Broadband for Rural Scotland:
a white paper

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Summary

The Tegola project is dedicated to research into the provision of high-speed internet access to remote and rural areas. As part of the project, we have built a testbed which demonstrates that it is now possible to provide the most remote parts of the Scottish mainland with speed and quality of service better than what is available in most UK cities.

This report describes our findings based on our experience from constructing and monitoring this testbed for over a year. To summarise:

- If speed and quality of service are important, they are doubly important in remote areas, where other forms of communication are lacking.

- With the existing infrastructure, as many as 20% of the residences in Scotland may be unable to receive the speed of 2Mbps advocated in [CAR09] – a speed which is, in our opinion still far too low to meet the needs of remote communities. Even by upgrading the existing infrastructure, this figure is unlikely to change.

- An alternative form of distribution based on terrestrial wireless is both workable and cost-effective thanks to the recent and dramatic fall in the cost of wireless technology.

- While commercial distribution to consumers in remote areas is unlikely to prove profitable, community-driven partnerships can succeed.

- In order that rural Scotland does not get left further behind in the broadband revolution, immediate planning is needed for the backhaul to support internet access by remote communities.

In writing this report we have tried to minimise the jargon and technical details. But there are a few terms that are important to understand, and we have included explanatory footnotes where needed. For further information, please consult our website www.tegola.org.uk and the various technical reports cited in this paper.

1. Introduction

Initiated in the Autumn of 2007, the Tegola project – a joint project between the University of Edinburgh and the University of the Highlands and Islands – installed a testbed that covers the mouth of Loch Hourn and the North-West coast of Knoydart, which is claimed to the most remote part of the UK mainland. Residents of these areas are now experiencing speed and quality of service that is better than that available to most residents of UK cities.

Figure 1: Coverage of the Tegola testbed

The Tegola project is dedicated to research into challenges concerning high-speed affordable internet access to remote and rural communities. While we briefly describe the research of the project at the end of this report, our main purpose in writing it is to set out what we believe to be important findings for developing next generation of broadband in rural Scotland. These are based purely on our practical experience in building and maintaining a network, and monitoring its use by a remote community of users for over a year; around 35-45 households are connected by the network as testbed participants.

To provide a brief background to the project, the testbed covers an area of the Scottish Highlands (see Figure 1) which, until a year ago had little hope of getting broadband. In 2001, the then Scottish Executive set out a clear statement for the need for broadband in remote communities. This resulted in the investment of £16.5m [SG1] in June 2004; BT was awarded the contract, which was used for upgrading telephone exchanges and making other changes to BT's communication backbone, but it did nothing to change the wired infrastructure of remote communities. A further £3.5m was given to BT in December 2006 to deliver broadband to those without coverage. However, this did not benefit many areas including those covered by the Tegola project, which were more than 15km from an exchange. In the past year the Scottish Government has invested a further £3.3m [SG1] to subsidise satellite connections for some residents of rural Scotland, however this service is neither affordable, nor does it provide the speed and quality of service needed for many applications.

The Tegola testbed, which is now capable of providing speeds of up to 25Mbps, extends the reach of a high-bandwidth Internet connection over long distances using commodity wireless (WiFi) hardware that has recently become extremely cheap. For example, it is possible to build a 10km wireless link for as little as £80. And this is what it costs us in equipment to add a new subscriber to the system.

Figure 2: Willie Sandaig "teleconferences" with his grandchildren in New Zealand. Teleconferencing needs both speed and quality of service.

The following sections describe lessons learned from deploying and maintaining the Tegola network for over an year. We describe first why speed and quality of service are so important in rural areas and describe what technologies are likely (and what are unlikely) to fulfil this need. We then – briefly – look at the economics of deployment of broadband in rural areas, and argue that a deployment model with some form of *community involvement* has better chances of success in quickly and cost-effectively bringing broadband to remote communities. We indicate that if rural Scotland is not to be left even further behind in the delivery of high-speed internet, a suitable backhaul needs to be made available for community deployments in the very near future. Finally, we briefly mention some of our research activities in the Tegola project.

2. The importance of speed and quality of service

The case for broadband in remote and rural areas has been made in [CON01] and hardly needs to be restated here. One of the crucial points is that remote communities are reliant on mail-order for many of their supplies and many mail-order companies now only take orders via the web. We should also add that while it is in principle possible to use the web over a dial-up line, many of these communities are so far from an exchange that modems do not work. This was certainly the case for some of the residents covered by the Tegola testbed.

