Institution: Lancaster University

Unit of Assessment: UoA 11: Computer Science and Informatics

Title of case study: Efficient video for wireless broadband standards

1. Summary of the impact

Our research on cross-layer optimised video distribution over wireless networks has led to wide-reaching economic and societal impact, via the following pathways:
- *Standardisation*: our research results were directly adopted in WirelessMAN and LTE, the two global standards for the next generation of wireless broadband networks.
- *Collaborative research*: the work resulted in a product that has been commercialised by our collaborators Rinicom Ltd, an SME specialising in mobile video, and recognised with a Queen's Award for Enterprise (2013), for achievements to which our research contributed significantly.
- *User engagement*: the work resulted in the deployment of a WiMAX network in Slavutych/Chernobyl, Ukraine; contributing to community regeneration in a UK Government programme to address social and economic consequences of nuclear power plant closure.

2. Underpinning research

Context. The underpinning research was concerned to optimise the efficiency of video distribution over wireless networks, as required by key application areas such as surveillance and tele-medicine: such areas require solutions that scale to multiple high resolution streams, and can be handled in real-time and under challenging conditions. At the time the research was initiated, it was well-established that video services should negotiate bandwidth at the medium access (MAC) layer, but the physical (PHY) layer was not considered. We saw this as problematic because streaming at peak rates leads to PHY-level signal deterioration, and consequent reduction of available bandwidth.

Description of the research. In our research, this problem was tackled with a cross-layer application/MAC/PHY approach, and investigated in the context of IEEE 802.16 ("WiMAX") wireless metropolitan area networks and OFDM/OFDMA communication systems. The research was initiated by Markarian (Professor in Communication Systems) in 2007, as a collaborative project with Rinicom Ltd, an SME specialising in video over OFDM. The project was sponsored by Rinicom: they funded 5 PhD students in Markarian's research group.

At the time the project started, the Dept. for Business, Enterprise and Regulatory Reform (BERR) approached us for assistance with a WiMAX deployment in Slavutych (a new town in Ukraine, built following the Chernobyl disaster). We grasped the opportunity to integrate this activity into the project as a challenging real-world context in which to ground the research.

The overall result of the research was a novel cross-layer solution for efficient video distribution over IEEE802.16, evaluated in a substantial real-world deployment. The solution rests on the following three research contributions at a more fundamental level:
1) MAC support for video splitting. We developed a technique that significantly increases video throughput and QoS by judicious splitting of video into sub-streams. These are then assigned to QoS classes [1,2], and differentially scheduled over the 802.16 MAC [3].
2) PHY-level relaying for split video. We developed a concept for optimally relaying split video so that all sub-streams reach their destination with minimal latency and distortion, taking into account network architecture, link quality and bandwidth availability [4].
3) PHY-level pre-distortion algorithm. Continuous streaming over OFDM/OFDMA leads to signal deterioration and bandwidth reduction because the signal's peak-to-average-power-ratio (PAPR) is raised (due to non-linearity). We mitigated this by developing a novel pre-distortion algorithm that introduces a hybrid approach to model estimation in the time and frequency domains [5,6].

Research outcomes. In terms of tangible outputs, the research resulted in:
1) a system solution for video over WiMAX (commercialised by our sponsor/collaborator)
2) peer-reviewed publication of the key concepts in venues of international excellence [1,2,3,4]
3) specification of key techniques for direct adoption in the IEEE 802.16m standard [5,6]

4) doctoral training of 5 students (Ali, Kim, Noordin, Tsitserov, Zvikhachevskaya)
5) deployment and handover of a WiMAX network for the municipality of Slavutych.

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

[1] Markarian, G., Tsitserov, D., & Zvikhachevskaya, A. (2010). Novel technique for efficient video distribution over WiMAX networks. *Proc. IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, 399-404. DOI: 10.1109/PIMRCW.2010.5670403
PIMRC is one of the IEEE Communication Society's flagship conferences in telecommunications. The paper presents the video splitting and QoS mapping technique developed on top of 802.16 MAC.

