Report for Ofcom

Use of wired vs. wireless technologies

Spectrum planning for the London 2012 Olympic and Paralympic Games

Final report

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Contents

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1 Glossary

BOB	Beijing Olympic Broadcaster
BOC	Broadcast Operations Centre
BVT	Broadcast Venue Team
COFDM	Coded Orthogonal Frequency-Division Multiplexing
DAB	Digital Audio Broadcasting
DVB-T	Digital Video Broadcasting – Terrestrial
EHF	Extra High Frequency
ENG	Electronic News Gathering
FEC	Forward Error Correction
FOP	Field of Play – the area and its extensions on which a sports discipline takes place
HB	Host Broadcaster
HD	High Definition
HD-SDI	High Definition - Serial Digital Interface (SMPTE 292M)
IBC	International Broadcast Centre. The facility where the host broadcaster receives the ITVR signals from the venues and distributes them to the RHBs, who send their programmes around the world.
IF	Intermediate Frequency
IFB	Interruptible Feedback
ITVR	International Television and Radio signals
Mixed zone	Designated interview area within a sports venue where athletes are required to pass through. Facilitates contact between the media and the athletes.
MPEG	Moving Pictures Expert Group
MRC	Maximum Ratio Combining
NBC	The American rights holding broadcaster for the Olympic Games
NHK	The Japanese rights holding broadcaster for the Olympic Games
OB	Outside broadcast. Refers to any television or radio programme that is broadcast from a location away from the normal studio setting.
OBS	Olympic Broadcasting Services
ODA	Olympic Delivery Authority
PBR	Personal Business Radio
PMSE	Programme Making and Special Events
POV	Point of View (type of camera)
QAM	Quadrature amplitude modulation
RAU	Remote Antenna Unit
RF	Radio frequency
RHB	Rights Holding Broadcaster
ROFMOD	RF on Fibre Mobile Data Network Demonstrator - a BAE Systems project
SD-SDI	Standard Definition - Serial Digital Interface (SMPTE 259M)
TOC	Technology Operations Centre
VHF	Very High Frequency

2 Executive summary

2.1 Introduction

2.1.1 This report has been prepared by Analysys Mason Limited (Analysys Mason) on behalf of the Office of Communications (Ofcom), and provides the report of a study into the potential to use wired technology where the host organising committee and broadcast operations for the Olympic and Paralympic Games typically use wireless technology at present.

2.1.2 The study is one input into Ofcom's spectrum planning work for the London 2012 Olympic and Paralympic Games. Ofcom wishes to explore the potential to use wired technologies to reduce the demand for wireless applications, and therefore reduce the requirement for spectrum for the duration of the Games and test events prior to the Games.

2.1.3 We identified alternative wired or hybrid wired-wireless technologies and developed deployment scenarios for these technologies that could replace some of the wireless requirements. We assessed the scenarios in terms of technical feasibility, advantages and disadvantages of deployment, costs and legacy benefits.

2.1.4 The main focus of the study is on wireless cameras used by the broadcasters because this is the application with potentially the largest spectrum demand, and whose use has almost doubled since the Athens Games in 2004. The study also covered private business radio (PBR), wireless microphones, wireless talkback systems and IFB circuits (in-ear monitors).

2.2 We do not believe a reduction of the key wireless broadcasting applications from usage levels seen in Beijing is a viable option

2.2.1 The use of wireless cameras has become widespread over the past few years as the related technologies improve, and broadcasters now regard wireless cameras as an indispensible element of many live sports and ENG productions, to capture the 'money shots'. There are two main sources of demand for broadcasting wireless applications for which Ofcom must provide spectrum under guarantees the Government made to the IOC:

i. The Host Broadcaster (HB) – multilateral sport coverage from venues
ii. Rights Holding Broadcasters (RHBs) – unilateral sport coverage from venues.

2.2.2 Demand for spectrum will also come from RHBs for Electronic News Gathering (ENG) in and around venues and key locations of interest in the city.

2.2.3 Wireless cameras are universally perceived within the broadcast industry to add significant value to the depth of the production, and make for exciting and engaging footage. At the same time the sports governing bodies often favour the use of wireless cameras over cabled cameras near the field of play, for the safety of the athletes that populate these areas.

2.2.4 To scale back the wireless camera levels from the previous Games would be viewed by broadcasters as a significant setback, particularly given the vast worldwide audiences and the ever-increasing range of devices and on-demand services through which the live footage can be viewed. Some in the industry believed that wireless camera use at the Beijing 2008 Olympic Games would be restricted by the host broadcaster to similar levels as those seen in Athens. However, there were nearly twice as many wireless cameras used at the competition venues.

