Final Report for Ofcom

Estimating the demand for spectrum use for the Glasgow 2014 Commonwealth Games

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Janette Stewart, Michal Gabrielczyk

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Analysys Mason Limited
Apex 3, 95 Haymarket Terrace
Edinburgh EH12 5HD
Scotland
Tel: +44 (0)845 600 5244
Fax +44 (0)131 443 9944
edinburgh@analysysmason.com
www.analysysmason.com
Registered in England No. 5177472

1 Executive summary

This document is the final report of a project conducted by Analysys Mason Limited ('Analysys Mason') on behalf of the Office of Communications ('Ofcom'), to examine spectrum requirements for the Glasgow 2014 Commonwealth Games ('the Games').

During the Games, access to spectrum will be required both to organise and run the Games, and to provide live broadcast of events.

This study estimates what demand there might be for spectrum both to support the Games' operation, and to support domestic and incoming broadcasters that will wish to provide live coverage of the Games. A 'bottom up' approach to estimating demand has been used, based upon demand estimates provided to us by possible users of spectrum during the Games. It is noted that this does not take account of whether the stated demand can be accommodated within the available spectrum, and there may be trade-offs inherent in meeting the demand estimates of all users that will need to be taken account of when developing a detailed spectrum assignment plan for the Games.

The output of this study will be used by Ofcom in due course to inform further detailed assessment of how to meet the spectrum requirements for the Games, and to develop a spectrum assignment plan.

1.1 Categories of use

We have grouped spectrum demand during the Games into eight categories:

- private business radio (PBR) – also referred to as private mobile radio (PMR). In the remainder of this report, we refer to this as PBR
- wireless microphones and in-ear monitors
- temporary audio links
- outside broadcast talkback
- telemetry (e.g. camera control)
- wireless cameras, including airborne links
- video links – including temporary (portable) point-to-point links that might be deployed at certain locations or sporting events, and microwave links that might be used to provide connection from venues (in lieu of fibre)
- satellite news gathering.

In addition to the categories above, it was noted during stakeholder interviews that there may be additional uses of wireless during the Games, such as timing for events and at medal ceremonies and any 'radio props' that might be used at opening or closing ceremonies. For the purposes of our demand estimation we have also distinguished between terrestrially deployed wireless cameras, and cameras deployed in helicopters (requiring an airborne downlink) in our estimates.

We have undertaken an assessment of where demand will arise for the use of each type of system as defined above, and how much spectrum might be needed to accommodate the different systems.

1.2 Spectrum users

We have anticipated that the main users of wireless equipment during the Games will be:

- Glasgow 2014 – the organising committee for the Games.
- Glasgow City Council – responsible for transport, roads, public information and events management within the Glasgow City area; also responsible, in consultation with Glasgow 2014, for the development and implementation of a city-wide cultural programme (via Glasgow Life).
- Host broadcaster (HB) – at the time of producing this report, Glasgow 2014 has not yet confirmed publicly the HB for the Games; we understand an announcement is to be made during May 2012
- BBC Sport – the domestic rights holder of live broadcasting for the Games. It is noted that BBC Sport is not the HB, unlike for the Manchester Commonwealth Games, when BBC Sports was the HB as well as providing domestic broadcasting
- BBC Scotland – which will be responsible for producing sports and other events coverage for the BBC Scotland schedule.
- Other domestic broadcasters (e.g. STV, Channel 4, Sky) – which might also produce sports and other events coverage for their schedules during the Games.
- Other international broadcasters from Commonwealth countries – who might also produce supports and other events coverage for their own domestic schedules during the Games.

For each category of use we have identified which users are most likely to require spectrum:

Figure 1.1: Likely users of wireless systems at the Glasgow Games [Source: Analysys Mason, 2012]

Category	Likely users
PBR	Glasgow 2014, Glasgow City Council, HB, BBC Sport, BBC Scotland, other domestic broadcasters, other international broadcasters
Wireless microphones and in-ear monitors	Glasgow 2014, HB, BBC Sport, BBC Scotland, other domestic broadcasters, other international broadcasters
Audio links	HB, BBC Sport, BBC Scotland, other domestic broadcasters, other international broadcasters
Talkback	Glasgow 2014, HB, BBC Sport, BBC Scotland, other domestic broadcasters, other international broadcasters
In-ear monitoring (IEM)	Glasgow 2014, HB, BBC Sport, BBC Scotland, other domestic broadcasters, other international broadcasters
Wireless cameras	HB, BBC Sport, BBC Scotland, other domestic broadcasters, other international broadcasters
Point to point video links	HB, BBC Sport, BBC Scotland, other domestic broadcasters, other international broadcasters
Satellite news gathering	HB, BBC Sport, BBC Scotland, other domestic broadcasters, other

(SNG) uplinks	international broadcasters
Airborne links	HB

Note that we have assumed that BBC Sports, other domestic broadcasters and other international broadcasters will use aerial video feeds from the HB and so will not deploy their own helicopters at each event.

1.3 Demand for spectrum

Figure 1.2 shows our spectrum demand estimates for the Games in terms of the number of frequency channels required, compared to similar requirements for the London 2012 Olympic and Paralympic Games.

Figure 1.2: Spectrum demand estimate for the Games [Source: Analysys Mason, 2012]

Categories	*Glasgow demand (number of channels to be assigned)*	*London demand (number of channels being assigned)*	*Percentage difference (%)*
PBR	598	1770	-66
Wireless microphones	320	659	-51
In-ear monitoring (IEM)	267	563	-53
Talkback	113	238	-53
Camera control	44	88	-50
Wireless cameras including airborne cameras	44	52	-20
Point-to-point video links	30	14	114
Airborne downlink	2	–	–
Satellite news-gathering (SNG) uplinks	18	–	–
Fixed satellite links (between venues)	9	–	–
Radio control for props	5	–	–

It is noted that the different categories of use have different channel bandwidths – for example, PBR systems typically use a 12.5 kHz (or smaller) channel, whereas wireless cameras use 10MHz. in the table above, the number of channels refers to channels of the appropriate size for the category of system being considered i.e. it is not a total spectrum requirement in MHz.

1.4 Conclusions

In addition to the demand for spectrum identified above, from this study we also have the following observations and conclusions:

- The HB for the Glasgow Games is contracted to supply HD coverage, and domestic broadcasters (e.g. BBC Sports) are also planning for HD coverage. Therefore, in preparing a

spectrum plan for the Glasgow Games, Ofcom assumes that an all-HD wireless camera frequency plan will be required for the Glasgow Games. There are certain operational constraints that broadcasters have identified in relation to frequency planning for HD cameras, such as at locations where multiple cameras are used, a 20MHz separation between centre frequencies is preferred.

- It is noted that broadcasters (e.g. Sky) have started using 3D for sports events, and BBC Sport has informed Analysys Mason that the BBC is entering into trials of 3D (although 3D will not be used during the London 2012 Olympics and Paralympic Games). A 3D camera would typically require two 10MHz channels (involving two pictures captured from two cameras). However, it is apparent from the stakeholders interviewed for this study that there is some operational reluctance to use 20MHz carriers; therefore, we understand equipment suppliers are focused on optimising 3D use, using better encoding to fit within a 10MHz channel. This suggests that in preparing the spectrum plan for the Glasgow Games, planning of wireless camera frequencies in 10MHz channels is still appropriate.

- Until a PBR supplier is appointed by Glasgow 2014, there will be no confirmation of what form of PBR technology will be used at the Games, as a technology-neutral Invitation to Tender (ITT) is being anticipated. Our analysis suggests that some frequency re-use is possible with PBR channels in Glasgow (specifically, we have calculated that 13 sites in Glasgow can be covered using 5 unique frequencies). Our analysis assumes typical digital mobile radio (DMR) parameters, and so other PBR technologies (e.g. analogue or TETRA) will have different requirements.

- By 2014, is expected that there will be a wider adoption of digital UHF wireless microphones than is currently the case, but we do not anticipate any further developments beyond this. According to a wireless microphone equipment supplier that we have interviewed for this study, digital equipment in theory allows more microphones to be used per channel (eight per channel being a typical benchmark for analogue microphones at present). However, there is an impact on latency, robustness to interference and audio quality, and so there may be some operational resistance to this assumption being used within the Glasgow 2014 spectrum plan until such time that new technology has been operationally tested and verified.

- Various equipment manufacturers and hire companies have indicated that there is more widespread use of higher frequency wireless cameras (e.g. 7.5GHz) now that frequencies in the 2GHz range are becoming increasingly scarce. However, the Glasgow Games HB's view is that frequencies beyond 3GHz do not lend themselves as well to non-line-of-sight propagation, and additional costs are incurred in order to transition to use new frequencies (e.g. all antennas, low noise filters and transmitter RF stages need changing). The HB has also noted that higher frequencies (5–6GHz) range may be used successfully for portable wireless cameras, but for high speed operation (e.g. racing cars, helicopters) Doppler shift becomes an increasing issue as frequency increases, meaning that lower frequencies are needed.

- Suppliers have noted a particular issue in relation to the wireless camera frequencies being offered for use in the London 2012 Olympics and Paralympic Games is that some of the frequencies (e.g. 2.7–3.1GHz) are only available for the duration of the Olympic Games, and will then revert to their original use. Broadcasters and hire companies are unwilling invest in new equipment that can only be used during the Olympic Games (and require a sufficient degree of certainty that the band(s) will be available for use after the Olympics is needed in order to justify investment in the new camera, antenna, filter and converter equipment that is needed). Broadcasters and hire companies that we have spoken to as part of this study have therefore stressed the need for greater regulatory certainty regarding frequencies that will be available for wireless camera use in the UK post 2012 (noting that this is particularly for the Glasgow Games, which will take place after the 2.5–2.7GHz band is auctioned for mobile broadband use later this year).

1.5 Areas of uncertainty

We have noted the following areas of uncertainty within our analysis of spectrum demand for the Glasgow Games, which are unlikely to be clarified until organisations involved in delivering the Games have established firm plans for certain aspects of the Games delivery:

- The precise technology and frequency requirements for the Glasgow 2014 PBR system will not be known until a supplier is appointed – which is not envisaged to be confirmed until later in 2012.

- It is noted that a number of suppliers to the Games venues are yet to be appointed by Glasgow 2014, and these suppliers may have additional PBR requirements not identified so far.

- We have not been able to confirm requirements from Glasgow 2014 in relation to the opening and closing ceremonies, nor location and events associated with the culture programme (such as large screens that are expected to be located in Glasgow for public viewing of the Games). It is noted that until the content and format of the opening and closing ceremonies is identified and any suppliers have been appointed, the precise wireless requirements will not be known. For example, it is noted that previous Games have used flares that use radio frequency (RF) technology for their timing.

2 Introduction

This document is the final report of a project conducted by Analysys Mason Limited ('Analysys Mason') on behalf of the Office of Communications ('Ofcom') to examine spectrum requirements for the Glasgow 2014 Commonwealth Games ('the Games').

Specifically, Ofcom wants to understand:

- what wireless systems potential spectrum users at the Games wish to use, and in what bands
- what technologies potential users wish to deploy in 2014, and how those technologies might differ from technologies being deployed for the Olympic Games in 2012
- how much spectrum potential users would require
- what the overall spectrum demand might be for the Games, based upon inputs from potential spectrum users
- how the spectrum demand estimated for the Games compares with demand for similar events (e.g. the London 2012 Olympic and Paralympic Games and the Melbourne 2006 Commonwealth Games).

As discussed with Ofcom, our approach to estimating demand for spectrum for the Glasgow Games has involved two elements:

- interviews conducted face-to-face and by telephone with those organisations expected to have a requirement to use wireless equipment at the Games, and equipment vendors that might supply equipment for the Games (i.e. bottom-up demand estimation)
- a top-down comparison of demand for spectrum for the London 2012 Olympic and Paralympic Games, to identify potential changes (including significant variations, and areas of uncertainty) between London and Glasgow.

