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BSense: A System for Enabling Automated Broadband Census

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Abstract : Broadband Internet access is increasingly being looked at as the new *utility*, in the same way as water supply and electricity networks. Broadband networks are also being viewed as infrastructural assets, such has roads or highways, because of the strategic importance they carry in relation to economic growth. This new view is driving the need for policy makers and governments to get a better understanding of broadband coverage and quality, with a particular emphasis on identifying underserved areas.

In the last few months, a vast number of broadband mapping initiatives have started, often with significant investments from public organizations. However, there is a lack of systematic approaches focused on creating reusable tools, that do not make assumptions on specific geographies or regulatory impositions on ISPs.

We propose `BSense`, a broadband census system based on open-source software that attempts to utilize broadband data from different sources and enable an automated broadband census. Besides describing `BSense` in detail, we also discuss how our framework offers incentives for all stakeholders to encourage their participation. Additionally, we provide a sample use case for `BSense` that focuses on creating a broadband census for Scotland.

Keywords : Broadband Access, Digital Divide, Mapping, GIS, Decision Systems

1 Introduction

There exists a digital divide in terms of broadband Internet access[1] in most countries across the world. The underlying reasons can be varied from location (remoteness, terrain) and population density to lack of infrastructure, deployment costs and socio-economic factors. For example, in the UK, of the 10 million people who have never used the Internet (roughly 17% of the population), 4 million are economically and socially disadvantaged [1]. US provides another example of the divide in developed countries. A recent FCC survey found that 5% of US homes are in locations where they have no broadband access and 36% of the population without broadband cite cost as the main reason for not subscribing for broadband at home [2]. The divide widens when it comes to developing regions. In India, for example, there are only 2.5 million broadband subscribers in a population of over a billion and only less than 10% use the Internet [3].

While the above figures, usually obtained via personal surveys, are useful for highlighting the existence of the broadband digital divide, they cannot completely and precisely quantify the problem. *Broadband census or mapping* is a term typically used to describe the latter exercise. Broadband census is considered important by all stake holders — consumers, Internet Service Providers (ISPs) and policy makers. This is evident from the plethora of consumer broadband tests available (e.g., [4, 5, 6, 7, 8]), business models underlying companies like Epitiro [9], and recent initiatives by telecom regulators and governments in the UK, US and elsewhere [10, 11]. Quantifying the broadband digital divide broadly requires study of three aspects: coverage, choice (cost) and quality. Studying coverage involves identifying *"notspots"*, i.e., areas not serviced by even one broadband access technology. In order to determine the amount of choice that a consumer has, one needs to find out the number of access technologies and ISPs available at the consumer's location. Greater choice usually also implies lower cost (per Mbps) for the consumer. Finally, broadband quality is measured using a set of metrics such as download/upload speeds, latency, jitter and packet loss rate. Several technology-specific and network provisioning factors affect quality in practice (e.g., line length, number of concurrent users, contention ratio, backhaul capacity). Note that all these three aspects of coverage, choice and quality vary with time.

In this paper, we develop a flexible software system based on open source tools called `BSense` for enabling automated broadband census for any region. We take an integrated approach that utilizes estimated and measurement data from different sources (e.g., ISPs, user tests) and overlays it on demographic and geographic data to get a more complete picture of the broadband coverage. By viewing the estimated data as "models" and using measurement data to continually *validate* those models, the accuracy of the system improves over time as more measurement data becomes available and ISPs provide updated estimated data and/or upgrade their service quality/infrastructure. All this process can be automated to generate an evolving broadband census with the help of well defined web services API that the stakeholders use to interact with the `BSense` system and a fully developed data fusion engine inside the `BSense` server.

To demonstrate the working and utility of the `BSense` system, we present a case study focusing on creating a broadband census for Scotland. For this case study, we use publicly available broadband data from ISPs along with measurement results obtained via web-based broadband quality tests (using the Network Diagnostic Tool (NDT) [4]) taken more than 300 times by more users spread across Scotland. We show maps generated using `BSense` for estimated data obtained from ISPs for three different access technologies (DSL, cable and 3G), measured broadband quality and notspots based on both estimated and measured data.