2.2.5 At Beijing we believe that between 105 and 110 wireless cameras were used by the host broadcaster across the sports disciplines[1]. Only a proportion of these wireless cameras would be in use on any single competition day. If the level of use at Beijing is taken as the base case for London, and mapped onto the provisional timetable and proposed venue geography, we estimate up to 65 concurrent channels of at least 10 MHz would be needed to support this level of use, in addition to the RHB sports requirement of approximately 10 concurrent channels and the RHB ENG use around the city.

2.2.6 When looking for examples of non-essential use of wireless cameras, we found that some current uses do not especially demand wireless technology, but if they are used for the competition then they will certainly be used for the non-competition formalities.

2.2.7 We found some opportunity for providing underground ducts and wired access points to enable the use of wired instead of wireless cameras. This solution addresses the safety concerns caused by trailing cables on the field of play, but the mobility that the majority of the wireless cameras need would still be restricted. The opportunity to reduce the number of wireless cameras in this way is not certain without knowing the detailed venue plans, camera positions and, in the case of the temporary venues outside the Olympic Park, the ability to gain permission for civil engineering works.

2.2.8 We found that broadcasters, and certainly the host broadcaster, are to an extent united with Ofcom in their goal of limiting wireless camera use because of the additional costs, reduced reliability, and increased complexity they can introduce. In general for the sports coverage, the host broadcaster discourages the RHBs from using wireless cameras, particularly when the key rights holders have access to each and every camera chain from the host broadcast operation.

[1] Source: Broadcast venue teams, broadcasters, suppliers. This takes into account sharing of equipment between disciplines that take place in the same venue. Equipment is rarely moved between venues.

2.3 Certain wired technology options can reduce the number of channels needed to support the broadcasters' requirements, or enable a move to less-congested channels

2.3.1 We have explored the use of fixed receive points for wireless cameras in conjunction with fibre transmission ('hybrid wired-wireless solutions'), either within a venue, or over a wider area. These solutions are already well established in sports and ENG broadcasts in the 2 to 3 GHz bands, and if applied to certain outdoor venues can help improve frequency reuse potential, and therefore reduce the number of concurrent channels needed for wireless cameras.

2.3.2 Hybrid wired-wireless solutions using the 7 GHz band have been undergoing live tests by one camera supplier, with onboard cameras travelling at speeds of up to 200 mph. If these tests continue to go well, a move to less-congested channels, such as those in the 7 GHz band, could become viable for some applications. This would present significant benefits to spectrum planners and broadcasters alike. The reduced interference, and the potential for wider bandwidths that would facilitate optimum quality high definition (HD) live broadcasting, make the higher frequencies an attractive option, but the key drawback is the extensive investment needed by broadcasters, and the companies that supply them, to replace their current equipment.

2.3.3 Ofcom asked us to rule nothing out when exploring alternative wired solutions. The more radical options we considered involved the use of the 60 GHz band in conjunction with optical fibre transmission technology. The Olympic Games would represent a high stakes test of this technology, and the timescales to progress these technologies to a sufficient level by 2010, the date identified by LOCOG and the host broadcaster for a technology cut-off, are extremely challenging.

2.3.4 We found that an application of 60 GHz technology was used successfully with a fixed-trajectory camera at the Torino Winter Olympics in 2006, but we concluded that there is no obvious application for the system at the Summer Olympics that would directly replace any of the current wireless systems.

2.3.5 It is technically more challenging to develop a roving, completely mobile, camera solution for use at 60 GHz; research and development is in progress, and systems have been tested in a controlled studio environment. If a practical and cost-effective system were developed, it would represent a major breakthrough for live HD broadcasting.

2.3.6 We believe that Ofcom should remain open-minded about these solutions and encourage the development of 60 GHz technologies for broadcasting applications. We believe an investment of around £2 million over the next 18 months, and the formation of key industry partnerships, is necessary for these systems to remain in contention for use at London 2012.

2.3.7 We believe that the development of 60 GHz technologies is relevant to broadcasters across the world, since congestion in the bands currently used by wireless cameras is not a UK-only problem. If 60 GHz wireless camera systems can be proven to work effectively, and the broadcasters have the means to adopt the technology, then we believe that these solutions can remain relevant to the TV production for major sports and other events beyond London 2012.

2.4 Maximum spectrum savings will be realised by focusing on wireless camera use at the wide area sports events and the Olympic Park

2.4.1 We found that wireless cameras were used at 24 of the 40 sports disciplines in Beijing, plus the opening and closing ceremonies. Around 67% of the RF camera systems in Beijing were used for the wide-area sports that typically use a helicopter or other aerial mid-point to receive the signals from the cameras and relay them to a fixed receive point on the ground. It is these wide-area disciplines that drive the overall channel requirement for wireless cameras because large numbers of cameras are used, pairs of frequencies are required (camera to airborne unit; airborne unit to receive point), and signals are transmitted over long distances, so the frequency reuse potential on the ground is limited for these channels.