It is noted that the 'bottom up' approach to estimating demand does not take account of whether the stated demand can be accommodated within the available spectrum, and there may be trade-offs inherent in meeting the demand estimates of all users that will need to be taken account of when developing a detailed spectrum assignment plan for the Games.

This is the final report of the study, and describes the stakeholder input we have received to the study, and our analysis of the spectrum requirements for the Games based upon the identified requirements. The list of stakeholders that we have interviewed for the study is shown below in Figure 2.1.

Figure 2.1: Interviews completed for the study [Source: Analysys Mason, 2012]

Company	Interviewee	Role(s) envisaged for the Games
BBC Sport	Richard Morgan	BBC Sport will provide the BBC's live coverage of the Games
BBC Scotland	John Maxwell-Hobbs Susan Allman	BBC Scotland will provide BBC Scotland news coverage during the Games
Glasgow 2014	Brian Nourse	Glasgow 2014 is the organising committee for the Games and responsible for venue and event management
Prestiegne Charter	Christian Hazell	Prestiegne Charter provides professional hire of wireless audio and video equipment for programme making and outside broadcasting
Glasgow City Council	Neil Farnell	Glasgow City Council is responsible for the public facilities and services within the City of Glasgow, including the development and implementation of a city-wide cultural programme
SIS Live	Nick Buckley	SIS Live provides broadcast production and outside broadcast facilities for UK broadcasters, including the BBC
Broadcast RF	Mark Houghton	Broadcast RF provides professional hire of wireless camera and wireless video link equipment
Vislink	David Robins Mike Robinson	Vislink is a manufacturer of wireless cameras and wireless video link equipment
Sennheiser	Alan March	Sennheiser is a manufacturer of wireless microphones
Prospective host broadcaster (HB)	-	-

Structure of this report

The remainder of this report is laid out as follows:

- Section 3 describes our approach to the study
- Section 4 provides a summary of responses from potential users of the spectrum
- Section 5 summarises our bottom-up estimate of demand for spectrum for the Games, and provides a top-down comparison with spectrum estimates for the London 2012 Olympic and Paralympic Games
- Section 6 contains conclusions from the study.

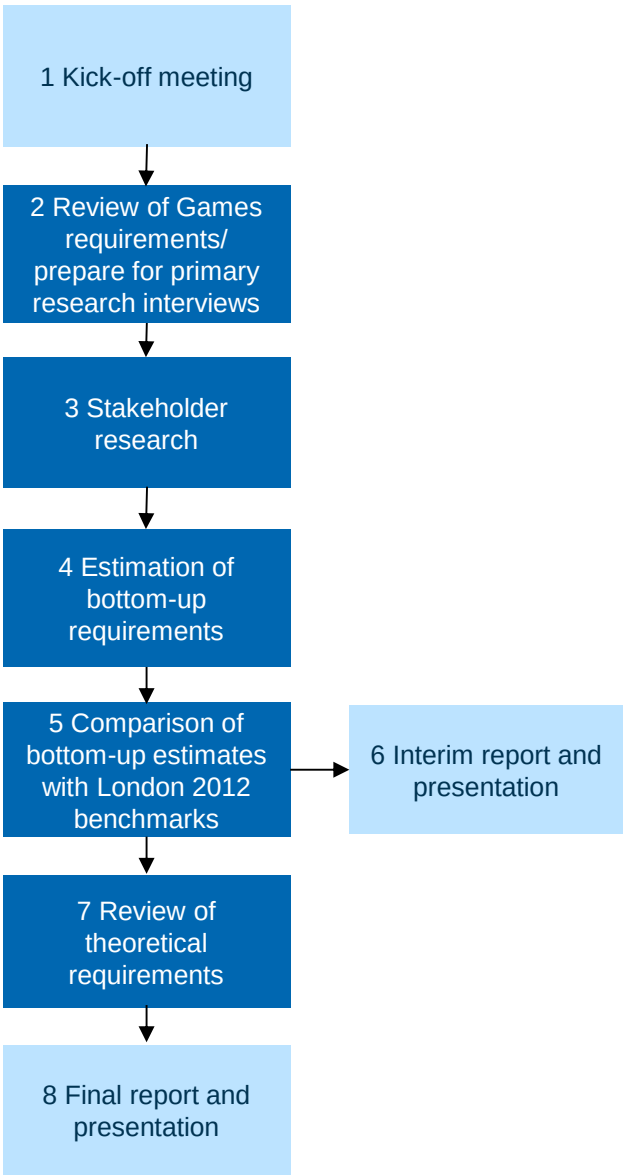
The report includes a number of annexes containing supplementary material:

- Annex A provides further detail on the methodology used to provide the bottom-up and top–down estimates
- Annex B includes our notes from the interviews carried out
- Annex C contains the link budget used to assess private business radio (PBR) theoretical frequency re-use
- Annex D lists the abbreviations used in this report.

3 Approach to the study

Our approach to the study is shown in Figure 3.1 and a brief description of each task is described in turn below (excluding meetings and presentations).

Figure 3.1: Approach to the study [Source: Analysys Mason, 2012]



3.1 Review of spectrum requirements for the Games/preparation for interviews

Ofcom had indicated in its Invitation to Tender (ITT) for this study that the spectrum requirements for the Games would likely fall into four key areas: PBR, audio links, telemetry and video links. This is based upon experience of planning spectrum requirements for the London 2012 Olympic

and Paralympic Games as well as data available from previous Commonwealth Games (specifically the Melbourne 2006 Commonwealth Games).

As part of this task we reviewed the four categories of use and sub-divided likely uses to create eight categories:

- **PBR to support voice communications over radio at Commonwealth venues**

  PBR systems normally use spectrum in a number of bands in the VHF and UHF portions of the radio spectrum. The Emergency Services also use a digital trunked PBR system for their nationwide day-to-day mobile communications, using a TETRA-based network supplied by Airwave. For the Glasgow Games, the main users of PBR are likely to be the organising committee (i.e. Glasgow 2014), Glasgow City Council and the Emergency Services.

- **Wireless microphones and in-ear monitors, for use by performers and presenters at Commonwealth venues**

  Wireless microphone systems are typically operated in spectrum interleaved with other broadcasting transmissions and as a result typically use channels within either VHF Band III (174–216MHz) or UHF (470–862MHz). Spectrum availability for radio microphones in VHF Band III has been impacted by the allocation of spectrum for digital audio broadcasting (DAB) in recent years and the majority of wireless microphone use takes place within UHF spectrum shared with digital terrestrial television (DTT) (470–790MHz). Rights holding and domestic broadcasters will require use of wireless microphones and in-ear monitors at the Glasgow Games, and performers at the opening and closing ceremonies are also expected to require wireless microphones and in-ear monitors. Glasgow 2014 will have a small requirement in order to provide 'games presentation', which relates to announcements to spectators, pre-event and half-time entertainment and announcements at Games venues.

- **Audio links**

  Temporary audio links are used at some events to transfer audio information from venues. Rights-holding and domestic broadcasters may require use of audio links during the Games.

- **Outside broadcast talkback systems**

  Talkback systems have characteristics similar to PBR and tend to use similar frequency bands to PBR systems (i.e. VHF and UHF). OB Talkback is typically licensed to operate in the following bands: 457–467MHz, 455–468MHz, 446–467MHz and 470–790MHz (sharing with analogue and digital television). Rights-holding and domestic broadcasters will require use of OB Talkback during the Games.

- **Telemetry (for OB camera control)**

  Telemetry also uses spectrum in VHF and UHF. Licensed camera control systems typically operate in VHF (e.g. 181MHz) and UHF (e.g. 462–463MHz) spectrum; however, it is also

possible to provide camera control using licence-exempt bands, such as 2.4GHz. Rights-holding and domestic broadcasters will require OB camera control during the Games.

- **Wireless cameras**

  Wireless cameras are typically used fairly widely at outside broadcast events and typically operate in spectrum between 2 and 4GHz in the UK, although higher bands such as 7.5GHz are becoming more widely used. Rights-holding and domestic broadcasters will require use of wireless cameras during the Games.

- **Temporary video links**

  Temporary video links are also used extensively at outside broadcast events and typically use spectrum between 2–20GHz. Rights-holding and domestic broadcasters may require use of temporary video links during the Games (although it is noted that point-to-point video connectivity can also be provided over fibre or satellite networks).

- **Satellite news gathering (SNG)**

  Many broadcasters make use of OB vehicles (e.g. news-gathering vans) that will include SNG equipment to uplink audio and video information from the event scene back to a studio. These links typically use the Ka-band in the UK (12–14GHz).

In addition to the categories above, it was noted during stakeholder interviews that there may be additional uses of wireless during the Games, such as timing for events and at medal ceremonies and any 'radio props' that might be used at opening or closing ceremonies. For the purposes of our demand estimation we have also distinguished between terrestrially deployed wireless cameras, and cameras deployed in helicopters (requiring an airborne downlink) in our estimates.

We prepared a series of questionnaires relating to usage requirements in each of the categories above. The questionnaires were issued to stakeholders to be interviewed as part of the study, to capture their requirements regarding wireless operations at the Games. Questions were grouped around the categories of wireless demand identified above, and considered the amount of equipment needed (per venue, per Games event or in total), timescales, frequency preferences, and any technological developments anticipated between now and 2014 that might impact requirements.

3.2 Stakeholder research

We consulted with various organisations that will be involved in delivering the Games, in order to capture their requirements for the use of wireless systems during the Games.

The list of stakeholders to be consulted for the study was developed in conjunction with Ofcom and included rights-holding and domestic broadcasters, professional OB equipment hire companies, wireless equipment vendors, Glasgow 2014 and Glasgow City Council. We identified

appropriate contacts in each organisation and arranged to hold either face-to-face or telephone interviews with each.

As part of the stakeholder research we have also attempted to gather likely usage information – for example, the likelihood of multiple international broadcasters producing individual coverage of different events (which would imply all broadcasters requiring the same amount of equipment as the HB), compared to international broadcasters taking live footage from the HB (which would suggest the HB having the greatest requirement for wireless equipment and other broadcasters having a much smaller requirement).

Summary notes from each interview were recorded within the questionnaire issued prior to the interviews.

3.3 Estimation of bottom-up requirements

The objective of this task was to estimate the demand for spectrum in each of the areas identified above. This involved scaling requirements by the number of estimated users (e.g. requirements per event per broadcaster scaled to the likely number of broadcasters producing live footage of that event).

In order to do this we initially assumed no frequency re-use will be achievable within Glasgow given the proximity of Games venues within the city centre. In other words, in our initial estimates, the pieces of equipment are equivalent to the numbers of radio channels for most categories of use (for PBR, our spectrum demand estimates are based on of the number of channels, however).

3.4 Comparison of bottom-up estimates with London 2012 benchmarks

The process of confirming frequency assignments in response to user requests for radio channels for the London 2012 Olympic and Paralympic Games had not been fully completed at the time of producing this report. However, for the purposes of comparing the estimated Glasgow demand with the London 2012 frequency plan, Ofcom has provided Analysys Mason with estimates of the numbers of frequency requests for the London 2012 Olympic and Paralympic Games. We have used this to provide a comparison with the Glasgow Games estimates, noting that it is expected that the Glasgow requirements will be somewhat less, for a number of reasons:

- there are fewer sporting events in the Glasgow Games compared to the London 2012 Olympic and Paralympic Games, and some key events requiring wireless use in the latter are not included in the Games (e.g. sailing)
- there are fewer countries involved in the Games compared to the London 2012 Olympic and Paralympic Games, and therefore media coverage is somewhat lower
- previous experience of Commonwealth Games reported to Analysys Mason by a number of stakeholders interviewed for this study suggests that fewer broadcasters produce their own live footage of Commonwealth Games, with many using pictures taken from the HB. The

estimates we have been given are that broadcasters from only four or five Commonwealth countries will produce their own footage, with the rest using the coverage provided by the HB.