Our work differs from existing work on broadband census in several ways. First, our approach is to use a combination of estimated and measured data, whereas existing approaches use one or the other. Second, we provide a flexible implementation of our `BSense` broadband census system based on open source software, making it generally applicable and low cost to deploy anywhere. We also discuss how our framework offers incentives for all stakeholders to contribute to the creation of a complete and reliable broadband map.

[1]For the purposes of this paper, we use a modest definition of broadband as a form of Internet access that is always on and with better than dial-up speeds. It can be provided via any of the several broadband access technologies: wired (e.g., DSL, cable, fibre) or wireless (satellite or terrestrial).

The remainder of this paper is structured as follows. Next section reviews related work. In Section 3, we describe the proposed `BSense` system along with a case study. We finally conclude in Section 5.

2 Related Work

Broadband census approaches can be broadly classified into two categories: estimation based and measurement based. We discuss each of them below. It is worth mentioning here that a large-scale broadband mapping effort is underway in the US with a $350 million funding from the NTIA as part of the broadband stimulus from 2009 American Recovery and Reinvestment Act, but the approach adopted by mapping efforts of individual states is still unclear.

2.1 Estimation Approach

In this approach, broadband coverage and quality can be estimated using the knowledge of ISP network infrastructure in conjunction with known models of the access technology in question. In the case of DSL, see [12, 13, 14, 15] for examples of such models and their use in estimating broadband coverage. [16] shows a similar approach for estimating 3G mobile broadband coverage in the UK. Alternatively, estimated broadband data can be provided directly by ISPs, obtained from their public websites or other public sources. Such estimation data could again be based on models and/or field tests (e.g., drive test measurements conducted by mobile telecom operators). As with any model based approach, especially if they are not empirically based, there is the possibility for the estimates to provide overoptimistic coverage and quality results due to underlying model assumptions (e.g., perfect line quality and no crosstalk in the case of DSL).

Both these approaches have severe limitations. In the absence of a regulatory imposition, it is difficult to obtain coverage data from the ISPs, as they often regard it as confidential information sensitive for their business operation. Several ISPs claim they are afraid that if they published a map of the services they offered, competitors would know exactly what pitch to send to which customers. Also, network operators inherently have the tendency of overestimating their network coverage, for both marketing reasons and technical factors (i.e. overselling, contention ratio, etc.). Finally, in countries dominated by the network incumbent, a overestimation or error from their side will reflect in a corresponding error to the coverage of all the ISPs the incumbent provides wholesale access to.

A particular example in this category that is worth mentioning is the approach taken by the US non-profit Connected Nation [17], which relies on broadband data from providers those who voluntarily choose to participate in their mapping project. Incentives to encourage providers to participate are unclear. This project depends on consumer feedback and surveys to verify ISP provided data, which potentially introduces a substantial manual element to maintain the mapping effort and thereby making it an expensive operation to sustain. Field tests conducted by Connected Nation engineers is also mentioned as yet another verification approach, but solely relying on such field tests can also make the project unsustainable.

2.2 Measurement Approach

Instead of estimated data, actual measurement data can be used for broadband mapping. Although ISPs can in theory contribute measurement data that they may collect continuously to monitor and optimize their networks, they may not have any incentive to do so in practice. So we *focus on provider independent measurement approaches* as practical alternatives to obtain measurement data. They fall under two sub-categories: (1) user dependent, and (2) user and provider independent. We discuss each of these below.

1. *User Dependant Approach.* In this approach, users (consumers) explicitly or implicitly participates in measuring the quality of their broadband connections.

(a) *Software-based:* There are many broadband tests that the user can run on their computer when connected at home [4, 5, 6, 7, 8, 9]. These tests differ widely in their test methodology (e.g., packet dispersion vs. file transfer time), server locations and data collection mechanisms. Some of these are open source like the NDT test [4] we use in our implementation, whereas others like Speedtest.net from Ookla [5] are commercial. In fact, one of these two tests is chosen randomly with the recently launched FCC consumer broadband test [2]. Some of these tests like Isposure [9] automatically and repeatedly run in the background on the user's computer. The Isposure tool is also interesting in that it is paid for by the ISPs in exchange for the data collected from consumers. Software-based tests to be effective have to be easy to setup and configure. Also when geolocation techniques are used to infer the user's location based on the connection's global IP address, location errors could be introduced, especially in rural areas. Another common problem for user software tests is that they can be used for collecting measurements only when the user computer is on.

