

Impact case study (REF3b)

Institution: The University of Edinburgh
Unit of Assessment: B11 — Computer Science and Informatics
Title of case study: The Tegola Wireless Community Broadband Project

1. Summary of the impact

The Tegola Project has undertaken basic research on deploying wireless networking in remote communities, focusing on problems distinct to the Scottish Highlands. The engineering of the Tegola research testbed has had a profound impact on community broadband in Scotland. As a direct result, some of Scotland’s most remote communities are now enjoying superfast broadband for the first time. This, together with a novel analysis of broadband infrastructure that underpins the Royal Society of Edinburgh’s *Digital Scotland* report, has substantially influenced government policy in Scotland and changed the focus of the debate across the UK and beyond.

2. Underpinning research

2.1. University of Edinburgh staff involved in the research

The research was performed at the University of Edinburgh between 2008 and the present by Peter Buneman (professor), Michael Fourman (professor), Mahesh Marina (lecturer), Giacomo Bernardi, Konstantinos Balampekos and Valentin Radu (PhD students) with contributions from several other student researchers.

2.2. Tegola network

Even after several government subsidized schemes, broadband Internet is unavailable in remote areas of Scotland, motivating our exploration of alternative technologies. Deploying conventional wired broadband is not cost-effective for low population density rural areas, leading to the rural-urban broadband divide. Our study focused on the area around Loch Hourn in the northwest of Scotland: it was very poorly served by current Internet and mobile communications infrastructure and one of the researchers had first hand experience of that area.

Figure 1: The Tegola network on the map of Scotland (reproduced from [1])



We settled on long distance WiFi as the most promising technology, due to low cost, operation in the unlicensed spectrum and successful trials in other parts of the world. However, rural Scotland is quite different from previous trial locations with many residents living in coastal areas and challenging terrain and weather conditions.

Redundancy in the network topology and hardware at each mast site was a key feature of the network. It has proved invaluable in robust operation of the network over the last 4 years with downtimes limited to just a few days. The original network as described in [1] featured several links over water and two mast sites that were self-powered based on wind and solar power sources. Regarding both of these aspects, the use of diversity proved to be effective in achieving low cost and robust operation. Mast construction tailored to the deployment model and terrain also made setting up masts cheaper and faster.

Research on the Tegola network continued by considering wireless transmission over tidal water showing the significance of the problem using signal strength measurements taken from over-water links in the Tegola network [4]. The existing channel allocation literature on long-distance mesh networks does not consider channel width adaptation, which is the key aspect of the Edinburgh Tegola research. Measurement data from wireless backhaul sites in the Tegola network allowed the Edinburgh researchers to develop a novel polynomial time, greedy channel allocation algorithm that guarantees valid channel allocations for each node in a long-distance 802.11 mesh network [5].

2.3. Digital Scotland report

In 2009, following the publication of Lord Carter's Digital Britain report—and prompted in part by Buneman's experience with Tegola, which called into question Carter's key recommendations—the Royal Society of Edinburgh initiated its 'Digital Scotland' inquiry. The inquiry was chaired by Fourman, who was also the lead author on the interim and final reports. The primary contribution of the Digital Scotland report [2] was to recommend that each circle on the map of Scotland that includes a population of at least 2000 people should include a 'fibre hub'. This novel criterion was first formulated by Buneman. It provides a single criterion for equitable infrastructure provision that can be applied uniformly across the entire range of population densities. Fourman designed a novel hitting-set algorithm that produces more efficient hub placements than standard methods; it has been critical in arguing for the practicality of the recommendation.

2.4. BSense broadband mapping system

Assessing and tracking the state of broadband coverage and performance is also vital for policy makers and consumers alike. With this goal in mind, we have developed the BSense system [3] for identifying so-called *notspots* (that is, areas with very poor or no connectivity) in a given geographical region and for continuously monitoring the quality of wired, wireless and mobile broadband connections over time.

3. References to the research

3.1. Publications

1. G. Bernardi, P. Buneman and M. K. Marina, "Tegola Tiered Mesh Network Testbed in Rural Scotland," In *Proc. ACM MobiCom 2008 Workshop on Wireless Networks and Systems for Developing Regions (WiNS-DR'08)*, San Francisco, USA, Sep 2008.
DOI: <http://dx.doi.org/10.1145/1410064.1410067>
Quality: A workshop co-located with ACM MobiCom conference, the *de facto* top venue for publication of research results in rural networking.
2. M. Fourman et al., "Digital Scotland," The Royal Society of Edinburgh Inquiry Report, Oct 2010. ISBN: 978 0 902198 36 4
URL: <http://bit.ly/11bciYa>
3. G. Bernardi, D. Fenacci, M. K. Marina and D. Pezaros, "BSense: A Flexible and Open-Source Broadband Mapping Framework," In *Proc. 11th IFIP Networking Conference*, 2012.
DOI: http://dx.doi.org/10.1007/978-3-642-30045-5_26
Quality: An established networks conference with paper acceptance rates under 25%.

Impact case study (REF3b)

4. A. Macmillan, M. K. Marina and J. T. Triana, "Slow Frequency Hopping for Mitigating Tidal Fading on Rural Long Distance Over-Water Wireless Links," In *Proc. IEEE INFOCOM*, 2010. DOI: <http://dx.doi.org/10.1109/INFCOMW.2010.5466612>
Quality: A reputed networks conference with paper acceptance rates below 25%.
5. S. Padiaditaki, M. K. Marina and D. Tyrode, "Traffic-Aware Channel Width Adaptation in Long-Distance 802.11 Mesh Networks," In *Proc. 15th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM'12)*, 2012. DOI: <http://dx.doi.org/10.1145/2387238.2387283>
Quality: An established networks conference with paper acceptance rates under 25%.