Again, the need for higher quality broadband in the UK has been advocated in the media and recently in the "Digital Britain" report [CAR09]. Apart from improving efficiency of work for the many of us who constantly use the internet, there are some services such as streaming video and internet TV that are only effective at higher speeds. However we claim that speed is particularly important for rural areas for a number of reasons. We shall use the Tegola testbed as an example, but we believe the findings will be similar in other remote locations.

Internet telephony. There is no mobile coverage in much of the testbed area, and the telephone land-lines are prone to failure. People are increasingly making use of Voice over IP (VoIP) via Skype or by installing internet telephones, both of which provide substantially reduced call charges. While VoIP does not require particularly high speed, it does require good quality of service[1].

Internet radio and TV. Radio coverage is also very poor in area covered by the testbed, and this has led to an uptake of internet radios. These require speeds well in excess of what is currently available in most rural areas[2]. Increasingly, the Internet is becoming the preferred medium for (downloading and) watching TV programmes (e.g., via BBC iPlayer). Enabling this in rural and remote areas is necessary not just from an entertainment point of view but crucially from the educational and information access perspective. However, this entails providing broadband access with much higher speeds[3].

Figure 2: Finlay studies geography. Like any healthy 8-year-old, his attention span is limited and slow downloads mean that he'll go and do something else.

1 *Quality of Service* (QoS) is a general term to describe the communication quality experienced by end users. QoS requirements are usually specific to an application (e.g., teleconferencing). They include not only download speed, but also upload speed, latency and loss sensitivity. For satellite broadband – the only commercial alternative available to the Tegola residents – the signal has to go to a geostationary satellite and back. This introduces a delay – or latency -- of over half a second into each "turn" of a conversation. This is enough to make it extremely difficult to carry out a conversation. VoIP is effectively impossible over satellite and slow DSL. Also, certain emerging applications (e.g., peer-to-peer applications) require more *symmetric* access in which upload and download speeds are similar.

2 On the face of it, music radio stations require 128Kbps, which is one quarter of what a "slow" broadband package will provide (512Kbps). However one must remember that commercial Internet Service Providers (ISPs) provide broadband with a contention ratio of, say, 50:1. This means, roughly, that they are putting 50 people on a channel whose capacity is 512Kbps and relying on the fact that each subscribers will be using their 512Kbps for one fiftieth of the time. Now people with radios tend to leave them on all the time, and it only takes four (out of fifty) people playing music to use up the total allocation. So when more than four people switch on their internet radios, the whole community will suffer.

3 A high-quality version of an hour long TV programme on BBC iPlayer is typically around 350MB in size. Downloading it on a home broadband connection with 2Mbps download speed (the minimum

Teleconferencing. By this we mean voice and video interaction with one or more people. Teleconferencing requires both speed and quality of service. It is being increasingly adopted by businesses as an alternative to travel, and it is one of the key components of telecommuting. Several people connected by the Tegola testbed are using it for just this purpose.

What surprised us was the uptake of broadband – and computer technology – by the older generation. At least three people in the testbed area, all over 60 and with little or no computer experience, started to use computers. A major attraction was the ability to use teleconferencing software such as Skype and MSN that enable them to communicate with distant relatives. These people would not be able to afford an expensive broadband package.

Other applications (including educational, health care and business applications). There are several other example applications which require both speed and quality of service. For instance, tele-medicine and broadband-enabled ambulances are necessary to deliver high quality health care in remote areas. These are obviously appropriate for the people living in the area covered by the Tegola testbed, where the nearest hospital is a minimum of 1 hour by road. A number of other Internet-enabled applications relevant to rural [EC09] areas have been outlined in a recent communication from the European commission aiming at improving sustainability, competitiveness and growth of businesses based in rural areas, rural tourism, agriculture, forestry and food industry sectors.

3. Technology for delivering high quality broadband to rural areas

There is substantial literature on the current broadband situation and discussion of technical options for improving it. Some of the recent and relevant reports are: [OFCOM09], which assesses the current situation in the UK; [MAS06], which was commissioned by the Scottish Government for broadband delivery to remote areas; [EC07], which was commissioned by the European Commission to survey broadband coverage, take-up and speeds in Europe, distinguishing between urban/suburban and rural areas and across access technologies; and [SAG08], which discusses the theoretical limits to the broadband speeds over copper cable.

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speed advocated by the Digital Britain interim report) and (typical) 100ms round-trip delay to the BBC iPlayer website would take more than 23 minutes! This shows that 2Mbps speed itself is not quite satisfactory, but most users in rural and remote areas have Internet connections which are much slower – those users have to either settle for low-quality versions of programmes or treat this as a luxury and forego it altogether.