(b) *Hardware-based:* An alternative approach that does not involve installing test software on the user's computer is to install a hardware device (as an additional computer in the home) dedicated for monitoring the user's broadband connection 24/7. This is the approach followed by SamKnows[3] for its UK broadband speeds study with Ofcom [10]. SamKnows was recently selected by the FCC to conduct a similar study in the US. This approach requires a large number of diverse volunteer users to agreeing to install such a hardware monitoring device in their homes, which can be expensive. Privacy concerns of users may also come in the way in implementing this approach.

2. *User and Provider Independent Approach.* The above mentioned measurement approaches require the participation of the user either one time initially to agree to host a hardware device or repeatedly in the case of software tests. An alternate approach has emerged recently to enable large-scale active measurement without user or provider involvement by continuous, low overhead probing of consumer broadband routers from a remote measurement server [18, 19]. This approach relies on certain specific but standard functionality from routers (e.g., responding with TCP RST packets upon receiving unsolicited ACKs). Such functionality may be disabled due to security concerns. If a particular ISP does not support this functionality on all its broadband routers, then that ISP is effectively ignored by this approach, which is undesirable from a broadband mapping perspective.

One common limitation of all measurement approaches is that results may be sensitive to cross traffic (other active traffic from the user during the time his/her connection is being tested) and may not be robust across a heterogeneous set of access technologies (e.g., DSL, cable, WiFi, satellite). However, this is a very active research area as evident from several recent papers (e.g., [20, 21]), so it is reasonable to expect improved measurement techniques to be available in near future. Note that our focus is not on improved measurement techniques nor is our approach dependent on a specific measurement technique. In our current implementation of the `BSense` system, we use the NDT test as a "placeholder"; replacing it with another technique in future (if deemed necessary) is straightforward.

3 `BSense` System

Broadband census is needed by each of the various stakeholders — consumers, ISPs and policy makers. Moreover, broadband coverage and quality changes over time with newer deployments, network upgrades and emergence of new access technologies. We believe that cooperation among different stakeholders is needed for a complete, reliable and an evolving broadband map. Keeping

[2] `http://www.broadband.gov/qualitytest/about/`

[3] `http://www.samknows.com/`

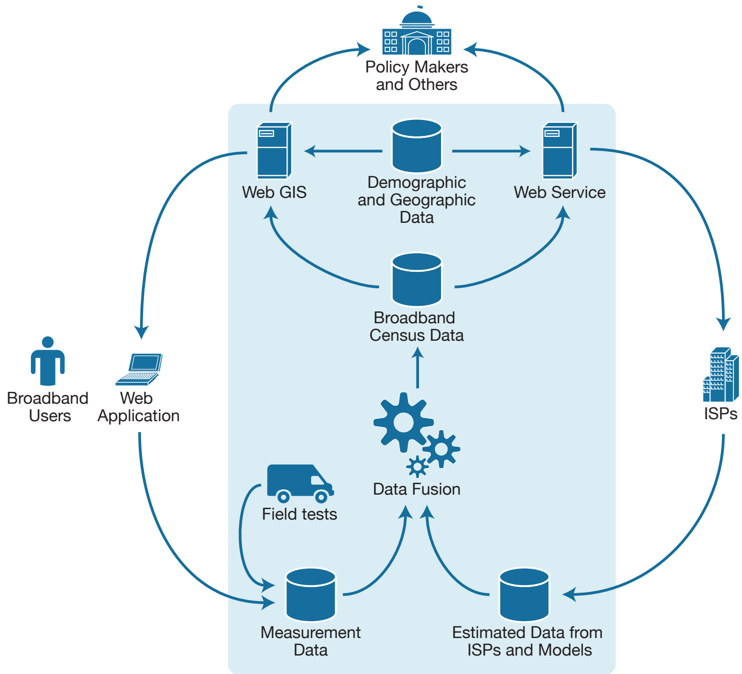


Figure 1: `BSense` broadband census life cycle.