2.4.2 The Olympic Park will have a high concentration of wireless camera use. There are five venues within close proximity that will use wireless cameras in the base case. High levels of ENG use around the Olympic Park will add to the pressure on wireless camera channels in this zone.

2.5 Implementation of proven alternative technology options could result in a channel saving of 35% on the wireless camera base case

2.5.1 We have identified three deployment options of varying technical feasibility for alternatives to the wireless camera base case that would reduce the overall channel requirement in licensed bands:

	Deployment option	*Technical feasibility by 2010*
1	Replacement of wireless cameras with wired wherever possible	HIGH
2	In-venue hybrid wired-wireless solutions	
a	Roving cameras using 2 to 7 GHz	HIGH
b	Roving cameras using EHF, e.g. 60 GHz	LOW
c	Fixed trajectory cameras using EHF, e.g. 60 GHz	MEDIUM
3	City-wide cellular receive system	HIGH

Figure 2.1: Summary of deployment options

2.5.2 We have estimated the channel saving that could be realised through each option, and the cumulative result in relation to technical feasibility is illustrated in Figure 2.2.

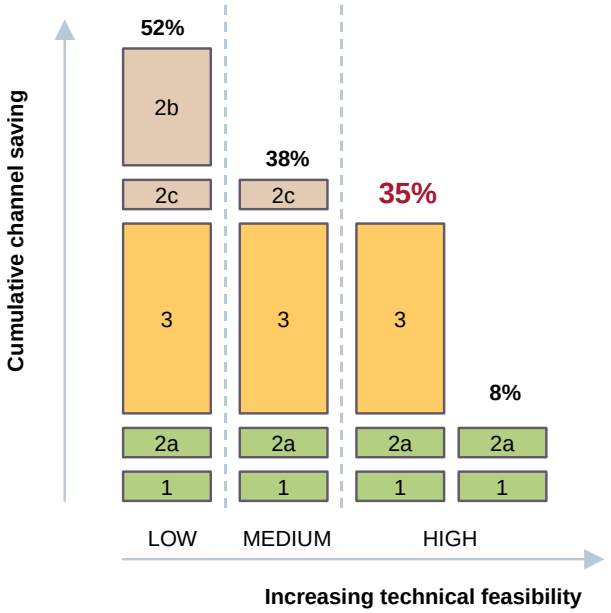

Figure 2.2: Channel saving vs. technical feasibility [Source: Analysys Mason]

2.5.3 We have concluded that the best opportunity for reducing wireless camera channel requirements is to deploy a city-wide cellular receive system (Option 3), in which a number of fixed receive points are set up around a city and connected into a fibre network. This system could be applied to the wide-area sports and ENG applications in central London to eliminate the need for aerial relays of signals back to the studio or International Broadcast Centre (IBC) in the Olympic Park.

2.5.4 City-wide receive systems are not a new broadcasting technology; individual broadcasters have deployed single receive points in a number of cities, including London. The main challenge is the funding of a shared cellular network of these receive points. We believe a city-wide system would cost between £0.5m and £1m to design and implement, plus the costs of connecting into a fibre network and the recurring managed service cost.

2.6 Legacy

2.6.1 A new technology or approach, whether at 2-3 GHz, 7 GHz or 60 GHz, will only be adopted if the long-term benefits can be proven; new systems that can be used only for the duration of the London Games will not be realistic options. A sustainable legacy of benefits will not only encourage broadcasters to invest in new approaches, but also help attract the necessary external investment to enable these to become financially practical options for the London Games.

2.6.2 We concluded that the degree of legacy benefit as a result of deploying hybrid wired-wireless solutions (strategic option 2) is high in terms of the infrastructure legacy if the venue is permanent, and if it will be used for televised sports on a regular basis following the London Games.

2.6.3 In terms of infrastructure, the most significant benefits would be realised through the deployment of the shared city-wide cellular network of receive points for broadcasting signals (strategic option 3). There is an ongoing requirement for this infrastructure for ENG use, and a shared network covering a wider area would offer advantages for broadcasters who are currently using individual city networks for ENG broadcasts.

2.6.4 Another legacy benefit for live HD outside broadcasting and for Ofcom is the opportunity to use the London 2012 Olympics to promote and accelerate the development of new wireless broadcasting solutions that can be sustained in the long term and become widespread, particularly those using the higher frequencies for HD wireless cameras.