The residents of the Tegola testbed are connected by copper cable to various exchanges. The distances vary between 10 and 15 km, and over these distances no available copper-based technology will provide broadband; in fact, some residents cannot even get a dial-up connection. More generally, a simple analysis of postcodes and exchanges shows that about 20% of Scottish residences (this is all of Scotland, not just rural Scotland) are more than 3km from an exchange. According to statistics gathered in [OFCOM09], these residences are unlikely to get even the 2Mbps, the minimum advocated in [CAR09]. Details of our analysis are discussed in the appendix.

The implication of these statistics for rural communities is simple. If one believes (a) that new technology will appear that will deliver bandwidth over long copper cables that is nearly two orders of magnitude higher than what is currently available and (b) that the government will invest first in optic fibre in remote areas rather than urban and semi-rural areas, then there is nothing to worry about. But we believe neither of these to be likely, therefore rural broadband has to be delivered via an alternative technology.

There is no doubt that the needs of substantial fraction of the UK will be met by progressively replacing the copper infrastructure with optic fibre. But even with further upgrades to exchanges and with deployment of optic fibre to these exchanges and beyond, the remote areas of the UK will be the last to be served, largely due to low population density in rural areas that makes the business case weak for commercial ISPs. And until this happens they will be locked into the lowest grade of service.

An alternative is satellite based Internet access, and this has been subsidised by Scottish Government to deal with areas that, like the Tegola testbed, are out of reach. Unfortunately this is not only quite expensive[4], but also suffers from low quality of service (as discussed earlier) and lower speed per user. It fails to fulfil nearly all the requirements of the applications discussed in the previous section.

Without going into detailed analysis, the only practical alternative for the next 5-10 years is terrestrial wireless – the technology that we have adopted (and are innovating further) in the Tegola project. The cost of necessary wireless equipment has fallen dramatically in the past two years from reaching economies of scale, and deployments of such

4 Consumers in some remote and rural areas of Scotland have only one choice, which is the recent Scottish Government initiative to provide heavily subsidised satellite-based Internet access via Avanti Communications. Comparatively, the authors living in a city like Edinburgh can choose from 13 possibilities (8 ADSL, 1 cable modem, 1 satellite and 3 mobile broadband). On the price front, the differences are even more stark. The best broadband package from Avanti is comparable to only low-end mobile broadband connection speeds offered in Edinburgh and at around 4-6 times the cost. The remaining broadband offerings (including ADSL) in Edinburgh start with minimum advertised speeds of 8Mbps.

equipment, as the testbed has demonstrated, is both technically and economically possible. The question is how this can be done sustainably on a wider scale. The sustainability issue arises from the need to have affordable and accessible *backhaul*; we elaborate on this in Section 5. Replication of our effort in other remote areas can be more easily done with active community involvement and we have already been contacted by a few communities in rural Scotland wanting to do just this; we discuss the community involvement aspect further in the next section.

4. Commercial vs. community broadband deployment models

During the deployment of the Tegola testbed, it became much clearer why commercial deployment in very remote areas is – without massive subsidies – impossible. There is the obvious reason that the amount of equipment and cable (in the case of a wired infrastructure) per consumer is much higher, but there are other factors.

• Commercial acquisition of mast sites can be problematic. They may be regarded as an eyesore. A problem we have seen in the Highlands is potential disputes between landowners and crofters about who benefits from the rent paid for mast sites. In addition to acquiring a mast site, one also wants to negotiate a non-stop power connection. If this cannot be done one has to build, at significant extra expense, a solar/wind powered mast. On the other hand, the more likely option for commercial deployments is to co-locate masts on public land with masts of mobile operators, but this is quite expensive and will ultimately end up being charged to the end users as part of their broadband connection cost.

• Travel for installation and maintenance is very expensive and time consuming. To visit some residents in the Tegola network area, the most cost-effective method of commercial transport may be by helicopter!

• Neighbours in remote communities are much more likely to share internet connections than in cities. This further reduces the effective client base for commercial service providers.

4.1. The case for community involvement in broadband deployment

While, for the reasons we have just stated, commercial deployment in remote areas is less likely succeed without massive subsidies, we believe that some form of community-driven or community-assisted deployment can. The Tegola testbed could not have been built without a huge contribution by the community. This is not just manpower in erecting masts and digging in power cables, but increasingly in the maintenance of the testbed.