[2] Markarian, G., Mihaylova, L., Tsitserov, D., & Zvikhachevskaya, A. (2012). Video Distribution Techniques over WiMAX Networks for m-Health Applications. In *IEEE Transactions on Information Technology in Biomedicine*, 16(1), 24-30. DOI: 10.1109/TITB.2011.2174157
High-impact IEEE Transactions (IF=1.978 in 2012). The article, first submitted in 2010, expands on [1], evaluating the technique for video traffic scenarios in mobile health / tele-medic applications.

[3] Noordin, K.A. and Markarian, G. (2011) Providing QoS support through scheduling in WiMAX systems. *International Journal of the Physical Sciences* 6(16): 4070-4081.
International peer-reviewed open access journal. The article complements [1] with a description of differential scheduling of split video streams on top of 802.16 MAC.

[4] Kim, H., Zein, N., Markarian, G., "Transparent and Non-transparent relay structure for diversity gain". IEEE802.16m-09_0067. Submitted 05.01.2009
Submitted to the WiMAX Forum as a proposal for inclusion in the 802.16m standard.

[5] Ali, S., Markarian, G. and Arikan, E. (2009) Novel Predistortion Algorithm for OFDMA. In *IEEE 69th Vehicular Technology Conference (VTC Spring 2009),* 1-5. DOI: 10.1109/VETECS.2009.5073716
International peer-reviewed conference on wireless communications, organised by IEEE's Vehicular Technology Society. Describes the development of a novel predistortion algorithm.

[6] Ali, S., Markarian, G., Arikan, E., "Hybrid Predistortion Algorithm for HPA Non-linearity Mitigation". IEEE802.16m -08/939. Submitted 05.09.2009
Submitted to the WiMAX Forum as a proposal for inclusion in the 802.16m standard. This directly matches the academic publication above [5].

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

Pathways to impact. We employed the following three pathways:
- Contribution to standards. Jointly with Rinicom, the University made specific, significant and traceable contributions to IEEE 802.16m standardisation, aimed at adoption of research outcomes as a global technical standard.
- Collaborative research. All of the underpinning research was conducted in collaboration with Rinicom Ltd, as sponsor and immediate beneficiary.
- Engagement with user communities. The research involved a real-world network deployment in Slavutych/Chernobyl (population 25,000).

Areas of impact. The impact is wide-reaching and significant, comprising both economic and societal aspects; and it is evident at local, international and global scales:

1) Global impact through the adoption of enhanced technical standards. The ITU (International Telecommunication Union) is the United Nation's specialized agency responsible for the allocation of the global radio spectrum and development of technical standards. In Jan. 2012, ITU determined that WirelessMAN and LTE should be accorded the official designation of IMT-Advanced, defining next-generation global wireless broadband communications beyond 3G. Our research had direct impact on both WirelessMAN and LTE, as detailed in a letter provided by the Certification Working Group (CWG) of the WiMAX Forum [A]. This includes adoption of the technical content of the proposals submitted by Markarian and Rinicom first in the WirelessMAN standard IEEE802.16.1-2012, and subsequently in the LTE specification (3GPP TS 36.216, "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer for relaying operation") [A].

Reach: The reach is global, benefitting the wireless broadband business sector (vendors and operators), and ultimately users of next generation wireless networks on a global scale. Vendors have to implement techniques that originate from our collaborative research with Rinicom in order to comply with the standards. Within the REF period, the techniques have already been implemented in chipsets produced by Comtech AHA, USA (AHA-4501 ASIC); Runcom, Israel (RNA300 ASIC); and Sequance, France (SQN1220 SOC). ***Significance***: The significance of the contribution is evident in its selection for both standards, and is also highlighted by the CWG in their corroborating statement: *"… presents an important and significant technical advancement to the mobile broad band technology and systems as it introduces an efficient method for the operation of transparent and non-transparent Relay stations to improve capacity and coverage of a serviced cell".* [A]