3 Introduction

3.1.1 This report has been prepared by Analysys Mason Limited (Analysys Mason) on behalf of the Office of Communications (Ofcom), and provides the report of a study into the potential to use wired technology where the host organising committee and broadcasting operations for the Olympic and Paralympic Games typically use wireless technology at present.

3.1.2 Between 27 July and 9 September 2012, London will host the 2012 Olympic and Paralympic Games ('The Games'). The Games will be an extremely spectrum-intensive event. Based on the demand for spectrum at similar large-scale multi-sport events, the main spectrum requirement is likely to come from broadcasting (particularly the use of wireless cameras) and private business radio (PBR)[2].

3.1.3 The Government has given two guarantees to the International Olympic Committee (IOC) regarding the use of spectrum for the Games:

i. The allocation of all spectrum required for the organisation of the Games
ii. The waiving of fees otherwise payable for that spectrum by members of the Olympic Family[3].

3.1.4 Ofcom is required to design and implement a full spectrum plan for the relevant period of time, which includes any test events that take place, typically, up to a year before the Games[4]. In its discussion document on spectrum planning for the London 2012 Olympic and Paralympic Games[5], Ofcom indicated its intention to explore the potential to use wired instead of wireless technologies as part of its consideration of the overall spectrum requirement for the Games, and how this will be met.

3.1.5 As a result, Ofcom has appointed Analysys Mason to identify and evaluate deployment scenarios for wired technology solutions, or wired-wireless hybrid solutions, in the context of reducing the spectrum requirements covered by the above Government guarantees. The brief was to:

i. capture users' operational and quality requirements.

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2 This is the direct spectrum requirement for hosting the Games, and does not consider spectrum requirements for public mobile networks.

3 The 'Games Family' includes LOCOG, LOCOG sponsors, IOC sponsors, Contractors to LOCOG, the National Olympic Committees (NOCs), sports governing bodies, the host broadcaster (OBS), Rights Holding Broadcasters (RHBs). The guarantees do not include the public safety services, other public services, non-RHBs.

4 Two years in the case of sailing events.

5 http://www.ofcom.org.uk/consult/condocs/spectrum2012/condoc.pdf (4.34 and 4.43).

ii. develop alternative deployment scenarios for the applications identified for use within venues, around venues and between venues.

iii. Present a complete evaluation of each deployment scenario to include technical feasibility, advantages and disadvantages of deployment, costs and legacy benefits.

3.1.6 The main focus of the study was wireless cameras used by the broadcasters because this is the application with potentially the largest spectrum demand, and whose use has almost doubled since the Athens Games in 2004. The study also covered private business radio (PBR), wireless microphones, wireless talkback systems and IFB circuits (in-ear monitors).

3.2 Key issues

3.2.1 In meeting the above brief we set out to address the three underlying questions set out below. We identified five key issues that emerged as a result.

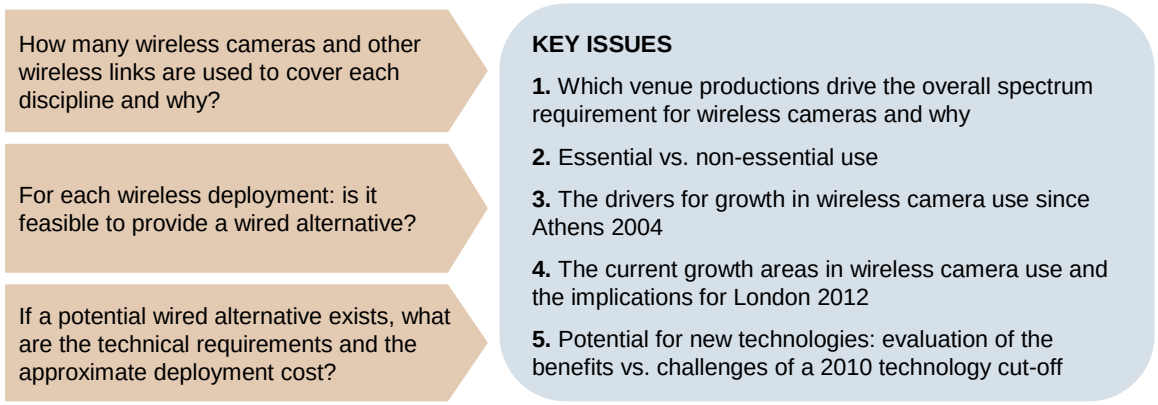

Figure 3.1: Key issues for the study to address [Source: Analysys Mason]