3.5 Review of theoretical requirements

To finalise conclusions to Ofcom in relation to inputs to a spectrum plan for the Glasgow Games, the final task was to conduct a theoretical estimate of the potential for certain frequency re-use to be employed. This was undertaken using a radio planning tool to assess theoretical frequency re-use for digital mobile radio (DMR) based PBR systems.

4 Summary of responses from the stakeholders interviewed

This section provides a summary of responses from potential users of spectrum during the Games. It is structured as follows:

- Section 4.1 describes proposed services to be delivered during the Glasgow Games requiring use of radio spectrum
- Section 4.2 describes technologies to be deployed
- Section 4.3 describes spectrum requirements to deliver the identified services
- Section 4.4 includes other comments raised by stakeholders.

4.1 Proposed services to be delivered during the Games

A summary of services that are proposed or envisaged during the Glasgow Games that will require radio frequencies for their operation is provided below.

PMR/PBR

The main users of PBR during the Games will be the Games organisers (Glasgow 2014) and Glasgow City Council. Glasgow 2014 is likely to require use of handheld PBR radios within each of the Games venues, for a variety of purposes including management of ticketing, events management, maintenance, security, catering and other organisational functions. Some vehicle mounted radios may be required within vehicles used to transport visiting teams and dignitaries between venues. Therefore, the Glasgow 2014 requirement will typically be for PBR within venues, and a city-wide network across Glasgow is not envisaged.

By comparison, Glasgow City Council is expected to require wide-area PBR for communications in relation to various Council-managed services, such as transport, public information, roads management, security and resilience. The Council already operates a joint control room with the Emergency Services and makes use of Airwave radios for resilience purposes. The Council owns a number of Airwave radios and there is a dedicated talk-group for their use.

Glasgow City Council also uses an MPT1327 trunked radio system at present, which is a TaitNet system, operating across its main sites in Glasgow.[1] This system is estimated to have spare capacity that can be used at major events and so it is not expected that further spectrum will be required for temporary expansion of this network during the Games.

The HB, BBC Sport and other broadcasters may also have a small requirement for PBR use within venues. BBC Sport has indicated that it typically uses licence-exempt PBR for this purpose (e.g. PMR446). The HB indicated that they would only have a minimal requirement for PBR use within

[1] The TaitNet system operates in frequencies at 440MHz, with 15W power (base stations).

Games venues, but that systems to be used would be based upon what is available in the UK market (e.g. via UK hire companies).

We also note that the technical characteristics of the Glasgow 2014 PBR requirement will not be known until a contract has been placed with a PBR supplier for provision of services during the Games. It is possible that the PBR services that Glasgow 2014 requires could be achieved through a trunked PBR system or alternatively from a series of handheld radios.

The Queen's Baton Relay will also be managed using PBR radios. As the relay route is expected to cover most of Scotland, frequencies for this will be required on a Scotland-wide basis. In addition, it is likely that there will be a small PBR requirement to support 'sports presentation', which refers to presentations and announcements made to spectators before and during events (including half-time entertainment).

As noted above, it is expected that the HB and BBC Sport will have a small requirement for PMR use around the Games venues. In the absence of a precise number of handheld radios required per venue or per location, we have made an assumption within our demand estimates in Section 5 that the HB will require four PMRs per Games venue, plus an additional four radios for use across Glasgow for road events such as the marathon and cycling.

Wireless cameras

Most broadcasters use wireless cameras as part of live sports events, which are either touchline cameras, handheld or vehicle mounted. Typical sports that would attract use of wireless cameras include those where there is a lot of movement and/or where the use of wires is infeasible (e.g. in a swimming pool area). The following sporting events may attract use of wireless cameras by broadcasters in the Games, in particular:

- aquatics
- athletics
- cycling
- gymnastics
- hockey
- netball
- rugby sevens
- road races, such as marathon.

As well as terrestrial wireless cameras, some broadcasters use aerial shots of sports events obtained from using cameras within a helicopter. Arial shots would typically be used to provide coverage of road races such as marathons.

It is possible that wireless cameras used at different locations can re-use the same frequency channel. The number of concurrent wireless camera channels needed in the spectrum plan for the Games will depend on the distance over which the channels can be re-used (which varies

depending on which frequency is used). Time-dependent factors are also relevant, such as the competition timetable.

The largest requirement for wireless camera use is envisaged to be from the HB. The information we have been able to collect for this study suggests that the HB may envisaging using the following wireless cameras, per event:

- between 8 and 12 wireless cameras at opening and closing ceremonies, and at athletics, cycling track and open race events (e.g. cycling, marathon, mountain biking)
- between 3 and 4 wireless cameras at other events.

We have noted that it is likely that, subject to the sports schedule, it may be possible to use the same wireless camera equipment for different events (for example, the same equipment used at opening and closing ceremonies can be used at athletics events, and at open race events, providing that the open race and the athletics events are not held at the same time). Based on this, we have estimated that the HB may have a total wireless camera requirement of 36 units, excluding airborne units (which are described further below).

Broadcasters and equipment suppliers we have contacted for this study confirmed that the peak requirement for wireless camera use will be at the opening and closing ceremonies and the athletics stadium, and the remainder of the cameras will mostly be required to cover open race events such as marathons, road and mountain biking.

As the domestic rights holder, BBC Sport has identified a somewhat lesser requirement than that of the likely HB, estimating a need for three wireless cameras: one to be used at the opening and closing ceremonies; one at athletics events; and one 'roving' camera for road races and other events.

It is also expected that the HB will require aerial shots of road races, which will require use of a video camera in a helicopter and the associated video downlinks. Discussion with the HB for this study identified that they expected to deploy two helicopters per event and that there would be one downlink per helicopter.

BBC Sport has indicated to Analysys Mason that, fort the Glasgow Games, it would not expect to deploy aerial cameras and will use the images received from the HB. We have made a similar assumption concerning other domestic and international broadcasters.

Audio links

Most broadcasters use various forms of wireless audio equipment for sporting events, including wireless microphones, in-ear monitors and talkback systems. Typically, every crew using a wireless camera will also require a talkback channel, plus a number of wireless microphones and in-ear monitors.

BBC Sport estimated it will require two wireless microphones and one talkback channel per wireless camera, with additional wireless microphones, talkback channels and in-ear monitors for

studio use for presentations, for opening and closing ceremonies and for 'roving' film crews. In addition, BBC Sport indicated that BBC Radio will probably require use of wireless microphones (and typically use higher power, 1 Watt versions) and temporary point-to-point audio links at the opening and closing ceremonies, and for athletics events.

Broadcasters and equipment suppliers have indicated that the HB will have a significant requirement for talkback and in-ear monitor use, and a more modest requirement for wireless microphones. For the HB we have assumed the following audio requirements:

- two wireless microphones per wireless camera
- four in-ear monitor channels per studio, three per indoor event and three for outside events
- three talkback channels per venue
- one camera control channel per wireless camera.

Camera control and telemetry

Camera control refers to the data links used to control video cameras (both wired and wireless). Wireless camera control is typically required per wireless camera using either UHF radio or, alternatively, various licence-exempt links can be used (e.g. via Bluetooth or Wi-Fi using 2.4GHz frequencies).

BBC Sport estimates that it would typically require one camera control channel per wireless camera, and we have assumed that the HB, and other broadcasters using wireless cameras, will have a similar requirement.

Point-to-point video links

It is assumed that each of the venues used for the Games will be linked by fibre to the international broadcast centre (IBC) located at the Scottish Exhibition and Conference Centre (SECC). This will reduce the number of point-to-point wireless links needed to transport video and data information between venues. Notwithstanding this, there will be a possible requirement for point-to-point wireless links to be used as back-up links between venues and the SECC (i.e. for resilience). In addition, BBC Sport has indicated that temporary point-to-point video links are often used at satellite-news gathering sites (see below).

Broadcasters and equipment suppliers have pointed out that point-to point-video requirements will be dependent upon confirmation of the availability of suitable fibre connection at each venue. Broadcasters would only envisage using point-to-point video links where a suitable fibre connection is not available. However, they may use portable (i.e. temporary) links at open race events (e.g. marathon, road and mountain biking).

Satellite-news gathering

The UK's major news broadcasters typically implement electronic news gathering (ENG) central receive sites in major cities across the UK, which are used for capture of live footage to support news and current affairs programming. These systems are typically designed to cover the main news locations, typically using a 1W camera back transmitter operating at 2GHz (or another wireless camera frequency), along with either satellite uplinks or temporary point-to-point links.

BBC Sport was not able to identify specific locations that it would expect to use SNG during the Games but indicated that it is common practice for SNG trucks to be supported by temporary point-to-point links, for resilience and/or to provide additional bandwidth.

We have assumed the HB will use one SMG truck during the Games that will be moved around according to the sports schedule, to provide resilience as a back-up to the main fibre (or microwave) links connecting each venue. The SNG truck will therefore be used at opening and closing ceremonies and could also be used during the Games at any other venue according to the sports schedule.

One venue in particular (the shooting event, at Barry Buddon Shooting Centre) was questioned during the study in relation to whether a fibre connection is available.

Licence-exempt radio

In addition to the services above, the following requirements have been noted as typically using licence-exempt frequencies:

- Timing and medal ceremonies at events tend to use some form of wireless link. Based on experience from the previous two Commonwealth Games, in certain (but not all) situations, timing and medal ceremonies at events tend to use some form of wireless connectivity and this has been licence-exempt frequencies in those countries. Exact requirements for the Glasgow 2014 Games would be subject to further planning once the relevant partners are appointed. We understand that the timing service for London 2012 is being accommodated within licensed UHF frequencies
- Glasgow 2014 will potentially deploy Wi-Fi hotspots within the Games venues and within the Athletes village, for wireless data connectivity.
- Depending on the format of the opening and closing ceremonies, props might be envisaged (e.g. flares) that use some form of wireless control, which would typically be provided using a short-range device (SRD) or other licence-exempt radio.

4.2 Technologies to be deployed

We have discussed technology requirements with stakeholders with a view to determining any significant changes likely to occur between now and 2014 that will impact the types of technology used at the Games.

A summary of our findings is as follows:

- For the London 2012 Olympic and Paralympic Games we understand that a mix of standard definition (SD) and high definition (HD) wireless cameras will be used by different broadcasters. By 2014, it is expected that all broadcasters will be using HD. At present, HD cameras typically use an 8MHz carrier (DVB-T, MPEG-2/MPEG-4 type camera), or 10MHz (e.g. Vislink's LMS-T type camera). By 2014, it is expected that other forms of modulation and coding may be employed (e.g. DVB-T2 with MPEG-4, DVB-S2 or the newer form of LMS-T). These will typically use the same channel widths as are currently employed (i.e. 8MHz or 10MHz), although the new LMS-T cameras will support variable bandwidths, from 3MHz to 12MHz. There is also the possibility of 20MHz versions, and the so-called 'super HD' or 1080-P (progressive scan) HD would require 20MHz carriers. However, it is not clear whether demand will exist for super HD (and some stakeholders have indicated that broadcasters are reluctant to use technologies requiring 20MHz carriers due to the additional cost of having to acquire double the number of RF channels than would be required for 10MHz bandwidth systems).

- We understand that the HB for the Glasgow Games is contracted to supply HD coverage, and therefore we have assumed that all broadcasting provided by the HB for the Glasgow Games will be in HD. The HB has indicated that all of their broadcast usage uses 16 QAM modulation, all-HD systems using 10MHz LMS-T wireless cameras.