this in mind, we present what we call a broadband census life cycle (see Fig. 1) with incentives for everyone to continually contribute to the broadband census exercise. Consumers would benefit from comparing their observed broadband quality over time with their ISP's advertised service. Equally, they would be interested in knowing the broadband coverage and quality in their neighborhood from different ISPs. They can obtain this information in exchange for performing web-based broadband quality tests over their broadband connection from time to time; the results of such tests feed into the measurement database, which will be used in validating the estimated broadband data from ISPs. ISPs normally pay for market research information to determine the areas to upgrade their networks and improve their service quality. They could get this information in return for being an active participant of the broadband census system and contributing estimated data of their services and other associated data to the system with interaction between them occurring via web service APIs (described shortly). Finally, policy makers can query the broadband census system using the API to get a true picture of broadband coverage and quality and accordingly make informed policy decisions (e.g., public sector intervention, providing incentives for investments in underserved areas, telecom market regulation).

`BSense` system integrates both estimated and measured broadband data and overlays it over demographic and geographic data to generate broadband maps as needed. All data is stored in a relational database as shown in Fig. 2. The geographic region of interest is assumed to be split into distinct `GeoUnits`, each with an associated unique ID, name and boundaries. A GeoUnits can in turn be organized in a hierarchical fashion to provide coarser geographical level. Taking Scotland as an example, a GeoUnit maps to a postcode while multiple postcodes combine to form a council area (the immediately higher GeoUnit tier, which is accessed via the `GeoUnitTiers` table in Fig. 2). Details about participating ISPs is listed in the `Operators` table, whereas their service packages are stored in the `Packages` table. The `EstimatedData` table contains the estimated broadband data and service availability obtained from ISPs (or some other means) for each GeoUnit. Finally, web-based user broadband quality test measurement results are stored in the `MeasurementData` table. The concept of broadband speed appears in the database in three different places, with different meanings: the attribute *AdvertisedSpeed* in the `Packages` table refers to the service characteristic

GeoUnits

GeoUnitID	varchar	PK
GeoUnitName	varchar	
Boundaries	polygon	
GeounitParentID	varchar	
TierID	int	

GeoUnitTiers

TierID	int	PK
TierName	varchar	

GeoUnitStatistics

GeoUnitID	varchar	PK
Population	int	
AddressCount	int	
SmallBusinessCount	int	
...		

Technologies

TechnologyID	int	PK
TechnologyName	varchar	

EstimatedData

GeoUnitID	varchar	PK
PackageID	int	PK
ExpectedSpeedDown	float	
ExpectedSpeedUp	float	
Details	xml	

Operators

OperatorID	int	PK
OperatorName	varchar	

Packages

PackagtID	int	PK
OperatorID	int	
TechnologyID	int	
PackageName	varchar	
Description	varchar	
AdvertisedSpeedDown	float	
AdvertisedSpeedUp	float	
Details	xml	

MeasurementData

TestID	int	PK
GeoUnitID	varchar	
PackageID	int	
OperatorID	int	
AdvertisedSpeedDown	float	
AdvertisedSpeedUp	float	
ServerIp	varchar	
ClientIp	varchar	
ClientStats	xml	
MeasuredSpeedDown	float	
MeasuredSpeedUp	float	
Latency	float	
Jitter	float	
Detailedstats	xml	
Timestamp	DateTime	

Figure 2: Database schema in the current `BSense` implementation.

advertised by the ISP, and it typically an *"up to"* value and tied to the subscription cost. ISPs can also provide an *ExpectedSpeed* for each GeoUnit, which is stored in table `EstimatedData`. This is useful when some sort of performance baseline is known in advance, such as with DSL or mobile broadband access. The results of broadband quality measurements update the *MeasuredSpeed* attribute value in the `MeasurementData` table. In our implementation, we used the open source PostgreSQL[4] database management system augmented with the PostGIS[5] extensions to handle spatial data.

Fig. 3 illustrates the `BSense` software architecture. External communication to the `BSense` system is primarily via web service API calls over SOAP; they are handled by a component that also enforces security control. As mentioned earlier, we use NDT [4] in the current implementation for web-based user broadband quality measurement tests.

Currently implemented set of APIs are listed below:

- `BroadbandTestRecord()`, called by a NDT server every time a broadband test is completed. It records the results into `MeasurementData` table in the database.
- `AddPackage()`, `EditPackage()`, `DeletePackage()` are used by participating ISPs to manage their broadband service packages stored in the database.
- `AddEstimatedData()`, `EditEstimatedData()`, `DeleteEstimatedData()`, called by ISPs to update the estimated broadband data for each covered GeoUnit by any of their service packages.