3.3 Related documents

3.3.1 This study forms part of Ofcom's programme of work for the spectrum planning for the London 2012 Olympic and Paralympic Games, and builds on the consultation and studies set out in the following three documents:

Spectrum planning for the London 2012 Olympic Games and Paralympic Games	Discussion document (Ofcom)	31 November 2007
Examining the potential to use SHF and EHF spectrum to support Wireless Camera PMSE applications	Study (Sagentia)	25 January 2008
Spectrum planning for London 2012: summary of discussion document responses	Statement (Ofcom)	07 May 2008

Figure 3.2: Previous spectrum studies for Ofcom

3.4 Document structure

3.4.1 The remainder of this document is laid out as follows:

i. Section 4 provides an overview of the Olympic Games broadcast operations.
ii. Section 5 describes the wireless applications included in this study, including the level of use of these applications at the 2008 Beijing Olympic Games.
iii. Our analysis of alternative wired technology deployment scenarios is presented in Section 6 and Section 7.
iv. Section 8 provides our conclusions of the study.

3.4.2 The report includes a number of annexes containing supplementary material:

i. Annex A: Wireless cameras – example pictures
ii. Annex B: Detailed wireless camera use in Beijing
iii. Annex C: EHF wireless cameras used by NHK
iv. Annex D: Wireless microphone and in-ear monitor technology
v. Annex E: London 2012 Competition and non-Competition Venues.

4 Overview of Olympic Games broadcast operations

4.1 Background

4.1.1 Our first task was to capture users' operational and quality requirements. The wireless applications considered in this study relate almost exclusively to the television broadcast operations for the Olympic Games, and this section presents a summary of the typical process for Olympic Games broadcast production planning, which has a fundamental bearing on these users' technical solutions requirements.

4.1.2 The broadcast operations timeline is particularly significant when assessing the feasibility of any alternatives to the current preferred technical solutions. The host broadcaster, and, in turn, its suppliers, will typically place contracts for services during 2010, so this is the target deadline for which any new approach will have to be developed, tested thoroughly, and accepted by its users.

4.1.3 There are two categories of broadcasting organisation whose needs will be considered in Ofcom's spectrum plan for London 2012: The Host Broadcaster (HB), and the Rights Holding Broadcasters (RHBs). Together, the broadcast operations of these organisations include the sports production at the venues, and Electronic News Gathering (ENG) production at venues and around key positions within the host city.

4.1.4 Here we provide an overview of the typical broadcast operations for the Olympic and Paralympic Games, which includes both the planning phase and 'Games mode' phase, with particular reference to the Beijing Olympic and Paralympic Games that took place in August 2008 and September 2008 respectively[6].

The Beijing Olympic and Paralympic Games

4.1.5 The Beijing Games were the first in which each discipline was produced in High Definition (HD). There were around 1,000 HD cameras and 60 HD outside broadcast (OB) vehicles, or 'mobile units' in use. The host broadcaster's live broadcast from thirty-seven venue sites, as well as the seamless integration of Rights Holding Broadcasters (RHBs), presented itself as one of the most complex and challenging broadcast projects in television history.

4.1.6 As an indication of the size of the project, there were around 12,000 accredited broadcasting staff in Beijing from more than 200 broadcasting organisations, a television audience of 4

[6] The information in this report is based on the broadcast plans available to us, and from discussions with broadcasters. The timeframe for this study spanned the period immediately before, and the duration of, the Beijing Games, and in practice, the actual operations may have deviated a little from the plans.

billion, and 3,800 hours of Olympic coverage provided for viewers in around 200 countries and regions worldwide. On two particular days during the Games, twenty four different sports were contested.

4.2 Olympic broadcast operations timeline

4.2.1 The planning for the broadcast operations typically commences two to three years before the start of the Games, as shown in Figure 4.1.