First, people who live in remote communities are very resourceful. There are, for example, several competent electricians in the Tegola testbed, and they have rapidly learned to diagnose and deal with faults involving power supplies to our equipment – and power problems have been by far the most frequent cause of failure.

Second, even over the year in which the testbed has been running, not only has there be a dramatic fall in the cost of wireless equipment, it has also become much easier to install and configure. Much of our equipment has a simple web interface that allows easy configuration, antenna alignment and monitoring.

Third, in negotiating mast sites, it is much easier for a community to obtain permission (especially when the community has some control over the land) than for an external agency. We have had first-hand experience of this on the project.

3: An old community-installed TV relay

It is worth remembering that thirty years ago, well before the advent of satellite television, the Highlands and Islands of Scotland as well as many other remote areas of the UK were served by a network of community-built television relays. For over twenty years, this was how television reached the residents covered by the Tegola testbed. Although it attracted little publicity, it was a successful and stable system, and there is no reason for it not to be repeated. For technical reasons, we cannot make use of the now defunct mast sites in the Tegola area, but we know of at least one place where the site and the power supply may be salvaged for broadband distribution.

The extent to which communities can "go it alone" will vary. We are already advising other small communities in the Highlands and Islands on how to obtain a connection to remote access points. First of all, if there were a "resource centre" – information and some sort of help desk, we believe that many communities would be able to install their own connections. We also envisage that – just as is happening for alternative energy sources in rural areas – a network of consultants will evolve that will advise and maybe assist communities in the deployment of broadband wireless access networks.

To put this discussion in a broader context, community based efforts are growing in number across the country ranging from community owned wind farms (e.g., Westmill wind farm in Oxfordshire) to community-based fibre deployments (e.g., Fibremoor initiative in Alston, Cumbria). Our work in the Tegola project and the preceding discussion is in the same spirit as these other efforts even though it differs in the underlying technology (terrestrial wireless to make it cost-effective for broadband provisioning to remote communities with low population densities). Even more significantly, these efforts are seen as a key element of the next-generation broadband access infrastructure and therefore strongly encouraged by key reviews and policy documents such as [CAI08].

5. The need for affordable and accessible backhaul

No matter what technology is adopted for local (generally referred to as *"last-mile"* - but in these areas, often last 20 miles) access, there is still a need to connect to the Internet "backbone" at some point. We refer to this as the *backhaul* in keeping with common parlance. The backhaul will in practice consist of a mixture of optic fibre and microwave links. In the following, we briefly comment on various options and conclude that some form of public sector intervention is necessary to provide adequate service to areas of low population density.

The most basic backhaul option is to use one or more conventional home broadband connections (e.g., ADSL) for providing shared Internet connectivity to a larger number of users. In fact, this is the option we adopted in the Tegola project in our initial trials; it is being adopted by one or two individuals whom we have advised. This assumes that such a connection is available and that it is of adequate quality. In many cases the available speed may be quite poor (512Kbps or lower) and serving a community with such a connection – apart from violating the terms of the ADSL provider, would provide hopelessly low quality.

A slightly improved and more expensive option is for a community to collectively subscribe to a business broadband connection. This may not be available in rural areas. Even when it is feasible, typical business connections are capped at 8Mbps and still need to contend with other home/business broadband users in the area. Effectively this offers very little improvement over the previous, home ADSL option.

Another possibility is for each community to get a high-speed leased line from a local network service provider. A leased line is a dedicated wired connection between the customer's premises (in this case, one suitable location in the community area) and an access point[5], which is in turn connected to the national Internet backbone usually owned and maintained by another operator. While leased lines can provide the speed and quality of service we are advocating, they are prohibitively expensive, even for a

5 This access point is commonly called the point-of-presence (POP).

relatively large community. For example, leasing an E3 (34Mbps) line, to serve the Tegola project, could cost a few hundred thousand pounds to install and tens of thousands of pounds each month for rental.

Thus there are effectively no unsubsidised options for many residents of rural Scotland.

However, the Scottish Government has taken an impressive lead in already creating subsidised networks for educational institutions. These include the University of Highlands and Islands network [UHI], which supports the Tegola research testbed, and the even more substantial Pathfinder network [PATH], which serves every primary and secondary school in Scotland. These represent substantial investment of public funds, and it is possible that a relatively modest extension and upgrade to these networks could serve some form of community access in areas of low population density. Clearly appropriate charging mechanisms and conditions of use need to be established, but if we can “start where the task is toughest” as advocated in the original government report on broadband, we may be able to replicate in some form the Tegola project to make Scotland a world leader in the delivery of high quality rural broadband.