- Broadcasters such as Sky have started using 3D for sports events, and BBC Sport has informed Analysys Mason that the BBC is entering into trials of 3D (although 3D will not be used during the London 2012 Olympics and Paralympic Games). A 3D camera would typically require two 10MHz channels (involving two pictures captured from two cameras). As noted above, it is apparent that there is some reluctance to use 20MHz carriers; therefore, we understand equipment suppliers are focused on optimising 3D use using better encoding to fit within a 10MHz channel.

- The HB has indicated that although RF cameras can operate as DVB-T 8MHz, LMS-T 10MHz and LMS-T 20MHz, their preferred modulation scheme for HD events is LMS-T 10MHz. In addition, and at locations where multiple cameras are used, they prefer to have at least 20MHz between centre frequencies so that a camera near a receive antenna does not overpower another camera operating further away[2]. Closer spacing is possible, but requires additional channel filters to isolate the cameras and as such, the receive infrastructure needs to be multiplied by the number of cameras (i.e. additional antennas, filters and converters are required per camera).

- There is no clear indication of what form of PBR technology will be used at the Games until such time as a PBR supplier is appointed. Glasgow 2014 will issue an ITT for suitable suppliers; however, this will be technology-neutral and so suppliers will be expected to propose whichever technology best suits the requirements.

[2] This is a limitation of low noise block down converted signals using common receive antennae

- We understand that there is some research being developed within Europe on 'cognitive wireless microphones', which would use similar adaptive technology to that being considered in the context of cognitive radio. However, this will take a number of years to develop. The wireless microphone industry has traditionally been slow to adopt new technology and the majority of wireless equipment in use today is still analogue, although it is expected that there will be a slightly wider adoption of digital UHF wireless microphones by 2014. According to a wireless microphone equipment supplier that we have interviewed for this study, digital equipment in theory allows more microphones to be used per channel (compared to eight per channel, which is typical benchmark at present for analogue microphones). However, there is an impact on latency, robustness to interference and audio quality and therefore likely to be some reluctance from wireless microphone users to move towards increased frequency re-use until new digital systems have been fully tested and operational experience has been gained.

- Wireless cameras predominantly use spectrum in the 2–2.7GHz range. Various equipment manufacturers and hire companies have indicated that there is more widespread use of 7.5GHz wireless cameras now that frequencies in the 2GHz range are becoming increasingly scarce. Whilst wireless cameras can be developed to work in various bands between 2 and 7GHz, equipment is typically only produced to cover bands that are commonly available.

- Broadcasters and equipment suppliers of wireless cameras are of the view that frequencies beyond 3GHz do not lend themselves as well to non-line of sight propagation, and additional costs are incurred in order to transition to use new frequencies (e.g. all antennas, low noise filters and transmitter RF stages need changing). Higher frequencies (5–6GHz) range may be used successfully for portable wireless cameras, but for high speed operation (e.g. racing cars, helicopters) Doppler shift becomes an increasing issue as frequency increases. Typically at 2.5GHz speeds, radial velocities of 250km/h can be tolerated whilst at 5GHz wireless cameras could only tolerate about 125km/h, which has operational implications

- Suppliers have noted that a particular issue that has arisen with the wireless camera frequencies being offered for use in the London 2012 Olympics and Paralympic Games is that some of the frequencies (e.g. 2.7–3.1GHz) are only being made available for the duration of the Olympic Games, and will then revert to their original use. Since broadcasters and hire companies are unwilling invest in new equipment that can only be used during the Olympic Games (and a sufficient degree of certainty that the band(s) will be available for use after the Olympics is needed in order to justify investment in the new camera, antenna, filter and converter equipment that is needed), users are therefore unwilling to accept the temporary assignments being offered for the London Games. Broadcasters and hire companies that we have spoken to as part of this study have therefore stressed the need for greater regulatory certainty regarding frequencies that will be available for wireless camera use for future major events (particularly for the Glasgow Games, which will take place after the 2.5–2.7GHz band is auctioned for mobile broadband use).

4.3 Spectrum requirements to deliver these services

We have identified the following frequency bands that stakeholders have indicated will be required for the Games use for the various categories of wireless use defined in the previous section.

These are broadly similar to bands currently in use for PMSE and for PMR/PBR currently in the UK. A key issue noted from the below is that there will be insufficient frequencies available in the UK below 2.7GHz for wireless cameras by 2014, as a result of the anticipated auction of the 2500–2690MHz band in the UK.

Stakeholders interviewed for the study have indicated various operational constraints from using frequencies above 3GHz, as noted above (i.e. they cannot be used for high speed operation).

This suggests that a key issue for Ofcom to consider ahead of the Glasgow 2014 Games is to identify possible alternative frequencies for wireless camera use, in order to meet likely demand for channels in bands below 3GHz.

Figure 4.1: Demand forecasts for the Games by frequency [Source: Analysys Mason, 2012]

Type of use	*Potentially suitable frequency bands*
PBR	VHF (115–230MHz) and UHF (400–470MHz)
Wireless microphones and in-ear monitors	VHF Band III and UHF (470–790MHz)
Talkback	UHF (440–470MHz) and Channel 21 (470–478MHz)
Wireless cameras	2–2.7GHz, 3.4–3.6GHz, 7.5GHz
Point-to-point video links	5–7.5GHz
Licence-exempt	Channel 38 (wireless microphones), 446MHz (PMR), Wi-Fi (2.4GHz)

4.4 Other comments

We noted the following additional requirements identified by stakeholders:

- Various stakeholders commented that a monitoring scheme is required to ensure that frequencies and equipment used during the Games is in compliance with licence conditions. Various stakeholders commented that the monitoring arrangements being put in place for the London 2012 Olympics and Paralympic Games should be replicated in Glasgow. Also, Glasgow 2014 stated that a 'testing and tagging' scheme was employed during the Melbourne 2006 Commonwealth Games, which worked well.

- Wireless cameras equipment manufacturers commented on the need for greater certainty regarding future availability of frequencies for wireless cameras, as broadcasters and hire companies will only invest in new equipment if there is certainty that the frequency band will be available over a longer period than just that of the Games.

- The pre- and post-period of events associated with the Games is anticipated to be less than for the London 2012 Olympics and Paralympic Games. Most stakeholders stated that frequency

assignments would be needed up to one month before the Games commence in order to complete equipment set-up and testing. The Glasgow 2014 PMR system may need to be in place ahead of this (e.g. between three and six months beforehand). The Queen's Baton Relay is expected to run for a period of up to three months.

- Wireless microphone equipment manufacturers also commented on the need for greater certainty regarding frequency availability in light of the proposed award of 800MHz frequencies for 4G mobile. They also mentioned the potential loss of spectrum in the 700MHz band in future based upon the provisional agreement at the 2012 World Radiocommunication Conference (WRC-12) regarding a mobile allocation in that band (which may come into force from 2015).

5 Estimation of spectrum demand for the Games

This section summarises our bottom-up estimate of spectrum demand for the Games, and provides a top-down comparison with spectrum estimates for the London 2012 Olympic and Paralympic Games. It is structured as follows:

- Section 5.1 summarises of demand by user
- Section 5.2 summarises overall demand
- Section 5.3 compares the Glasgow Games' demand with estimated demand numbers obtained from Ofcom for the London 2012 Olympic Games
- Section 5.4 explores the re-use of frequencies
- Section 5.5 identifies areas of uncertainty and where further analysis may be required in the remainder of this study.

5.1 Summary of demand by user

Based upon the interviews conducted to date, we have estimated the following requirements per category of user at the Glasgow Games.

Figure 5.1: Requirements – HB [Source: Analysys Mason, 2012]

Category of use	*Number of channels*
PBR	64
Wireless microphones	68
In-ear monitors	76
Talkback	57
Camera control	34
Wireless cameras	34 (includes five airborne cameras)
Point-to-point video links[3]	15
Airborne downlink	1
SNG uplinks	5
Fixed satellite links (between venues)	6
Radio control for props	0
Timing/medal ceremony	0

[3] It includes redundant links between venues provided via wireless (as back-up to fibre links between all venues), plus an additional five temporary point-to-point links used at locations around Glasgow alongside SNG trucks.

Figure 5.2: Requirements – BBC Sport [Source: Analysys Mason, 2012]

Category of use	Number of channels
PBR	10
Wireless microphones	44
In-ear monitors	9
Talkback	16
Camera control	3
Wireless cameras	3
Point-to-point video links	8
Airborne downlink	0
SNG uplinks	5
Fixed satellite links (between venues)	2
Radio control for props	0
Timing/medal ceremony	0

Figure 5.3: Requirements – Glasgow 2014 [Source: Analysys Mason, 2012]

Category of use	Number of channels
PBR	509
Wireless microphones[4]	134
In-ear monitors[5]	168
Talkback	16
Camera control	0
Wireless cameras	0
Point-to-point video links	0
Airborne downlink	0
SNG uplink	0
Fixed satellite links (between venues)	0
Radio control for props	5
Timing/medal ceremony	Assumed to use licence-exempt spectrum and so no dedicated assignments necessary

4 This is an estimate of wireless microphone requirements which includes requirements for sports presentation as well as requirements for the opening and closing ceremonies – as the ceremonies have not been defined as yet, this number is unconfirmed.

5 As noted above, this is an estimated number pending confirmation of the requirements for the opening and closing ceremonies.

Figure 5.4: Requirements – Glasgow City Council [Source: Analysys Mason, 2012]

Category of use	*Number of channels*
PBR	Will use existing TaitNet system (440MHz), and will also use existing Airwave radios and talk-groups
Wireless microphones	May be required for opening and closing ceremonies but not defined yet
In-ear monitors	May be required for opening and closing ceremonies but not defined yet
Talkback	0
Camera control	0
Wireless cameras	0
Point-to-point video links	May be required for connectivity at locations for the public viewing screens, but not confirmed yet
Airborne downlink	0
SNG uplink	0
Fixed satellite links (between venues)	0
Radio control for props	May be required for opening and closing ceremonies but not defined yet
Timing/medal ceremony	0

5.2 Summary of overall demand

We have scaled the requirements identified above to provide a total demand across the Games. This is based upon the categories of demand identified above, scaled upwards to account for a further three international broadcasters potentially having an active presence at the Games. We have assumed these three broadcasters will have requirements that are slightly less than those of BBC Sport. The resulting demand estimate is summarised below in Figure 5.5.

As noted previously, the 'bottom up' approach to estimating does not take account of whether the stated demand can be accommodated within the available spectrum, and there may be trade-offs inherent in meeting the demand estimates of all users that will need to be taken account of when developing a detailed spectrum assignment plan for the Games.

Figure 5.5: Overall spectrum demand estimate for the Games [Source: Analysys Mason, 2012]

Category	*Glasgow Games' demand (number of channels)*
PBR	598
Wireless microphones	312
In-ear monitors	267
Talkback	113
Camera control	42
Wireless cameras including airborne cameras	42
Point-to-point video links	35
Airborne downlink	1
SNG uplinks	18
Fixed satellite links (between venues)	11
Radio control for props	5
Timing/medal ceremony	Assumed by Glasgow 2014 to use licence exempt spectrum and so no individual channel assignments necessary

5.3 Comparison with spectrum demand for London 2012 Olympic Games

To provide a top-down comparison with the Glasgow Games requirements, Ofcom provided Analysys Mason with information concerning adjusted demand (based upon frequency requests) for the London 2012 Olympic Games. This has been used to identify differences between the estimated Glasgow Games requirements and those for London 2012 (see Figure 5.6 below). It is noted that we would expect the Glasgow Games demand to be smaller than London 2012, because there are less sporting events in the Commonwealth Games than the Olympics, and less international broadcasters with a presence at the Glasgow Games. This is largely borne out by the comparison below – with the exception of the point to point video links category.