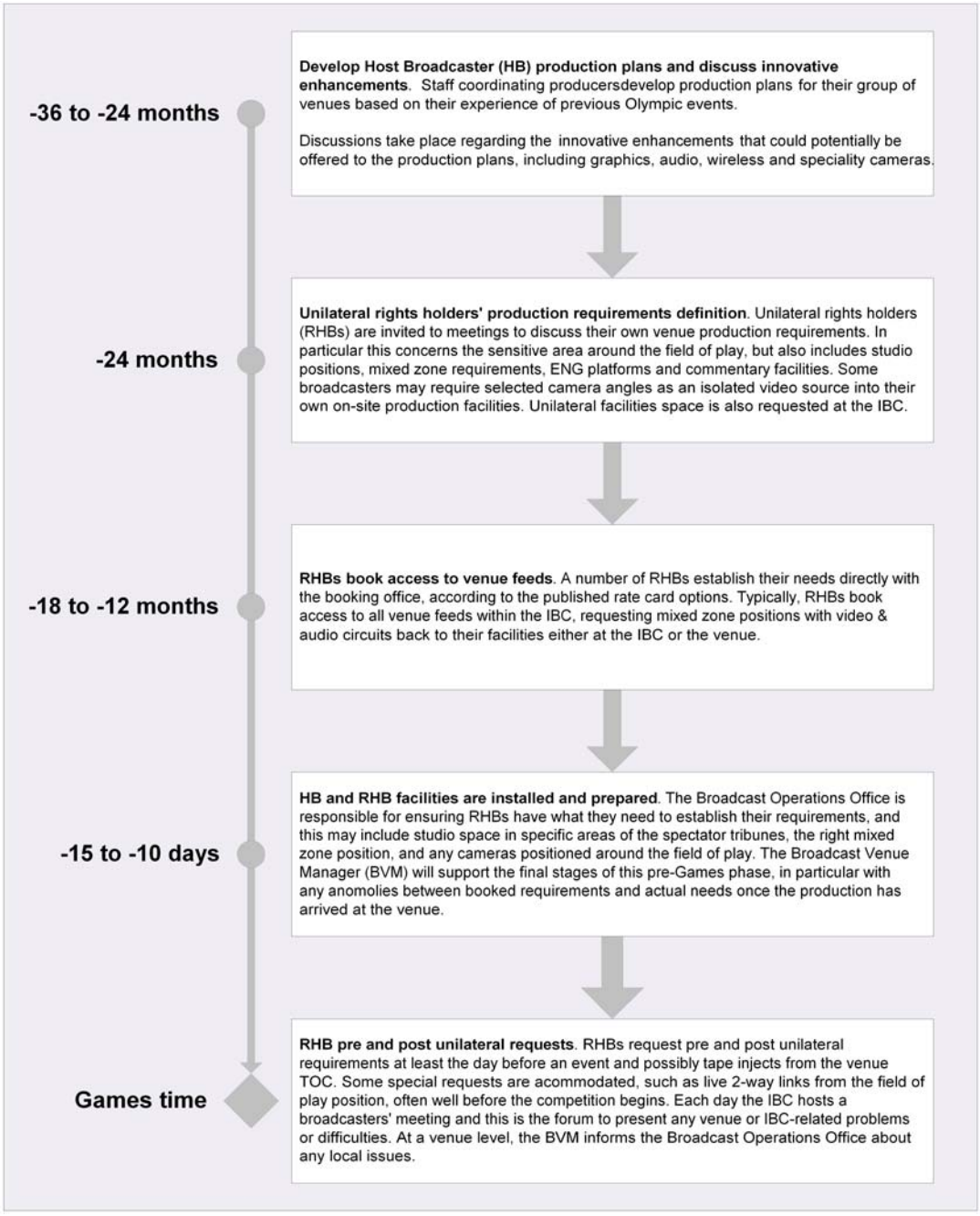

Figure 4.1: Olympic broadcast operations timeline [Source: Analysys Mason]

4.3 Sports production

4.3.1 Preparing and executing a sophisticated broadcast production plan for the forty disciplines of Olympic competition is a highly specialist and demanding operation that requires years of meticulous planning and considerable attention to detail.

4.3.2 The host broadcaster is responsible for the television and radio production of each sports discipline, and selects specialist Broadcast Venue Teams (BVTs) from established broadcasting organisations or specialist freelance teams to produce disciplines on their behalf. For example, Australia's Network 7 was contracted to produce the aquatics events at Beijing because they are recognised for their expertise in this field.

4.3.3 The supply chain also includes the outside broadcast facilities companies, fly away 'kit hire' companies and equipment suppliers, who together deliver the host broadcaster's or the unilateral broadcasters' production, as illustrated in Figure 4.2. Not all elements of the supply chain are necessary; the diagram illustrates all the potential parties contributing to the production. For example, the camera manufacturer might supply wireless systems directly to the host broadcaster, but also supplies the OB companies or the broadcaster, who could, in turn, supply services to the host broadcaster.

4.3.4 The extent of the RHB presence within a venue is subject to approval from the host broadcaster. NBC, the American broadcaster, and the principal RHB[7], usually has the largest in-venue operation of the unilateral broadcasters, as well as booking the largest production space at the IBC.

[7] NBC is arguably the most influential RHB. Historically it has contributed around half of the IOC's revenues for broadcasts rights for the Summer and Winter Olympic Games. Broadcast rights is the most important single revenue source for the Olympic movement.