The availability of backhaul is therefore the major obstacle in bringing broadband to remote and rural communities. The case for public sector intervention to subsidise this cost is particularly strong even going by existing guidance on such interventions for broadband provisioning [OFCOM07]. Rural communities in Scotland are severely disadvantaged when it comes to broadband both in terms of choice and price. A recent communication from the European commission [EC09b] proposes to invest 1 billion Euros towards developing broadband infrastructure in rural areas in Europe as a key step to achieve 100% high-speed internet coverage by 2010 (as set out in the European Economic Recovery Plan), using existing rural development programmes of the member states. This offers an excellent opportunity for public sector intervention to address the backhaul issue.

6. Tegola research

Everything we have mentioned in this report is based on our experience with existing technology and our findings based on the deployment of a working network. There is no reason why the Tegola testbed could not be replicated elsewhere and – thanks to the recent and rapid improvement in hardware – more easily and at a lower cost. Here we briefly enumerate some of the research projects for which we are using the testbed.

- **Embedded Applications**. One of the important things to know about our masts and the relays on people's roof tops is that they each contain quite a powerful computer that we can program.

    - Usually we can do this programming remotely, but occasionally we mess up and have to make a trip to the mast in question. It's no fun climbing up a mountain in miserable weather, so we want to develop software that helps us configure the masts, installs new software and tries to prevent us from messing up.
    - We can use these individual computers to make intelligent decisions about what to do with the data they are forwarding. For example, if you are using voice over IP even short interruptions are unacceptable, but if you are downloading a large picture or video, you would probably be more concerned about the overall speed of download, even if there are short interruptions. Smart software could understand that the two kinds of data should be treated differently.
    - Smart software at the masts could figure out automatically how to reconfigure the network in case of a failure. It could also figure out how to reduce the power needed for the computers and wireless cards. For self-powered masts this is very important.

- **Mast location**. Finding locations for masts is a very difficult task. The mast we have between Sabhal Mòr Ostaig and Arnisdale is at the lowest point (around 310m) that has line-of-sight to both places. It is quite hard to find such a position. And it's not just about finding connections with line-of-sight; there are other factors:
    - Ease of access. It's a slog climbing up 310m and something that is dangerous in bad weather.
    - Proximity of a power supply. Self-powered masts are more expensive, both to build and to maintain.
    - Access rights. We have to put these masts on someone's land.
    - In addition, we need more than just line-of-sight. In order to get a strong signal the line-of-sight has to be well clear of obstructions.
    - There are many computational problems here involving algorithms, optimization, computational geometry, user interfaces and encoding of geospatial data.
- **Self-powered masts**. A mast needs about the same power (around 20W) as a high-efficiency light-bulb; and it needs it all the time. It would require a rather large solar panel to produce enough energy in a Scottish winter, so we need to use a combination of solar and wind, and we need to have adequate battery storage. But what is the right combination? To answer this question we need to understand weather patterns, equipment cost and risk analysis.

- **Transmission over water**. Water can act as a mirror to wireless transmission between two masts. It can reflect a signal that interferes with the direct signal what this means is that broadband can be affected by the tide. One way to get round this is to move masts to higher positions, but this is not much use to people on low-lying islands. We are investigating less costly methods of dealing with this problem.

Appendix A: Mapping Broadband in Scotland

We present some initial statistics that indicate that with the current infrastructure, the prospects of high-speed broadband for much of rural Scotland are rather dismal.

Several reports claim that somewhere in the region of 98 to 99 percent of the households in UK can receive broadband over the existing terrestrial infrastructure [MAS06]. In this appendix, we show results of our analysis based on public postcode data and phone exchange locations to identify the "not-spots" in Scotland -- areas that are not served, or adequately served, by wired broadband and are that are most unlikely to get satisfactory wire-based broadband in the future.

Obtaining broadband at a household via Digital Subscriber Line (DSL) technology, the most widespread wired broadband approach in Scotland and the UK, not only requires that the nearest phone exchange is DSL-enabled but also is dependent on factors including the length and characteristics of the copper cable connecting the household and the closest phone exchange, the so called "local-loop" (also sometimes referred to as the last-mile). Not paying attention to these additional factors and basing broadband coverage of a household on whether or not the corresponding exchange is enabled suggests that that 98.81% of the households in Scotland have access to the fastest service currently available via the BT Wholesale service and only 0.20% of the houses (corresponding to around 5,400 postal addresses) cannot get broadband. We believe that the official coverage figures are obtained using this simplistic calculation.