The reason for this difference for the Glasgow Games demand is we have assumed a proportion of Games venues in Glasgow will have point to point wireless links deployed as a back-up to fibre links. We have also assumed that wireless links will be used to support ENG trucks, and have assumed that both the HB and BBC Sport will use those in and around the Glasgow area.

Figure 5.6: Comparison of spectrum demand with London 2012 [Source: Analysys Mason, 2012]

Category	Glasgow demand	London demand	Percentage difference (%)
PBR	598	1770	-66
Wireless microphones	320	659	-51
In-ear monitoring (IEM)	267	563	-53
Talkback	113	238	-53
Camera control	44	88	-50
Wireless cameras including airborne cameras	44	52	-20
Point to point video links	30	14	114
Airborne downlink	2	–	–
SNG uplinks	18	–	–
Fixed satellite links (between venues)	9	–	–
Radio control for props	5	–	–

5.4 Frequency re-use

It should be noted that throughout this report where demand is quoted, it is in terms of numbers of systems/units, excluding frequency re-use. However, it is noted that some frequency re-use might be possible for certain categories of wireless use.

In relation to wireless cameras, one stakeholder interviewed for the study indicated that, with 100mW wireless cameras in closed stadium environments, no more than a 2km re-use distance can be assumed (although we note that a considerably smaller re-use distance is being used for the London 2012 Games). Therefore, it is possible that some of the wireless camera use identified above can re-use the same frequencies at different locations. However, in practice we have assumed that the HB may re-deploy equipment at different venues (e.g. equipment that is used at athletics events is also used for open road races, subject to the sports schedule confirming these events do not overlap). The flexibility to be able to do this therefore requires individual frequencies to be assigned to each camera. This is important if different pieces of equipment assigned to the same channel are to be used in closer proximity than the planned re-use distance.

Therefore, for the purposes of this study we have not included frequency re-use within the calculation of channel demand for wireless cameras, but note that in preparing the detailed spectrum plan for the Glasgow Games, it may be possible for certain wireless camera frequencies to be re-used.

For PBR, we have undertaken a theoretical assessment using a radio planning tool[6] to determine a practical re-use distance. For this, we have analysed propagation paths between 13 of the Glasgow Games venues that are located within central Glasgow, as follows.

Figure 5.7: Latitude and longitude for Glasgow city-based Games venues [Source: Analysys Mason, 2012]

Venue	Latitude	Longitude
Strathclyde Country Park	55.7975	-4.023056
Cathkin Braes Country Park	55.798605	-4.232141
Hampden Park	55.825864	-4.252003
Glasgow Green (Hockey Centre)	55.844301	-4.235015
National Indoor Sports Arena/Sir Chris Hoy Velodrome	55.847222	-4.208042
Barry Buddon Shooting Centre	55.847879	-4.205264
Tollcross Aquatics Centre	55.848307	-4.17724
Celtic Park	55.849722	-4.205556
Ibrox Stadium	55.853206	-4.309256
Scottish National Arena	55.860297	-4.284926
Scottish Exhibition and Conference Centre	55.860849	-4.28812
Kelvingrove Lawn Bowls Centre	55.867666	-4.289163
Scotstoun Leisure Centre Precinct	55.881137	-4.34181

An illustration of the location of the Glasgow venues on a site and clutter map (referring to a representation of the local environment) generated in the radio planning tool is provided in Figure 5.8 below.

Using the planning tool, we have predicted coverage from each site assuming a 10 metre base station height, a base station effective isotropic radiated power (EIPR) of 1W and other link budget parameters in accordance with those listed in Annex C. This resulted in the coverage map in Figure 5.9 being predicted.

From this initial analysis, we optimised frequency assignment using the automatic frequency planning feature for PBR in the radio planning tool. The 'wanted' coverage shown in Figure 5.10 was achieved by removing 'overspill' coverage to provide the following illustration of coverage at 500m radius from each venue.[7]

6 We have used the ATDI ICS Telecom radio planning tool, version 10.5, which is the planning tool used in-house by Analysys Mason

7 Coverage within 500m radius of each venue is assumed to be acceptable since Glasgow 2014 have indicated that PBR systems are envisaged to be used only within venues, and not between venues

Figure 5.8: Site and clutter map showing Glasgow Games venues [Source: ATDI, Analysys Mason, 2012]

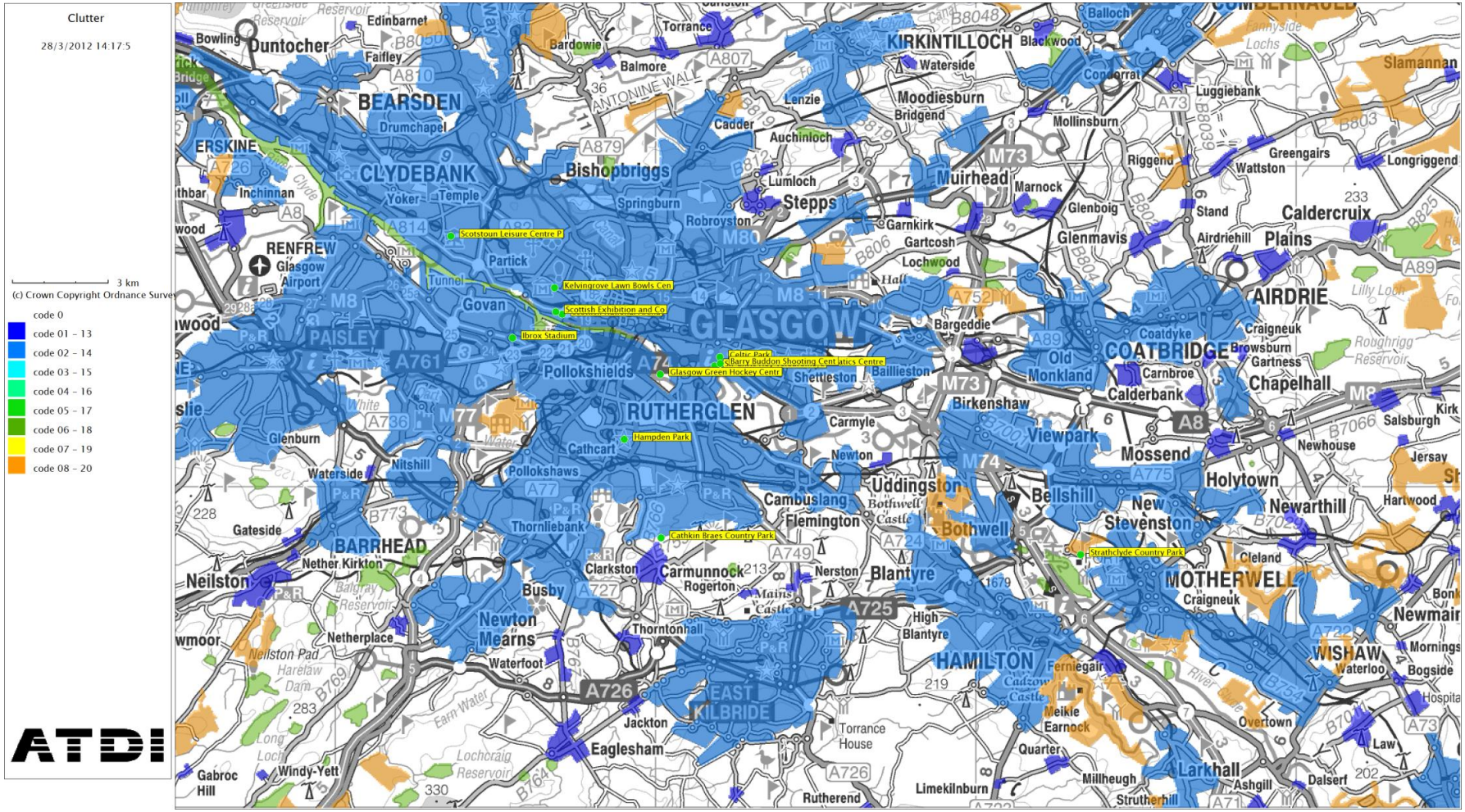


Figure 5.9: Predicted PBR coverage from selected Glasgow Games venues [Source: ATDI, Analysys Mason, 2012]