[4] `http://www.postgresql.org/`
[5] `http://postgis.refractions.net/`

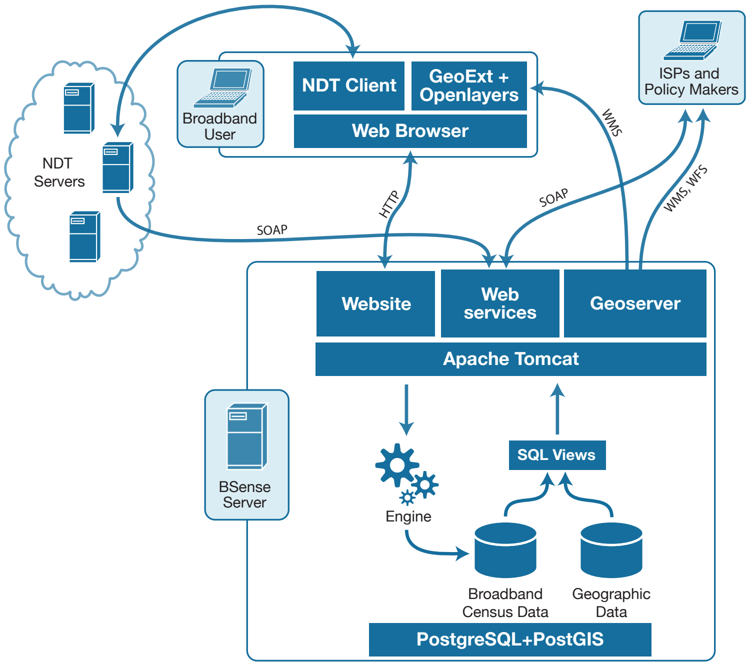


Figure 3: `BSense` software architecture.

- `LookUpCensusData()`, invoked by consumers via the public website and by ISPs and policy makers using SOAP calls to query the `BSense` system.

Besides SOAP based web service calls, `BSense` also provides outside access via the Open Geospatial Consortium's standard WMS (Web Map Service) and WFS (Web Feature Service) to obtain raster and vector geo-referenced images, respectively, of a geographical area of interest. While WMS and WFS services can be directly used by most open-source and commercial GIS software products, `BSense` also offers a built-in web application that uses WMS, developed using the GeoExt[6] and Openlayers[7] frameworks, to further ease (the access to and) visualization of broadband maps. To provide access to WMS and WFS service, that are used also by the web-application, we built on top of the well-known open source Geoserver[8], a Java software that allows users to view and edit geospatial data. This implementation choice reduces the complexity of projecting data in maps and rendering them as images. In our system architecture, spatial data is stored in the PostGIS database and is accessed by Geoserver via SQL View constructs to dynamically retrieve required broadband data in real time. Besides census data, `BSense` allows the storage of additional geospatial layers with geographic and demographic data that are useful when generating maps.

Web services API together with the data fusion engine in `BSense` can enable automated and evolving broadband census creation with the engine performing online model validation using measurement data. The engine component in the current implementation is very basic and its further development is a part of our future work.

[6] `http://www.geoext.org/`
[7] `http://openlayers.org/`
[8] `http://www.geoserver.org`

4 Case Study: A Broadband Census for Scotland

We now demonstrate the utility of the BSense system for creating a preliminary broadband census for Scotland. Scotland with a population of around 5.2 million people is demographically quite diverse with a handful of cities (e.g., Edinburgh, Glasgow), several small towns and scores of villages in the rural part of the mainland and across the several islands on the west and the north. Population density varies widely from as high as 3200 people per sq. km to just 8 in remote areas. This has resulted in the use of a wide range of broadband access technologies with ADSL being the prevalent one. In cities (the main population centers), consumers tend to have a choice between different access technologies — ADSL2/ADSL2+ is available both from the telecom incumbent (BT) and from independent providers (commonly referred to as Local Loop Unbundling or LLU operators); cable and, more recently, FTTH deployments offer advertised speeds of 50Mbps; 3G coverage is generally good. Away from cities, wired access is limited, at best with slow ADSL links. Due to a recent broadband reach initiative from the government, some of the users in rural and remote areas in previously notspot areas now connect via a subsidized yet relatively expensive satellite connections. Residents in a small part in the northwest of Scotland connect via the Tegola network, a long distance WiFi testbed we have deployed [22] two years ago. Finally, residents in the outer islands in the west and some residents in the northern islands are serviced by small commercial wireless ISPs.