2) Impact on business performance through the improvement of a product. Rinicom markets RiniMAX as a product for video surveillance over point-to-multi-point systems that utilise WiMAX compliant radio access. The cross-layer solution developed by Markarian's research group led to a new version of the product, "RiniMAX R8000", which launched in September 2009, replacing previous versions. As a result of the research, the improved product is able to support simultaneous transmission of multiple HD video streams over WiMAX. ***Reach:*** The primary beneficiary is Rinicom, i.e. a local SME, but the product has international reach; it has already been deployed for mobile metropolitan area wireless video surveillance in the UK, Germany, Malaysia, Russia and Ukraine. ***Significance***: The impact on Rinicom's business performance is highly significant, as evidenced by key indicators (see Table). Turnover on RiniMAX grew by 148% over the three years following the launch of the improved product. The product accounts for half of the company's total turnover, which grew by 143% in the same timeframe. The number of full-time employees rose from 5 to 15 [B].

	2008	2009	2010	2011	2012
Turnover on RiniMAX	£182,000	£398,000	£671,000	£723,000	£987,000
Total turnover of Rinicom	£577,000	£771,000	£1,370,000	£1,719,000	£1,871,000
Full-time UK employees	4	5	10	12	15

The research impact on Rinicom's business culminated in further impact in April 2013, when the company received a **Queen's Award for Enterprise in 2013**, one of the most prestigious accolades for businesses in the UK, in recognition of the company's achievements [C].

3) Impact on community regeneration. The UK Government initiated the development of a city-wide wireless network for Slavutych/Chernobyl in a programme to address the "*Social and Economic Consequences of Nuclear Power Plant Closure*", and this was delivered by Lancaster. Our research team developed the network specification, oversaw the deployment on site and monitored the network in the initial 3 months of operation, for optimisation and observation to inform the research. The deployment culminated in delivery of the "Town Information Network" to the community, formally launched on 26 March 2009. ***Reach***: The *primary beneficiary* is the municipality of Slavutych and its residents (population 25,000), who are provided with reliable Internet connectivity. The network covers the entire town and has complete reach to its business sector and residents. ***Significance:*** The network has had a transformative impact on the community, as economic growth had previously been hampered by a lack of modern and reliable telecommunications, especially internet connectivity. The Slavutych Business Development Agency reports that new information services led to the creation of 40 new jobs, and a 93.4% increase in the number of users of Internet services [D]. A *secondary beneficiary* is the UK Government, as our network deployment led to the completion of the above-mentioned government programme (see the Government's 2008 report on Global Threat Reduction activities [E], p.42]). Minister Mike O'Brian launched the network in a live telecast connecting Whitehall with Slavutych over the newly-established infrastructure, followed by a live telecast connecting pupils of the Slavutych Lyceum with pupils of Central Lancaster High School, highlighting the societal significance of the project. The Government's press release highlighted the "culmination of advanced technology transfer collaboration" as well as the "extensive support from a team spearheaded by Lancaster University" [F].

5. Sources to corroborate the impact

[A] WiMAX Forum correspondence, Certification Working Group, provided by the WG chair and received on 22 October 2013. *Confirms inclusion of Markarian's contribution into WirelessMAN and LTE standards, and corroborates significance of the contribution for mobile broadband.*

[B] The Managing Director of Rinicom Ltd can be contacted to corroborate evidence provided on collaboration with Markarian's research group, and on impact of the collaborative research on business performance.

[C] Queen's Award for Enterprise (Export) for Rinicom Limited. House of Commons EDM 1300. http://www.parliament.uk/edm/2012-13/1300

[D] Letter provided by the Director of Business Development Agency (BDA), Slavutych. *Confirms contribution of Lancaster University to the development of communication and information services and corroborates the project's impact on job creation.*

[E] Global threat reduction programme: sixth annual report 2008. URN 09/373. UK Government, Department of Energy and Climate Change. http://www.berr.gov.uk/files/file49982.pdf
The work on providing the municipality of Slavutych with a broadband network to attract investment and employment opportunities is reported on page 42.

[F] Official Press Release of the UK DTI programme in Slavutych.
http://investing.org.ua/en/print/news/pres_relis