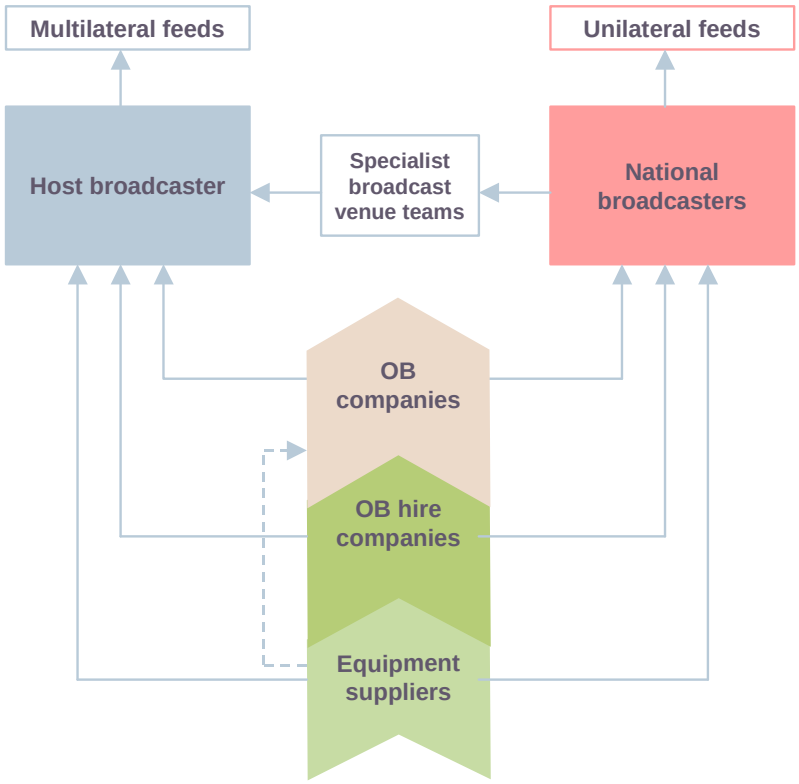

Figure 4.2: The broadcast production supply chain [Source: Analysys Mason]

Host broadcaster operations

4.3.5 Olympic Broadcasting Services (OBS) was created by the International Olympic Committee (IOC) in May 2001 to serve as the Host Broadcaster (HB) for the Summer and Winter Games, starting with Beijing. In Beijing, the on-site Host Broadcaster, Beijing Olympic Broadcasting, (BOB), was a joint venture between OBS and the local organising committee.

4.3.6 OBS is a specialist host broadcaster organisation whose primary responsibility is to develop and prepare a television and radio production plan for each Olympic discipline that best captures the drama, speed and excitement of the sport, with coverage that must be considered as inclusive, fair and equal for each Olympic competitor.

4.3.7 Under the supervision of the Head of Production from OBS, staff co-ordinating producers and technical supervisors are allocated a number of venues for which they must prepare and develop a production and engineering solution[8]. Typically this process would begin 24 months before the event phase, and is designed based on the knowledge and experience of the personnel concerned and previous Olympic Games production plans. The solution is also dependent on input from RHBs at World Broadcaster Meetings (WBMs), in which delegates of radio and television RHBs from around the world are briefed by the host broadcaster.

[8] These resources will work closely with LOCOG's venue technology resources.

4.3.8 The co-ordinating producer is also responsible for selecting a suitable specialist production team as well as facilities vendors, specialist camera facilities and the broadcast venue management team.

Unilateral presence

4.3.9 Some unilateral broadcasters request access to every HB camera source, as well as several of their own directable cameras around the field of play. RHBs typically hire their own vendors to install and manage unilateral facilities within the International Broadcast Centre (IBC).

4.3.10 Depending on their particular budget, any given RHB may seek studio space in selected venues, and possibly require sophisticated communications between multiple in-vision positions from a number of Olympic venues.

4.3.11 Some broadcasters may establish 'play out' facilities from the venue at specific times, depending on the event schedule. This may be booked during 'pre and post unilateral windows' - a window of opportunity (10 minutes each) for any given rights holder to perform a piece in vision, or an interview in the 45 minutes pre and post the competition schedule. The signal path is already designated in the multilateral signal delivery from the venue. It is an inexpensive and effective way of including some live customisation from a RHB without the necessity to book their own facilities or video and audio circuits. ENG from the mixed zone, for example, may need to be fed back to the IBC without the necessity for a permanent unilateral path.

4.3.12 In general OBS discourages unilateral broadcasters from using wireless cameras, particularly when the key rights holders have access to each and every camera chain from the host broadcast operation.