From the geographical perspective, the whole of UK is subdivided into "postcode" areas of varying size based on the population. In Scotland, there are a total of around 152,000 postcodes. Most of those are concentrated in cities, where they accurately determine a few houses or buildings. In rural areas, on the other hand, they may include several hectares of farming terrain. Several higher-order geographical subdivisions exist, but in this study we only consider "Councils Areas": 32 areas which are governed by unitary authorities. We successfully imported spatial data for both postcodes and councils from governmental sources into BSense .

For the purposes of creating an initial broadband census in this study, one source of our data is the estimated broadband data imported to our database (using the tools we developed) from public websites of the main ADSL provider (BT); two cable providers of which one of them (Virgin) is much larger than the other; and one of the 3G mobile telecom operators (Orange)[9]. Note that we updated the database using the same API that an ISP would use (as described earlier in this section). Maps generated by BSense when queried for the estimated broadband coverage data of each of these networks are shown in Fig. 4.

To obtain broadband quality measurement test results from users, we developed a website[10] that first prompts the user for a valid postcode in Scotland, then asks four basic questions (on access technology type, ISP name, advertised speeds for the service purchased by the user) followed by a java applet based test of the user's broadband connection using a modified version of the NDT software [4]. Through wide publicity of this test website after its launch on 30th March, 2010, we obtained more than 335 measurement test results from 233 unique postcodes spanning 26 of the 32 council areas in Scotland; these 26 council areas are home to 89.4% of Scotland's population. BSense measurement database was updated by having the NDT server input broadband test records as shown in Fig. 3 and described earlier in this section. Subsequent query to BSense for median measured download speed per council area generated the map shown in Fig. 5.

We close this section by showing an example of a simple fusion of estimated and measured data in BSense to infer notspots in Scotland. We define a postcode area as a notspot if neither the estimated data nor the measurement data in our database suggest a download speed greater than a specified threshold for four different threshold values (512Kbps, 1Mbps, 4Mbps, 8Mbps). Resulting notspot maps produced by BSense for these four threshold values is shown in Fig. 6. It can be clearly seen that most postcode areas outside of the central belt of Scotland (with the two main cities of Edinburgh and Glasgow and having the largest population concentration) become notspots as the threshold is raised.

[9]Even though the process to import data from the remaining four 3G operators is similar, we fell short of time to do it by the time of this submission.

[10]http://broadbandforall.net

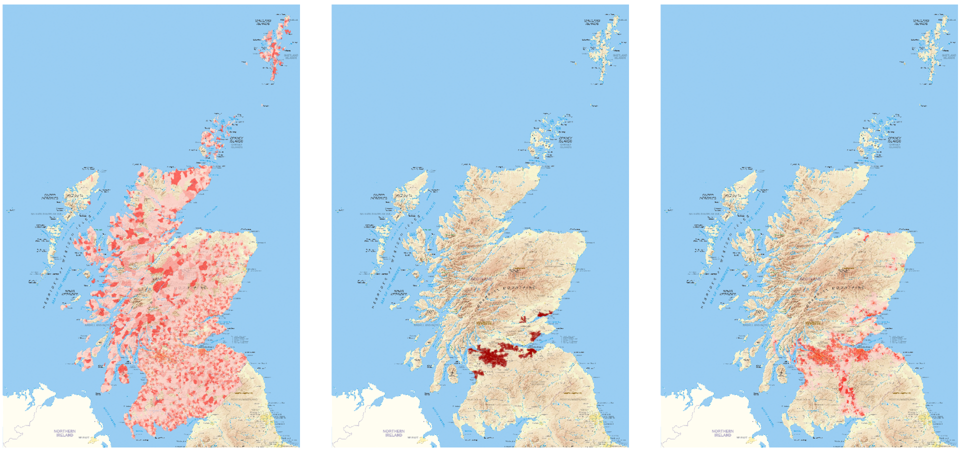


Figure 4: `BSense` generated broadband map for various access technologies and ISPs based on their estimated data: (a) ADSL — BT Wholesale; (b) Cable — Virgin and Smallworld; (c) 3G mobile broadband — Orange. In each of these maps, postcode areas with the corresponding service are colored with darker colors indicating faster expected speeds or better wireless coverage.

