to the entry of HWC into the TETRA standardisation activity, by the invitation of Dr Mark Rayne (then with Simoco, since 2001 with Sepura plc) [B].

Engagement with users. Engagement with LAMR resulted in a real-world application that was instrumental in conveying the importance of multimedia over TETRA. The application was featured in *Land Mobile – Wireless Communications for Business* [C], shown on the BBC's Tomorrows World programme, and selected for the *Best Application Award* at the TETRA World Congress in 2001.

Details of the impact on TETRA

The TETRA standard is overseen by ETSI, the European Telecommunications Standards Institute. As part of their standardisation activity, ETSI commission contributions from external experts under the framework of Special Task Force projects (STFs). Each STF is set up as a small group of experts who conduct technical work to address a specific challenge with the necessary research, and who produce results that directly feed into the standard.

Introduced by Rayne, HWC has worked on a succession of ETSI STF contracts, addressing special tasks on different parts of the standard. Two of these contracts concerned work on the MEX layer, allocated exclusively to HWC [D]. The first contract was under STF 179, a larger task force driving the whole TEDS specification from 2001-2006. HWC developed and authored the MEX layer specification, i.e. support for applications to negotiate QoS, mapping of application QoS to radio resources, and packet queuing. This was followed by a contract under STF 314, a task force that ETSI allocated exclusively to HWC, with Indika Samarakoon as task force lead. HWC developed updates of TETRA's Peripheral Equipment Interface (PEI) to support MEX, and refined MEX to support three different modes of operation for QoS management. The MEX layer then became included as a new clause 30 in the TETRA II air interface specification (ETSI TS 100 392-2, released in August 2010), with associated updates in the PEI specification (ETSI TS 100 392-5, released in July 2010) [E]. HWC also contributed to other parts of the TETRA II release, via STFs that leveraged other Lancaster University research (work on coding, interleaving and link control led by Honary in the Communication Systems Department).

The beneficiaries of TETRA II and MEX are i) vendors in the TETRA market – benefitting from a defined standard for developing enhanced products; ii) TETRA users in public services – enabled to exchange multimedia data via their terminals; and iii) the wider public – as more efficient communication of emergency and safety services results in lives saved.

Reach of the impact. The reach is global: TETRA is the world-wide leading technology for critical communications, adopted in over 120 countries. More than 250 networks are in use by Governments for public safety and related services, and TETRA is routinely used to create private mobile radio services at major events (e.g., London 2012 Olympics and Paralympics). The market is growing, with 12% more terminals shipped in 2012. Motorola and Cassidian are market leaders who spearhead TETRA II compliant deployments. For example, Asia's largest TETRA network, operated by the Beijing Government, is being extended based on the latest release to serve up to 110,000 users [F], and the City of Nanjing is deploying a new TETRA network ahead of hosting the Youth Olympic Games [G]. These new deployments are based on a version of a standard that includes MEX and manufacturers have the option to leverage QoS technology that has its roots in Lancaster University research. At the same time, standards development is progressing toward a next generation of critical broadband (e.g., based on LTE) extending TETRA, for which QoS management components such as MEX will become increasingly important in critical communications.

Significance of the change effected. The significance of the impact plays out on two levels:
(1) The MEX layer plays a significant role in the TETRA protocol stack, as it enables the network to balance the QoS requirements of multiple applications. The alternative to MEX would be that applications request underlying network services directly; but that would be unworkable as applications are unaware of the total application demand on the network. MEX, in contrast, supports that applications negotiate their QoS, and multiplexes applications to optimise overall throughput.
(2) The significance of efficiency and multimedia in mobile communications for public safety is widely documented, evidencing the link between efficiency of mobile communication, productivity of services, lives saved, and net cost savings for society [H].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Mux/DeMux software. *Code and release documentation are available for audit.*

[B] Sepura Plc. *The ETSI representative for Sepura Plc can be contacted to provide corroborating evidence on Lancaster and HWC's work on the Emergency Multimedia project leading to HWC's involvement in the standard, and the extent of HWC's contribution to the standard.*

[C] “Life-saving telemetry from the mountainside”. Land Mobile – Wireless Communications for Business, November 2001.

[D] HW Communications Ltd. *The technology manager of HWC can be contacted to provide corroborating evidence on collaboration of HWC with Lancaster University, technology transfer from the University to HWC, and HWC’s work in TETRA standardisation.*

[E] TETRA standards. European Telecommunications Standards Institute.
http://www.etsi.org/technologies-clusters/technologies/tetra/
The MEX layer standard is described in: TS 100 392-2 Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI) [Clause 30 on pages 1223-1260]

[F] “Cassidian wins contract to extend Asia's largest TETRA network in Beijing”. News Release, TETRA and Critical Communications Association (TCCA).
http://www.tandcca.com/about/article/20729

[G] “Chinese city invests in TETRA network”. News Release, TETRA Today.
http://www.tetratoday.com/news/chinese-city-invests-in-tetra-network/

[H] TETRA and Critical Communications Association (TCCA) – response to Ofcom 700 MHz consultation. *The response cites research results on evidence of more efficient mobile communication in safety and emergency services leading to net cost savings.*
http://stakeholders.ofcom.org.uk/binaries/consultations/700mhz-cfi/responses/TETRA_and_Critical_Communic1.pdf