However, the reality can be very different especially in rural areas, where houses can be geographically scattered and far from the exchanges. By associating each of the 211,600 postcodes in Scotland[6] with a phone exchange from a public database of over 1,000 exchanges across Scotland, we obtain arguably more accurate figures.

Since telephone cables are typically laid alongside roads, we use travel distance as a better approximation of the local-loop length compared to pure straight-line physical distance. The following figure shows the distribution of households in Scotland with respect to their road distance from the closest exchange. We observe that in about 20% of the cases (shown in red) the local-loop is longer than 3km.

[6] These postcodes correspond to 2.65 million households and over 120,000 small business locations.

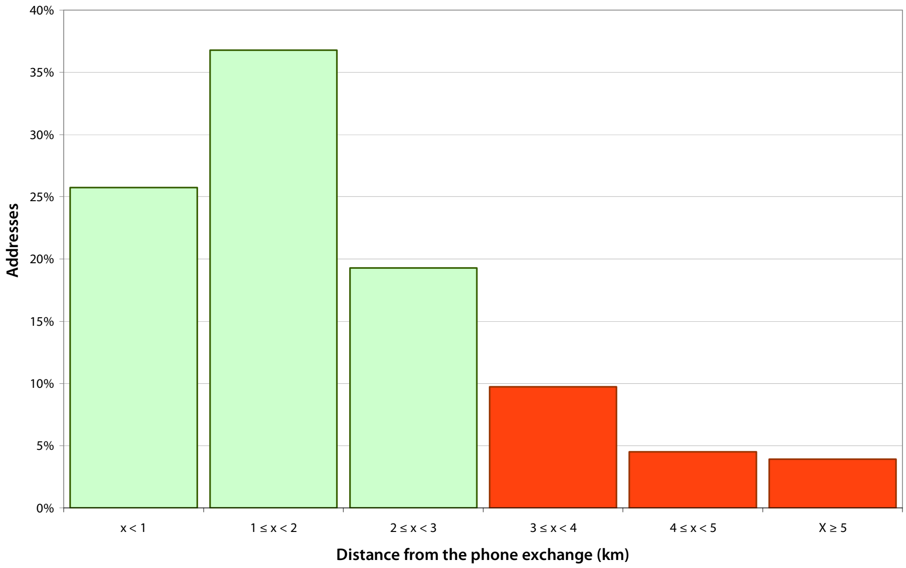

Figure 4 – Length of the local loop in Scotland

Why are these figures important? Because if the local loop is longer than 3km, the chances are that you will not be able to get better than 2mbs (the Carter report recommendation) and above 5km it is quite possible that you will not be able to get broadband at all. These claims need some substantiation. According to [OFCOM09] the *theoretical* maximum speeds at 3km and 5km are about 7Mbs and 2Mbs respectively, but a survey of what people actually get (see Figure 5) shows that the situation is very much worse; and it must be remembered that this was a survey taken of people who had a broadband connection. It is therefore likely to be optimistic.

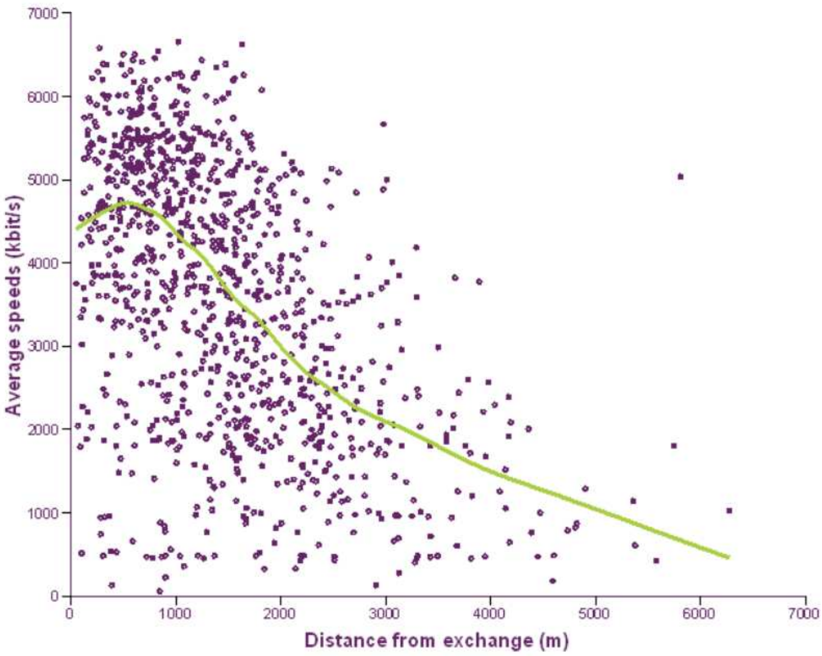

Figure 5 - Distance from exchange and maximum download speeds achieved by panellists on packages of 'up to' 8Mbit/s, from [OFCOM09]