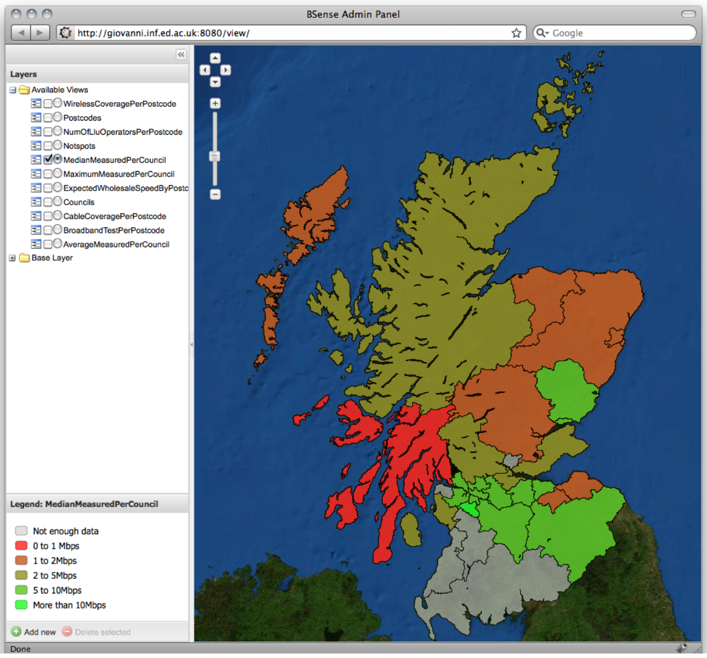
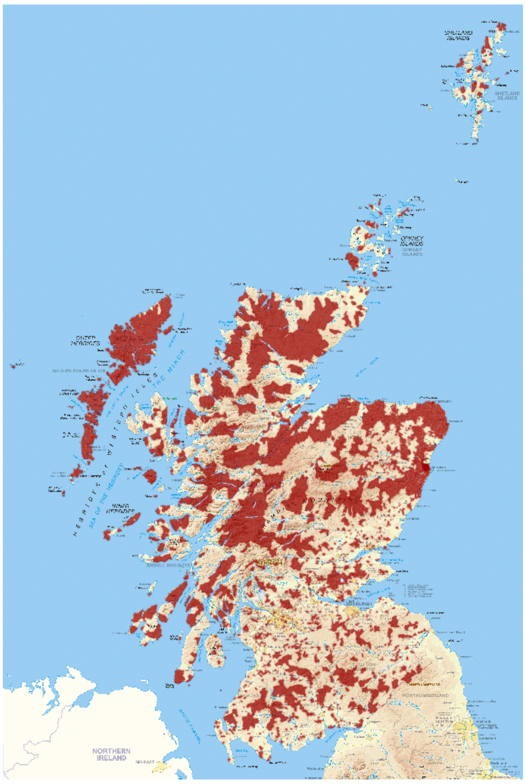
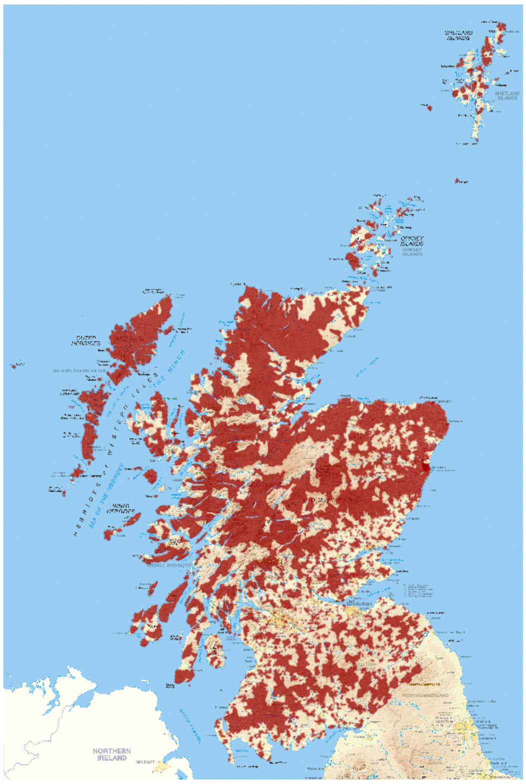