References [1], [4] and [5] are most indicative of the quality of the research undertaken.

3.2. Key Research Grants

- M. K. Marina, "Pilot Wireless Network Testbed Deployment based on Long-Distance WiFi in Rural Scotland," The University of Edinburgh Development Trust, Dec 2007 - Dec 2008. Amount: £5000.
- M. K. Marina, "Adaptive Spectrum Usage Techniques for Multihop Wireless Networks", Royal Society, Mar 2009 - Feb 2010. Amount: £15,000.
- M. Fayed, P. Buneman, M. K. Marina, M. Fourman et al., "High-speed Universal Broadband for Scotland (HUBS)", The Carnegie Trust for the Universities of Scotland, May 2012 - Aug 2013. Amount: £40,000.

4. Details of the impact

4.1. Impact on communities

Between late 2007 and summer of 2008, we deployed the experimental Tegola network based on long distance WiFi with active community involvement. It connected the residents of Arnisdale and Corran villages to the Internet, most of them for the first time in their lives. Local communities through their active participation in the installation and upkeep of the network contributed greatly to its sustenance. The Tegola network demonstrated the suitability of long-distance WiFi technology even for rural Scotland scenario when combined with certain engineering measures (e.g., planned redundancy, use of solar and wind power for self-powered masts). Even more crucially, it has become a replicable model for community-driven local access network deployments in Scotland. It has also inspired research into tools, systems and techniques to aid communities in deploying and maintaining rural networks like that of Tegola, e.g., for simplifying network management, adaptive spectrum use for robust and high performance operation.

Tegola has attracted substantial press coverage. The BBC technology correspondent Rory Cellan-Jones made a series of short television programmes in 2008 [A] and 2012 [B].

In 2011, Tegola was used for emergency medical services when a lightning strike knocked out the telephones to a wider area. The head of BT Scotland had expressed the opinion that mesh networks like Tegola were not "robust". Experience has shown otherwise: to date, the Tegola downtime on Knoydart has been about three days whereas the BT telephones have been down for over a month. Subsequently, Tegola won the NextGen Challenge award for community broadband [C]. As a result of this award, a motion in the Scottish Parliament cited Tegola [D]. Another community wireless network started by Tegola in 2010, Hebnet (<http://hebnet.co.uk/>), was shortlisted for the NextGen 2012 Award for Rural Leadership and Community Development. The Royal Society of Edinburgh commissioned a short documentary on the Tegola and Hebnet projects in 2010 [E].

4.2. Impact on public policy

Tegola was a stimulus for, and is mentioned in, the Royal Society of Edinburgh *Digital Scotland* report [2]. Since early 2010, Fourman has chaired the Digital Scotland working group of the Royal Society of Edinburgh, and has been the principal author of its reports. Buneman is a member of

Impact case study (REF3b)

this working group. A draft Digital Scotland report was circulated for comment in July 2010, and formally acknowledged by the Scottish Government in August 2010 [F]. The final Digital Scotland report was published in October 2010 [2]. This has led to a sustained programme of engagement with both the Scottish Government and Scottish Parliament. The Digital Scotland report was cited in the Scottish Government's strategy document "Scotland's Digital Future: A Strategy for Scotland" [G].

On 31 January 2012, the Scottish Government published "Scotland's Digital Future – Infrastructure Action Plan". On 2 February, the Scottish Parliament passed a resolution calling for action "to deliver open access future-proofed infrastructure and to support measures to increase take-up and participation in the digital economy" [H]. The Digital Scotland report, Professor Fourman's evidence on behalf of RSE, and the Tegola project were cited in the debates leading to the resolution [I]. In 2012 Fourman was Specialist Adviser to the House of Lords' Communications Committee for their 'Broadband for All' inquiry, leading to the House of Lords' report *Broadband for all -- an alternative vision* [J].

5. Sources to corroborate the impact

- A. BBC News, Rory Cellan-Jones, "Broadband in the Highlands" <http://news.bbc.co.uk/1/hi/technology/7433025.stm>, 3 June 2008.
- B. BBC News, Rory Cellan-Jones, "Highlands and Islands remote broadband scheme under way" <http://www.bbc.co.uk/news/uk-scotland-highlands-islands-19909081>, 12 Oct 2012.
- C. NextGen Challenge Award submission <http://www.tegola.org.uk/news/nextgen.html> and press release, 17 November 2011 <http://www.nextgenevents.co.uk/blog/id41/news-release-17-november-2011-bristol-uk>
- D. Motion recognizing Tegola, Scottish Parliament Business Bulletin, 8 November 2011 <http://www.scottish.parliament.uk/BusinessBulletins/bb-11-134w.pdf>
- E. "Digital Futures", Royal Society of Edinburgh-commissioned documentary on Tegola and Hebnet projects, 2011. <http://vimeo.com/25278290>
- F. RSE Digital Scotland Interim Report - Scottish Government Response, August 2010 <http://www.scotland.gov.uk/Resource/Doc/918/0105211.pdf>
- G. Scottish Government, "Scotland's Digital Future: A Strategy for Scotland", March 2011 <http://www.scotland.gov.uk/Resource/Doc/981/0114237.pdf>
- H. Scottish Parliament Motion S4M-01893, February 2012 http://www.scottish.parliament.uk/S4_BusinessTeam/pm-v1n50-S4.pdf
- I. Scottish Parliament proceedings <http://www.scottish.parliament.uk/parliamentarybusiness/28862.aspx?r=6835&mode=pdf>
<http://www.scottish.parliament.uk/parliamentarybusiness/28862.aspx?r=6780&i=61520&c=1274262>
- J. House of Lords report *Broadband for all -- an alternative vision* <http://www.publications.parliament.uk/pa/ld201213/ldselect/ldcomuni/41/41.pdf>

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