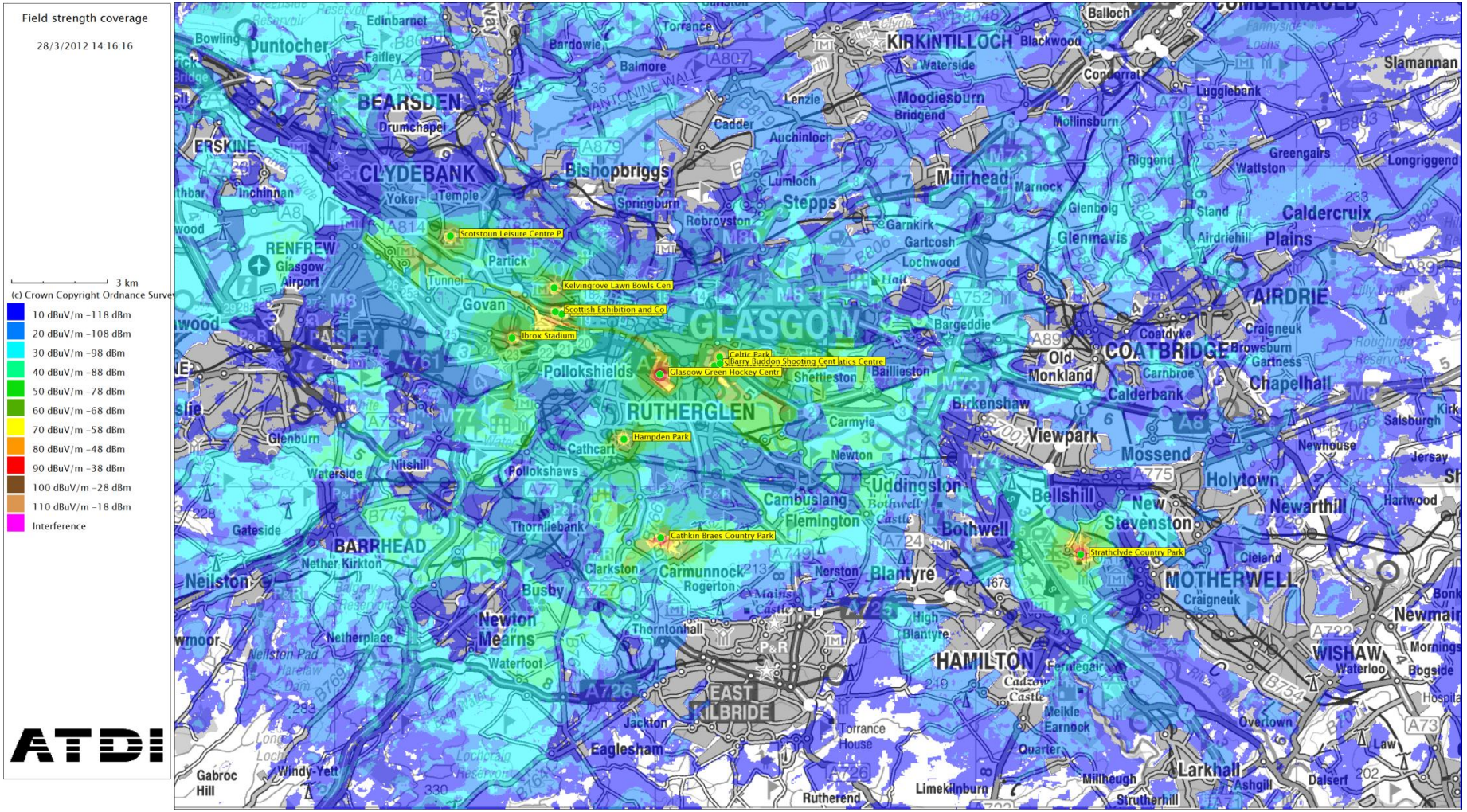
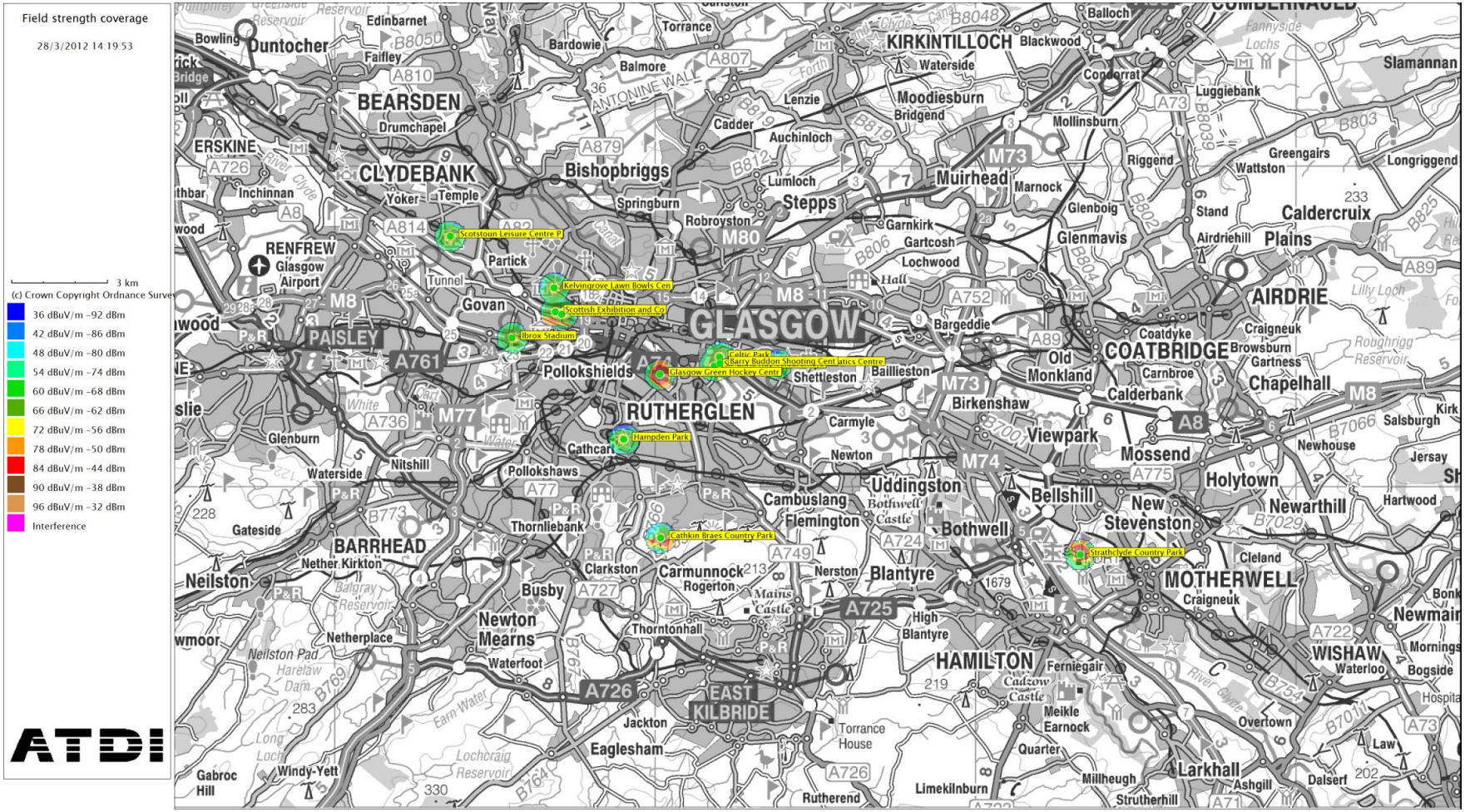


Figure 5.10: Wanted PBR coverage [Source: ATDI, Analysys Mason, 2012]



From an initial channel list of 12 frequencies for the 13 sites, we then used the planning tool to check for interference within the desired area of coverage, and then we were able to reduce the number of channels until unacceptable interference occurred (providing a lower limit of the number of frequencies required).[8]

A summary of the output of the analysis is provided below, confirming that for the 13 sites analysed, five unique frequencies are required to avoid co-channel interference (our analysis did not consider adjacent channel interference). It is noted however that additional frequencies may be required for capacity reasons – particularly if analogue PBR rather than digital mobile radio (DMR) is used.

Figure 5.11: Frequencies required for 13-site PBR for Glasgow Games [Source: Analysys Mason, 2012]

Site	Frequency
Tollcross Aquatics Centre	1
Scottish Exhibition and Conference Centre	1
Celtic Park	2
Cathkin Braes Country Park	2
Glasgow Green Hockey Centre	2
National Indoor Sports Arena/Sir Chris Hoy Velodrome	3
Scottish National Arena	3
Ibrox Stadium	3
Kelvingrove Lawn Bowls Centre	4
Barry Buddon Shooting Centre	4
Hampden Park	5
Scotstoun Leisure Centre	5
Strathclyde Country Park	5

Based on this analysis it can be concluded that the maximum PBR frequency requirements indicated in this report can be reduced slightly once frequency re-use is accounted for. Given that the PBR requirements are estimated at this stage, and will need to be verified once a supplier is selected, we have not attempted within this report to scale the total estimated requirement to account for the frequency re-use that we have estimated is possible. However, we note for Ofcom's information that once precise PBR requirements are identified, assignment of channels to a PBR system can use frequency re-use between selected sites, based upon our analysis. Therefore, the PBR requirement identified in this report can be considered to be a worst-case requirement.

5.5 Areas of uncertainty

We have noted the following areas of uncertainty within our analysis of spectrum demand for the Glasgow Games, which are unlikely to be clarified until organisations involved in delivering the Games have established firm plans for certain aspects of the Games delivery:

[8] The threshold used was that 2% of the wanted coverage area should have signal levels that give a protection ratio of less than 19dB

- The precise technology and frequency requirements for the Glasgow 2014 PMR system will not be known until a supplier is appointed – which is not envisaged to be confirmed until later in 2012.

- A catering supplier is also to be appointed by Glasgow 2014 for the Games venues, and this supplier may have additional PMR requirements not identified so far.

- We have not been able to confirm from Glasgow 2014 requirements in relation to the opening and closing ceremonies, nor location and events associated with the culture programme (such as large screens that are expected to be located in Glasgow for public viewing of the Games). It is noted that until the theme of the opening and closing ceremonies is identified and any suppliers have been appointed, the precise wireless requirements will not be known

6 Conclusions from the study

6.1 Conclusions arising from our estimation of spectrum demand

Our demand estimates suggest that spectrum requirements for Glasgow 2014 are typically lower than those for the London 2012 Olympic Games, for most categories of use, as noted below. This is mainly due to the smaller number of individual sports that take place within the Commonwealth Games compared to the Olympic Games, and the reduction in the number of participating countries involved, which has an impact upon the number of broadcasters that will provide live footage of the Games.

At previous Commonwealth Games, we understand that a national broadcasting presence is typical from broadcasters based in Canada, South Africa, Australia, New Zealand and the UK. Thus, our estimates assume that up to five broadcasters will be present at the Glasgow Games although the HB will have significantly higher requirements than either BBC Sports (the domestic rights holder in the UK) or other international broadcasters.

It is noted that for the Manchester Commonwealth Games in 2003, the BBC was appointed as both the HB and domestic rights holder. For Glasgow, the BBC is the domestic rights holder, but is not the HB and a separate broadcaster has been appointed as the HB. Therefore, spectrum requirements between Manchester and Glasgow will not be comparable, as for the Glasgow Games, at least two broadcasters (i.e. the HB and BBC Sports) will have a significant presence.

Other domestic and international broadcasters are expected to have a somewhat lower requirement for wireless equipment than the HB and the BBC, as they will predominantly use footage produced by the HB.

Figure 6.1: Summary of spectrum demand estimate for the Games [Source: Analysys Mason, 2012]

Category	Glasgow demand	London demand	Percentage difference (%)
PBR	598	1770	-66
Wireless microphones	320	659	-51
IEM	267	563	-53
Talkback	113	238	-53
Camera control	44	88	-50
Wireless cameras including airborne cameras	44	52	-20
Point-to-point video links	30	14	114
Airborne downlink	2	–	–
Satellite news-gathering (SNG) uplinks	18	–	–
Fixed satellite links (between venues)	9	–	–
Radio control for props	5	–	–

It is noted that the one area of demand that our estimates suggest may be greater for Glasgow than for London, is point-to-point video links. This is largely due to uncertainty regarding the availability of fibre connections at each of the venues for the Glasgow Games, and our assumption that, even with fibre being available, point-to-point links may be deployed in some cases as a back-up link. Once the availability of fibre to each venue is confirmed, it is expected that the requirement for point-to-point links can be more firmly defined, and is likely to reduce compared to our estimates.

It is also noted that point-to-point links may be used to connect certain venues for the London 2012 Olympics, but may not have been included in the London demand estimates that Ofcom has provided to Analysys Mason for the study. This is because the London demand estimates provided to Analysys Mason only provide the additional, Olympic-specific licensing requirements, whereas it is possible that additional annual point-to-point link licences have been assigned within standard microwave bands by Ofcom's fixed link licensing teams for use at Olympic venues.

6.2 Conclusions relating to frequency re-use

It should be noted that our conclusions in relation to demand for spectrum for the Glasgow 2014 Games present a worst-case estimate of the channel requirement, as frequency re-use is not accounted for.

In relation to wireless cameras, one stakeholder interviewed for the study indicated that, with 100mW wireless cameras in closed stadium environments, no more than a 2km re-use distance can be assumed (although we note that a considerably smaller re-use distance is being used for the London 2012 Games). We expect it is theoretically possible that some of the wireless camera use identified above can re-use the same frequencies at different locations. However, in practice, as we have assumed that the HB may re-deploy equipment at different venues (e.g. equipment that is used at athletics events is also used for open road races, subject to the sports schedule confirming these events do not overlap), it may be necessary for individual equipment to have uniquely assigned channels, to avoid a clash if equipment assigned to the same channel re-used at different venues with closer proximity than the planned re-use distance.

Therefore, for the purposes of this study we have not included frequency re-use within the calculation of channel demand for wireless cameras, but note that when Ofcom is preparing the detailed spectrum plan for the Glasgow Games, it may be possible for certain wireless camera frequencies to be re-used.

In relation to PBR, we have used a planning tool to estimate theoretical frequency re-use distances. Based on our analysis, we have concluded that the maximum PBR frequency requirements indicated in this report can be reduced slightly once frequency re-use is accounted for. In particular, our analysis suggests that the 13 sites within the Glasgow city area can be covered with 5 unique PBR frequencies.