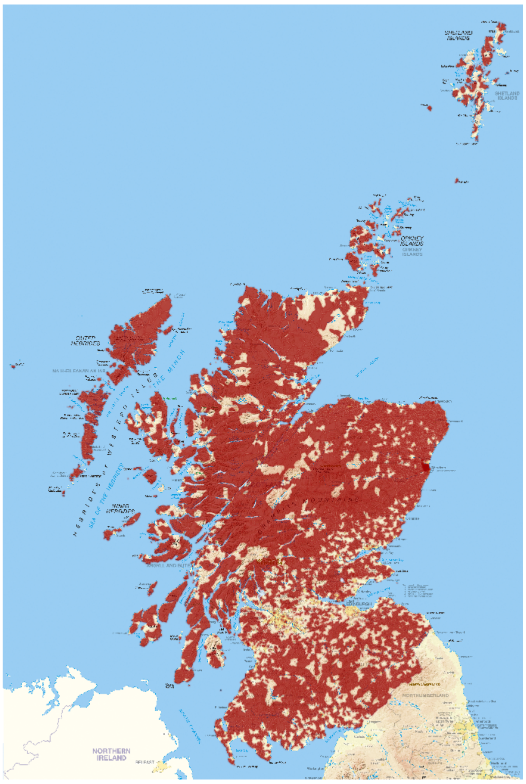
Figure 5: `BSense` web-based GUI showing a map for median measured download speed per council in Scotland based on the measurement data collected till 11 April, 2010.



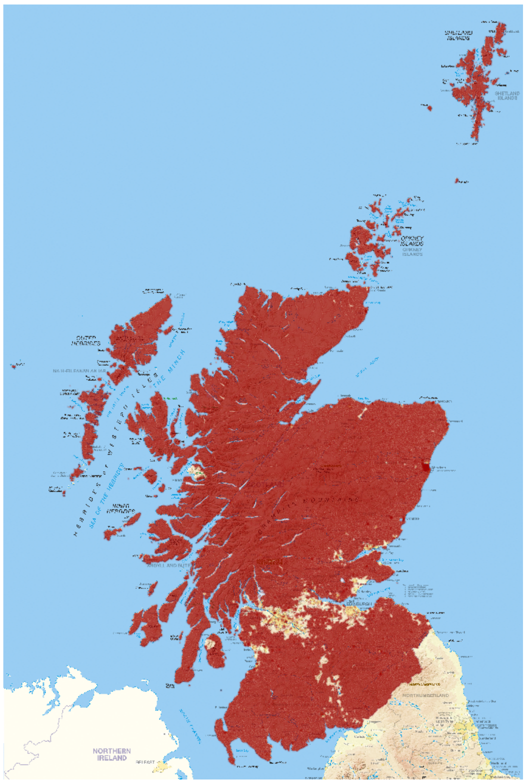
(a) Threshold=512Kbps



(b) Threshold=1Mbps



(c) Threshold=4Mbps



(d) Threshold=8Mbps

Figure 6: `BSense` generated map of notspots in Scotland that lack a service supporting download speed greater than the indicated threshold. Notspot postcode areas are shaded in red.

5 Conclusions

In this paper, we have considered the problem of broadband census, which is fast becoming very important in view of the quest for universal broadband and bridging the broadband digital divide in many parts of the world. We have a developed a flexible software broadband census system called `BSense` based on open source software. We have also discussed how the `BSense` framework can offer incentives to all concerned to contribute towards generating comprehensive and reliable broadband maps. `BSense` is unique in that it takes an integrated view of both measured and estimated broadband data using the former to validate the latter, thus potentially providing an automated platform for broadband census that improves with time. Though this work is not mature yet, we showed the value of the `BSense` approach through a case study involving creation of a preliminary broadband census for Scotland. Our future work will focus on enhancing the capabilities of the data fusion engine in `BSense` as well as a detailed investigation of measurement techniques from a broadband mapping viewpoint.

Acknowledgements

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