We can take a closer look to the local-loop situation by considering the Urban/Rural classification from the General Register Office for Scotland. Their Urban/Rural indicator groups addresses in Scotland into eight categories based on the local population and the travel distance to the closest settlement, as follows:

Urban Rural Indicator	Name	Description
1	Large Urban Area	Settlement of over 125,000 people
2	Other Urban Area	Settlement of 10,000 to 125,000 people
3	Accessible Small Town	Settlement of 3,000 to 10,000 people, within 30 minutes drive of a settlement of 10,000 or more
4	Remote Small Town	Settlement of 3,000 to 10,000 people, with a drive time of 30 to 60 minutes to a settlement of 10,000 or more
5	Very Remote Small Town	Settlement of 3,000 to 10,000 people, with a drive time of over 60 minutes to a settlement of 10,000 or more
6	Accessible Rural	Settlement of less than 3,000 people, within 30 minutes drive of a settlement of 10,000 or more
7	Remote Rural	Settlement of less than 3,000 people, with a drive time of 30 to 60 minutes to a settlement of 10,000 or more
8	Very Remote Rural	Settlement of less than 3,000 people, with a drive time of over 60 minutes to a settlement of 10,000 or more

Figure 6 – Urban/Rural indicator, as defined from the General Register Office for Scotland

Classifying each household using this Urban/Rural Indicator as done in the following figure provides further and unsurprising evidence that the local-loop length can be up to four times longer in remote rural areas compared to remote small towns.

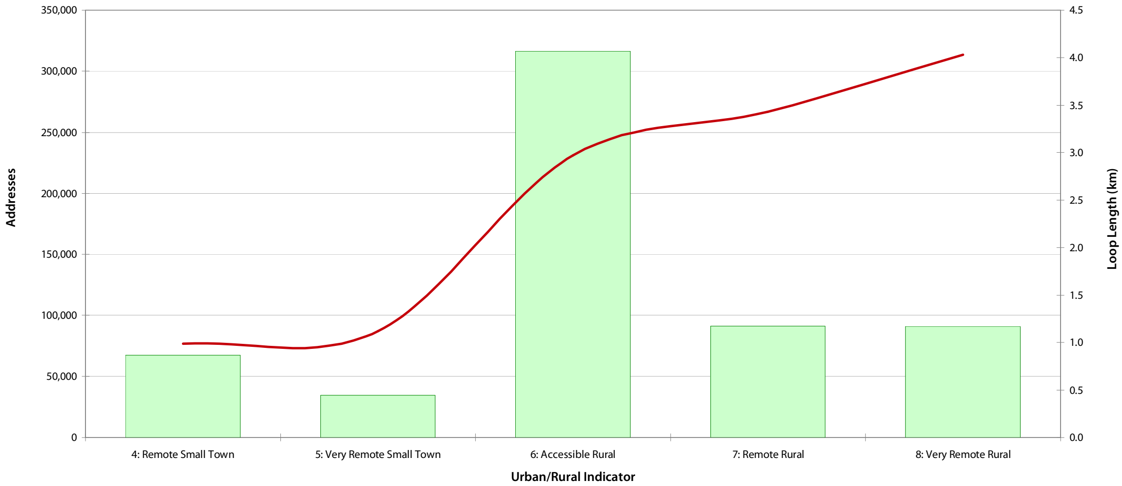

Figure 7 – Length of local loop by urban/rural indicator

Obviously, phone exchanges are not equally spaced across the land but tend to be more concentrated in urban regions, primarily due to the higher number of users to be served. The following map of Scotland shows red squares sized accordingly to the community size corresponding to areas farther than 3km from the local exchange, rural regions such as the Highlands look almost uniformly red indicating that local-loop lengths in those regions are much higher, an unfavourable condition for copper-based broadband access.