6.3 Conclusions arising in relation to spectrum planning for Glasgow 2014

In relation to spectrum planning for Glasgow 2014, we have noted the following points in order to finalise a spectrum plan for the Glasgow Games:

- We understand that the HB for the Glasgow Games is contracted to supply HD coverage, and therefore we have assumed that all broadcasting provided by the HB for the Glasgow Games will be in HD. The prospective HB has indicated that all of their broadcast usage uses 16 QAM modulation, all-HD systems using 10MHz LMS-T wireless cameras. It is therefore recommended that Ofcom assume that an all-HD wireless camera frequency plan will be required for the Glasgow Games

- The HB has indicated that although RF cameras can operate as DVB-T 8MHz, LMS-T 10MHz and LMS-T 20MHz, their preferred modulation scheme for HD events is LMS-T 10MHz. In addition, and at locations where multiple cameras are used, they prefer to have at least 20MHz between centre frequencies so that a camera near a receive antenna does not overpower another camera operating further away[9]. Closer spacing is possible, but requires additional channel filters to isolate the cameras and as such, the receive infrastructure needs to be multiplied by the number of cameras (i.e. additional antennas, filters and converters are required per camera)

- With regards to other wireless camera technology developments, it is noted that broadcasters such as Sky have started using 3D for sports events, and BBC Sport has informed Analysys Mason that the BBC is entering into trials of 3D (although 3D will not be used during the London 2012 Olympics and Paralympic Games). A 3D camera would typically require two 10MHz channels (involving two pictures captured from two cameras). However, it is apparent from the stakeholders interviewed for this study that there is some operational reluctance to use 20MHz carriers; therefore, we understand equipment suppliers are focused on optimising 3D use using better encoding to fit within a 10MHz channel

- It is noted that, at present, there is no clear indication of what form of PBR technology will be used at the Games until such time as a PBR supplier is appointed. Glasgow 2014 will issue an ITT for suitable suppliers; however, this will be technology-neutral and so suppliers will be expected to propose whichever technology best suits the requirements.

- With regards to wireless microphones, we understand that there is some research being developed within Europe on 'cognitive wireless microphones', which would use similar adaptive technology to that being considered in the context of cognitive radio. However, this will take some years to develop. By 2014, is expected that there will be a slightly increased adoption of digital UHF wireless microphones than is currently the case, but we do not anticipate widespread use. According to a wireless microphone equipment supplier that we have interviewed for this study, digital equipment in theory allows more microphones to be used per channel (compared to the eight per channel that is a typical benchmark for current

[9] This is a limitation of low noise block down converted signals using common receive antennae

deployment of analogue wireless microphones at present). However, there is an impact on latency, robustness to interference and audio quality, and so there may be some operational resistance to increasing the re-use assumptions used with any future spectrum plans until new technology has been operationally tested and verified

- Wireless cameras predominantly use spectrum in the 2–2.7GHz range. Various equipment manufacturers and hire companies have indicated that there is more widespread use of 7.5GHz wireless cameras now that frequencies in the 2GHz range are becoming increasingly scarce. However, broadcasters and suppliers of wireless camera equipment are of the view that frequencies beyond 3GHz do not lend themselves as well to non-line of sight propagation, and additional costs are incurred in order to transition to use new frequencies (e.g. all antennas, low noise filters and transmitter RF stages need changing). The HB has also noted that higher frequencies (5–6GHz) range may be used successfully for portable wireless cameras, but for high speed operation (e.g. racing cars, helicopters) Doppler shift becomes an increasing issue as frequency increases, meaning that lower frequencies are needed

- Suppliers have noted a particular issue in relation to the wireless camera frequencies being offered for use in the London 2012 Olympics and Paralympic Games is that some of the frequencies (e.g. 2.7–3.1GHz) are only available for the duration of the Olympic Games, and will then revert to their original use. Broadcasters and hire companies are unwilling invest in new equipment that can only be used during the Olympic Games (and require a sufficient degree of certainty that the band(s) will be available for use after the Olympics is needed in order to justify investment in the new camera, antenna, filter and converter equipment that is needed). Broadcasters and hire companies that we have spoken to as part of this study have therefore stressed the need for greater regulatory certainty regarding frequencies that will be available for wireless camera use in the UK post 2012 (noting that this is particularly for the Glasgow Games, which will take place after the 2.5–2.7GHz band is auctioned for mobile broadband use later this year).

6.4 Other observations

From the stakeholder interviews conducted for the study, we also note that:

- Various stakeholders have commented that a monitoring scheme is required to ensure that frequencies and equipment used during the Games is in compliance with licence conditions. Various stakeholders commented that the monitoring arrangements being put in place for the London 2012 Olympics and Paralympic Games should be replicated in Glasgow. Also, Glasgow 2014 stated that a ‘testing and tagging’ scheme was employed during the Melbourne 2006 Commonwealth Games, which worked well.

- Wireless cameras equipment manufacturers have commented on the need for greater certainty regarding future availability of frequencies for wireless cameras, as broadcasters and hire companies will only invest in new equipment if there is certainty that the frequency band will be available over a longer period than just that of the Games.

- The pre- and post-period of events associated with the Games is anticipated to be less than for the London 2012 Olympics and Paralympic Games. Most stakeholders stated that frequency assignments would be needed up to one month before the Games commence in order to complete equipment set-up and testing. The Glasgow 2014 PMR system may need to be in place ahead of this (e.g. between three and six months beforehand). The Queen's Baton Relay is expected to run for a period of up to three months.

- Wireless microphone equipment manufacturers have commented on the need for greater certainty regarding frequency availability in light of the proposed award of 800MHz frequencies for 4G mobile. They also mentioned the potential loss of spectrum in the 700MHz band in future based upon the provisional agreement at the 2012 World Radiocommunication Conference (WRC-12) regarding a mobile allocation in that band (which may come into force from 2015).

Annex A Demand estimation

A.1 Categories of demand

As additional categories of spectrum demand became apparent through the course of our interview programme, we have revised the categories of demand to include the following list:

- PBR/PMR
- audio links
  - wireless microphones
  - in-ear monitoring
  - talkback
  - camera control and telemetry
- wireless cameras
  - terrestrial cameras
  - aerial linked cameras
- temporary video links
- SNG uplink
- fixed satellite uplink/downlink
- props (e.g. flares or other props used in the opening or closing ceremonies that might be controlled by wireless devices).

A number of stakeholders have also identified use of various licence-exempt technologies at the Games such as GPS for location tracking of equipment and vehicles, Wi-Fi for wireless data connectivity within the Games venues, and various technologies such as Wi-Fi or Bluetooth that can be used to perform certain functions such as camera control.

A.2 Demand by user

A.2.1 Glasgow City Council

At this stage, the only requirement that we have been able to gather from the Council relates to resilient communications. For this, the following requirements were identified:

- The Council has a resilient extranet (part of a national network) that provides communications between Council buildings and externally.
- The joint Agency control room in Helen Street is connected to Hamden and other key venues by fibre and by wireless communication through Airwave.

- The Council have a MPT1327 trunked radio, 'TaitNet', system (the frequencies that this system uses have not been confirmed but we have requested this information from the Council). The Council's estimate is that this system has around 40–50% spare capacity that can be utilised at larger events such as the Glasgow Games.

- The Council's resilience officers have Airwave radios, with their own Airwave talk group. There is also scope to borrow Airwave radios from neighbouring Council areas, which use the same talk group. Initial estimates are that the Airwave network will have sufficient capacity within its current configuration within Glasgow to accommodate the additional usage that the Games will create, without requiring further spectrum.

- The Council also commented that in other large sporting events hosted in Glasgow (e.g. Glasgow half marathon), Glasgow Life (who organise the running events) make use of the radio amateur's network, Raynet.

A.2.2 Glasgow 2014

Requirements for the Commonwealth Games Organising Committee have been identified under the following sub-categories for the categories of demand described above in A.1.

Operational

Only PMR requirements were identified for the operational functioning of the Organising Committee. Glasgow 2014 identified that PMR communications would be self-contained at venues, with the exception of the road events, where wider area coverage may be required. Our estimate provides for 15 frequency channels for large venues, 12 channels for medium-sized venues and 8 channels for small venues, including the IBC and Athletes Village. We assumed that outdoor events would require 20 channels, slightly more than for a large venue, reflecting increased complexity. Inter-venue communications will use wired solutions or mobile telephony.

Timekeeping, synchronisation and results

Timekeeping, synchronisation and results services will be provided by a contractor to Glasgow 2014 which has yet to be chosen. At this stage, provision for one PMR channel for this use per venue, with a further channel for outdoor events are the only requirements we have included. Other requirements are expected to use unlicensed spectrum unless changes in working practices arise before 2014.

Other suppliers

The only PMR requirements were identified for a single supplier. It is possible Glasgow 2014 might appoint multiple suppliers that will have different requirements. One PMR channel was assumed per Games site as sufficient for this function.

Security

The requirements for PMR for the Games security were estimated at between 50% and 100% of the operational requirements by Glasgow 2014. For the interim estimate we have taken a worst-case scenario of 100% of the operational requirements. No other category of use was identified as relevant to security.

Fleet

Glasgow 2014 expects to provide cars but will make use of mobile telephony to communicate with these staff. Some use of PMR was expected for other Games transport, such as buses for athletes. We have estimated that a single PMR channel per Games site would be required. No further requirements were identified.

Queen's Baton Relay

The domestic leg of the Queen's Baton Relay is expected to have a PMR requirement. We have estimated that 50 handsets/users might be expected for this, which could be served by 15 channels, equivalent to the number of PMR channels required for a large venue in the Games. However, as the Queen's Baton Relay will potential cover the whole of the nation (of Scotland), then frequencies would need to be available nationally across Scotland.

Press conferences

A requirement for wireless microphones was identified by Glasgow 2014 for press conferences at each of the Games venues and key sites. We have assumed that two wireless microphones would be sufficient for these purposes at each site.

Opening and closing ceremonies

Requirements for wireless microphones and in-ear monitoring were identified for the opening and closing ceremony. These requirements will not be confirmed until after a ceremonies contractor has been appointed and has begun its planning. We have used benchmark figures from the London 2012 frequency requests to estimate the number of each type of equipment required for the Games.

Data provided by Ofcom show that 88 frequency requests below 400MHz being received; we assumed that these requests were for in-ear monitoring only. Also, 256 frequency requests were received between 502–862MHz; we assumed that these were intended for wireless microphones and in-ear monitors in equal proportions. These figures are not final numbers of requests or final allocations, but they do provide a benchmark value in the absence of more detailed information ahead of the appointment of a contractor.

Sports presentation

The following requirements have been estimated by Analysys Mason for sports presentation and the medal ceremonies:

- one PMR channel per venue and a further channel for outdoor events
- two wireless microphones per venue and a further two microphones for outdoor events
- one in-ear monitoring channel per venue and a further channel for outdoor events
- one talkback channel per venue and a further channel for outdoor events.

A.2.3 Broadcasters

A.2.4 HB

For the Commonwealth Games it is typically the case that an HB is appointed, which will provide the main live TV coverage that other Commonwealth country broadcasters will transmit in their own countries. A domestic rights holder is also appointed, referring to the national broadcaster in the country where the Games are being hosted.

For the Manchester Commonwealth Games in 2003, the BBC was appointed as both HB and domestic rights holder. For Glasgow, the BBC is the domestic rights holder, but is not the HB; the HB is yet to be confirmed by Glasgow 2014.

Therefore, for the Glasgow Games, it can be expected that the broadcasting equipment requirements will be greater than for the Manchester Games, as at least two broadcasters (i.e. HB and the BBC) will be present and providing extensive coverage of Games events. Other domestic and international broadcasters are expected to have a somewhat lower requirement for wireless equipment than the HB and the BBC, as they will predominantly use footage produced by the HB.

At previous Commonwealth Games we understand that a national broadcasting presence is typical from a broadcaster based in each of Canada, South Africa, Australia, New Zealand and the UK. Thus, it is assumed that our estimates should provide for up to five broadcasters being present at the Glasgow Games. The host broadcaster's requirements have been estimated as described below, based upon interviews with various stakeholders during this study. In addition, BBC Sport's requirements as domestic rights holder are estimated based on our interview with the BBC.

Estimates for a further three broadcasters were based on the following factors, assuming a smaller presence than BBC Sport:

- rights holding broadcaster #1: 75% of BBC Sport's requirements
- rights holding broadcaster #2: 75% of BBC Sport's requirements
- rights holding broadcaster #3: 75% of BBC Sport's requirements.

It was assumed that aerial uplinks/downlinks and helicopter cameras would be required only by the host broadcaster. The BBC stated that if the host broadcaster's provision of footage is sufficient it would not look to supplement footage by deploying an additional helicopter.

A.2.5 Host broadcaster's requirements

The host broadcaster's requirements for each category of use were estimated as follows:

- **PBR/PMR** – We estimated that four PMR channels would be required by the host broadcaster per venue for its own logistical and operational requirements, with four further channels for outdoor events.

- **Wireless microphones** – We assumed that only wireless cameras had associated wireless microphones, and wired cameras used wired options. We also assumed that two wireless microphones would be required per wireless camera. Hence, the number of wireless microphones required is twice the number of wireless cameras estimated below.

- **In-ear monitoring** – We assumed that four in-ear monitors would be required for the host broadcaster at each venue or Games site, sufficient for two presenters and two further guests on-screen simultaneously in a studio or venue environment. This is a generous estimate and we would therefore expect actual requirements to be less at many venues.

- **Talkback** – One outside broadcast supplier estimated that three talkback channels are typically required per venue or Games site. We used this estimate multiplied by the number of Games sites with a further three channels for outdoor events.

- **Camera control and telemetry** – On the assumption that a wireless camera will require wireless camera control wherever it is deployed alongside other cameras to ensure continuity of picture quality we assumed that each wireless camera deployed would require camera control. We assumed that wired cameras could be controlled through a wired option. Where wireless cameras are deployed for ENG/SNG we assumed that camera control was not required. No separate requirement for telemetry was identified.

- **Wireless cameras** – We believe that up to 36 wireless cameras will be required across all venues, with a further two aerial-mounted (e.g. helicopter) wireless cameras for outdoor events. This assumes re-use of equipment between events, which will be dependent upon the sports schedule. For example we assume that the same equipment used at opening and closing ceremonies can be used for athletics events. The HB requirement as provided to Analysys Mason was: between 8 and 12 wireless cameras for opening and closing ceremonies, and for athletics, road and mountain biking and marathon events, and between 3 and 4 cameras at other events. In addition, two helicopters will be used per event, with one video downlink per helicopter

- **Temporary video links** – We assumed that 50% of Games sites would require a fixed point-to-point microwave link for resilience against the failure of fibre links, and hence calculated

that the host broadcaster would require ten temporary fixed video links. A single helicopter downlink was added to account for relaying wireless camera footage from outdoor events and for aerial footage.

- **SNG uplink** – Provision for five SNG-type uplinks from OB trucks was included for the HB and BBC Sport, in line with an estimate for the number expected by BBC Sport (which said up to ten trucks might be used).

- **Fixed satellite uplink/downlink** – We assumed that a fixed satellite uplink would be required for redundancy at 25% of venues for the host broadcaster. We also assumed that a further uplink/downlink site would be required to receive these links and for distribution purposes.

- **Props** – No requirement for RF-controlled props was identified for the host broadcaster.

A.2.6 Domestic rights holder's requirements

BBC Sport's requirements were estimated as follows, based on discussions about its provisional requirements. BBC Sport will look more closely at requirements for the Glasgow Games after London 2012:

- **PBR/PMR** – BBC Sport estimated requirements of ten handsets at the two main stadiums for athletics and the opening and closing ceremonies (Hampden Park and Celtic Park), and a further ten handsets in the Pacific Quay area. As a worst-case scenario, we assumed three users per channel, giving a total requirement of ten channels.

- **Wireless microphones** – BBC Sport estimated the following requirements:
  - two wireless microphones per wireless camera
  - two wireless microphones for each of ten roving non-wireless cameras
  - six wireless microphones for the studio used for presentations
  - six wireless microphones each for Hampden Park and Celtic Park.

- **In-ear monitoring** – BBC Sport estimated the following requirements:
  - six channels of in-ear monitoring each for Hampden Park and Celtic Park
  - four channels for the studio used for presentations.

- **Talkback** – BBC Sport estimated the following requirements:
  - one talkback channel per wireless camera
  - four talkback channels for the studio
  - two talkback channels each for Hampden Park and Celtic Park.

- **Camera control and telemetry** – BBC Sport estimated the requirement of one camera control channel per wireless camera.

- **Wireless cameras** – BBC Sport expected to prepare fixed receivers at all venues and to use only three wireless cameras in total in and around venues.

- **Temporary video links** – Requirements are small, mainly for resilience/redundancy between key locations such as the studio, IBC and other presentation space to Pacific Quay. In addition, up to ten temporary links between roving cameras and OB trucks may be expected at venues. We have assumed that five will be used as a typical scenario.

- **SNG uplink** – A worst-case scenario of ten satellite uplinks would be required if fibre was unavailable and for resilience. These would be re-used between venues.

- **Fixed satellite uplink/downlink** – Two further fixed uplinks would be required for resilience from the two stadiums for athletics and the opening/closing ceremonies.

- **Props** – No requirements identified.

A.2.7 Business-as-usual requirements

In addition, business-as-usual requirements for national broadcasters have been identified. These refer to the annual wireless licences that the UK broadcasters hold covering Glasgow/Scotland, which they will potentially expect to use during the Games.

In this case, BBC Scotland's studio and external requirements have been collected and a scaling factor applied to account for similar operations by other national broadcasters such as STV, Sky and Channel 4, in Glasgow. The following factors have been applied for our interim estimates to derive requirements from BBC Scotland's requirements:

- STV: 50% of BBC Scotland's requirements
- Sky: 50% of BBC Scotland's requirements
- SITN/Channel 4: 50% of BBC Scotland's requirements.

A.2.8 BBC Scotland's requirements

BBC Scotland's business-as-usual requirements were identified as follows for each category of use:

- **PBR/PMR** – The BBC identified minimal usage for PMR for business-as-usual. We estimated that two channels would be required.
- **Audio links and wireless cameras** – Our estimate is based on the number of licences held by the BBC for use at its Pacific Quay studios for wireless microphones, in-ear monitoring, talkback, camera control and telemetry. In addition, we have provided for two wireless microphones, two channels for in-ear monitoring and two talkback channels each for an ENG/SNG crew and documentary crew in line with the number of crews that BBC Scotland indicated would be typical. We further accounted for a wireless camera for the ENG/SNG crew.
- **Temporary video links** – The BBC does not currently expect to make use of fixed microwave links in the Glasgow area.

- **SNG uplink** – In 2014 BBC Scotland will own seven SNG trucks, with more available from other divisions of the BBC. We have included a requirement for seven SNG uplinks, although we would not expect the BBC to simultaneously deploy all seven in Glasgow during the Games.
- **Fixed satellite uplink/downlink** – The BBC uses satellite uplinks and downlinks at its Pacific Quay studio to receive SNG data and for distribution and resilience purposes. We have therefore accounted for this single fixed site for satellite links.
- **Props** – No requirement for RF-controlled props was identified by BBC Scotland.

A.3 Demand by category for the Games

The above requirements for Glasgow City Council, the Glasgow 2014 Organising Committee and for broadcasters are summarised below in Figure A.1.

Figure A.1: Interim estimate of spectrum requirements for the Games [Source: Analysys Mason, 2012]

Category	Glasgow City Council	Glasgow 2014	Broadcasters	Total
PBR/PMR	0	509	89	598
Wireless microphones	0	134	186	320
In-ear monitoring	0	168	99	267
Talkback	0	16	97	113
Camera control and telemetry	0	0	44	44
Wireless cameras	0	0	44	44
Point-to-point video links	0	0	30	30
Airborne downlink	0	0	2	2
SNG uplink	0	0	18	18
Fixed satellite links	0	0	9	9
Props	0	5	0	5

Note: The PBR/PMR and the audio links categories estimate the number of channels required. In the remaining categories, we have estimated the number of pieces of equipment and assumed one channel per piece of equipment; i.e. this interim estimate does not take account of temporal or geographical sharing.

The estimates above exclude business-as-usual requirements, which are summarised in Figure A.2. Our business-as-usual estimates are based upon scaling the number of licences held by BBC Scotland to other national broadcasters, as described above.

Figure A.2: Estimated business-as-usual frequency requirements during the Games [Source: Analysys Mason, 2012]

Category	Glasgow City Council	Broadcasters	Total
PBR	–[10]	5	5
Wireless microphones	–	152	152

[10] TaitNet system uses 440MHz channels but the number of channels has not been confirmed. In addition, GCC use Airwave radios for resilient communications.

IEM	–	106	106
Talkback	–	32	32
Camera control	–	–	–
Wireless cameras	–	5	5
Temporary video links	–	–	–
SNG uplinks	–	16	16
Fixed satellite links	–	2	2

A.4 Comparison with spectrum demand for London 2012

Figure A.3 compares interim estimated additional demand for the Glasgow Games against adjusted demand figures for the London 2012 Olympic and Paralympic Games provided by Ofcom. These figures represent adjusted numbers of frequency requests at a particular moment in time but do not represent the final numbers of requests or allocations made. Nonetheless, these figures can be used for a sense-check of our estimates. Some categories have been aggregated or removed in order to provide a like with like comparison. However, the data provided by Ofcom was not categorised as per our schema, hence we have had to breakdown the allocations using our own estimates.

Figure A.3: Comparison of estimated requirements for the Games and estimated requirements for London 2012 [Source: Analysys Mason, 2012]

Category	*Glasgow demand*	*London demand*	*Percentage difference (%)*
PBR	598	1770	–66
Wireless microphones	320	659	–51
IEM	267	563	–53
Talkback	113	238	–53
Camera control	44	88	–50
Wireless cameras including airborne cameras	44	52	–20
Point to point video links	30	14	114
Airborne downlink	2	–	–
SNG uplinks	18	–	–
Fixed satellite links (between venues)	9	–	–
Radio control for props	5	–	–

Annex B Link budget used for frequency re-use analysis

The following link budget has been developed as being typically used for a hand-held voice PBR system.

	Source	Unit	Value	
			BS	**UE**
urban	*Typical Values*	m	40	1.5
Frequency		MHz	140	
			Value	
BS Transmit Power (Balanced)	*Typical Values*	dBm	25.8	
BS Ant Gain	*Typical Values*	dBi	3.0	
BS Feeder Loss	*Typical Values*	dB	2.0	
BS EIRP		dBm	26.8	
HH Useable Threshold	*BS Noise Calculation*	dBm	-112.1	
Downlink Path Loss		dB	138.9	
			Value	
HH Transmit Power	*Typical Values*	dBm	30.0	
HH Antenna Gain	*Typical Values*	dBi	-3.0	
HH EIRP	*Typical Values*	dBm	27.0	
BS Useable Threshold	*HH Noise Calculation*	dBm	-111.9	
Uplink Path Loss		dB	138.9	
			urban	
Combined lognormal and Rayleigh distribution				
% of Locations	*Typical Values*		90.00	
SD Log-normal Fading (150MHz Urban)	Saunders, 2007, p196	dB	6.0	
Fade Margin	ITU-R P.1057-2 Figure 3	dB	15.0	
HH Useable Threshold	*HH Noise Calculation*	dBuV/m	5.00	
HH Planning Threshold		dBuV/m	20.0	

Annex C Abbreviations used in this report

Abbreviation	*Meaning*
dB	Decibel
DMR	Digital mobile radio
ENG	Electronic news gathering
HB	Host Broadcaster
HD	High definition
IEM	In-ear monitoring
ITT	Invitation to tender
OB	Outside broadcast
PBR	Private business radio
PMR	Private mobile radio
RF	Radio frequency
SD	Standard Definition
SNG	Satellite news gathering
SRD	Short-range device
TV	Television
UHF	Ultra high frequency
VHF	Very high frequency