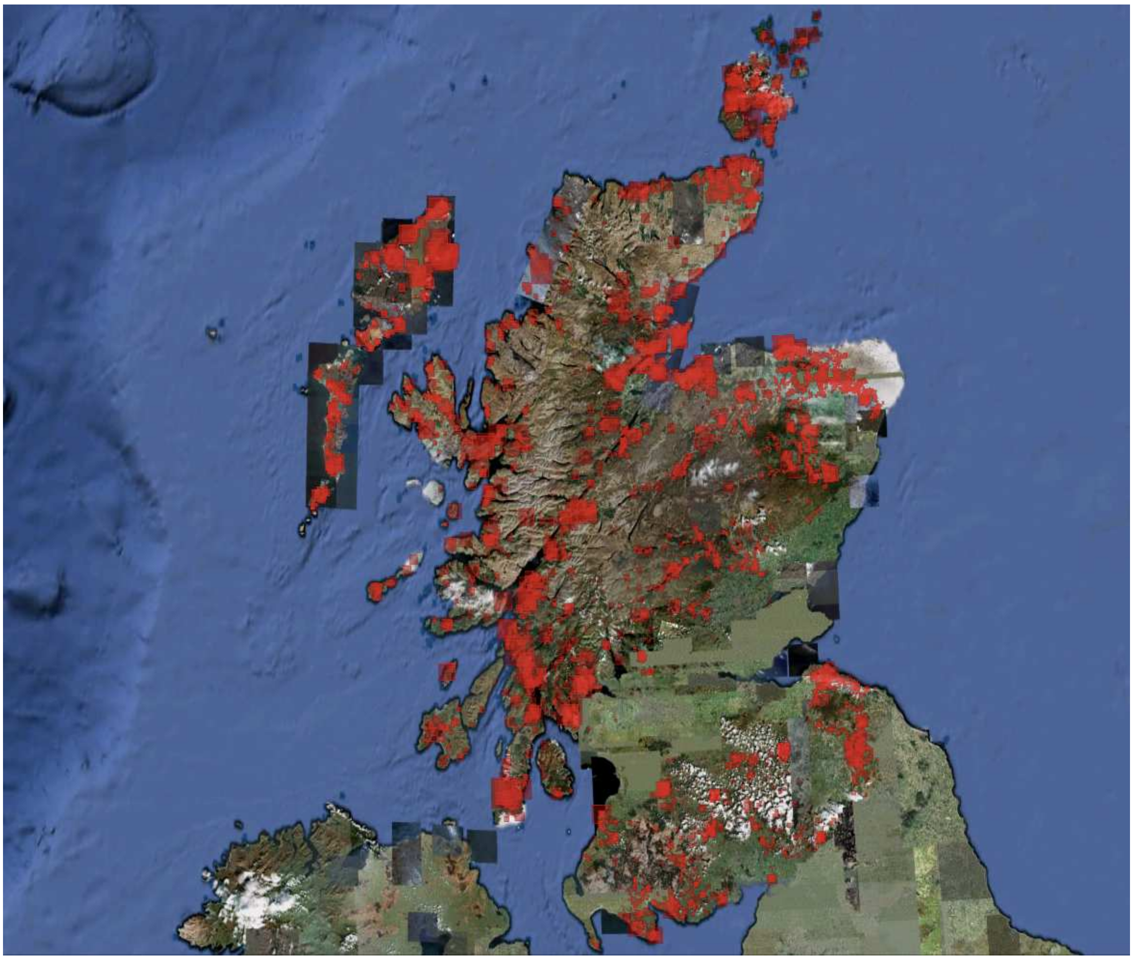

Figure 8 - A map indicating the "not spots" for high-speed broadband in rural Scotland. The individual squares locate postcodes that are more than 3km from an exchange. The area of each square is proportional to the number of households in that postcode.

Besides the local-loop length, there are several other factors that our calculations did not consider but still have a bearing on the broadband coverage, including:

- Poor quality cables, joints and aluminium wiring can dramatically reduce achievable broadband speeds, even for short lengths.
- Noise from external and unpredictable factors such as "cross talk" of signals between different lines.
- The contention between users accessing the same exchange can sometimes saturate the backhaul connection of the Internet Service Provider.
- Users in covered areas may still be unable to be get broadband if the phone

exchange is "full" -- that is to say that all ports on the communication equipment at the exchange are occupied.

Despite the fact that our calculations are based on optimistic estimates, it is clear that rural regions in Scotland are poorly served by the existing wired infrastructure. In particular, a substantial number of households (up to a fifth) will not be able to receive any current or future generation DSL-based broadband of acceptable quality.

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