Non-rights holders

4.3.13 Non-rights holding ENG crews will also wish conduct live broadcasts from key positions around the city. The Olympic organisers are protective of rights holders, and non-rights-holders' opportunities will be limited. For example, NBC had 2,900 workers in Beijing, including 106 announcers and 1,000 local hires. ESPN, its rival station in the USA, had fewer than 10 staff in Beijing[9].

4.3.14 Non-rights holders cannot bring recording devices or cameras into venues, even if they can get into official mixed zones that allow athletes and media members to conduct brief and informal interviews. The exception is the Games main press, but their footage or audio cannot be aired live.

[9] Source: *Broadcast Engineering*, August 2008.

4.4 ENG production

4.4.1 The level of news crew presence is, by its nature, less predictable than sports production, and is more difficult to control. Some ENG interviews take place in the mixed zone of a venue, but the majority of ENG production will be located around the Olympic Park, at the other popular sports venues (sailing and gymnastics would be included in this category), or at major points around the host city.

4.5 Implications for this study

4.5.1 Given the operational requirements detailed in this section, the key factors to consider when assessing the potential to use wired technologies to help reduce the Games spectrum requirements are summarised below.

i. The host broadcaster is the heaviest user of wireless cameras, and controls the level of RHB wireless use within venues
ii. The host broadcaster will strongly favour the use of tried-and-tested technologies for the multilateral sports production, and will impose a technology cut-off in 2010 when it places its contracts for the London Games
iii. Technology choices for the Olympic Games are a key element of the World Broadcaster Meetings (WBMs)
iv. NBC is the principal RHB for Ofcom to consider in its spectrum plan, and has significant influence on provision for its camera positions in venues
v. The supply chain for the venue broadcast production and ENG production consists of a number of different organisations, all of whom would be affected by changes to the current accepted technology approach to live HD broadcasts.

4.5.2 In the remaining sections we look at the wireless camera use in Beijing, and predicted levels for the London Games, and analyse the potential for replacing some of this use with wired alternatives. We also look at how the deployment of wired technologies could help Ofcom develop an effective spectrum plan that would accommodate all current and predicted future levels of use.

5 Overview of the wireless applications

5.1.1 This section examines the current level of use and the drivers for wireless applications in an Olympic Games environment, a thorough understanding of which was essential before formulating potential deployment scenarios for alternative or complementary wired solutions.

5.1.2 Here we summarise how, and to what extent, wireless applications are used, including the users' current technical and operational requirements.

5.1.3 We have grouped the categories of demand for wireless applications into four main classes:

i. Wireless (RF) cameras and associated camera control telemetry
ii. Audio links (wireless microphones, talkback and in-ear monitors)
iii. Temporary video and data links
iv. Private business radio (PBR).

5.1.4 In order to estimate the level of requests for Olympic uses, we have investigated the planned and actual use of wireless applications at the Games in Beijing. However, in doing so we note that the initial demand from broadcasters at London 2012 could be higher than the previous Games, for two principal reasons:

i. In Beijing, broadcasters were operating in what they perceived to be a relatively restrictive environment, and these perceived barriers may not exist in London. The cost and complexity of transporting equipment, and the cost of deploying resources in Beijing for two to three months were the key reasons cited by the key industry players.
ii. Developments are continuing in broadcasting technology and techniques, and creating trends to provide more in-depth action at sporting events that can only be provided by wireless cameras, such as mini point-of-view (POV) and onboard cameras.

5.1.5 We believe that an increase in wireless camera demand will be moderate in comparison to the those seen between Sydney to Athens, and Athens to Beijing. Their use for many disciplines such as the wide-area events is well-established and is now fairly stable.

5.2 Wireless cameras

5.2.1 Wireless cameras, also known as RF (Radio Frequency) cameras, are used extensively for outside broadcast events, and are widely perceived in the industry to add genuine value to the broadcast coverage of sports.

5.2.2 Wireless cameras typically operate in 10 MHz channels in the spectrum between 2 and 3GHz in the UK at present. Use in the higher frequency bands such as the 7 GHz band is increasing in

[10], and there is evidence that the OB hire companies are starting to buy this equipment. In Japan, the bands 6 GHz to 11 GHz are widely used for wireless cameras.

5.2.3 Wireless cameras form the main focus of this study for a number of reasons:

i. Wireless cameras are the most spectrum-intensive of the various wireless applications normally used to support the Olympic Games
ii. The use of wireless cameras for sports coverage has proliferated in recent years
iii. A rapid increase in the proportion of HD to SD cameras is taking place (which benefits from higher bandwidths for optimum quality)
iv. The frequencies available in the UK and other countries for Programme Making and Special Events (PMSE) will be reduced by 2012. In particular, wireless cameras previously used the 2500-2690 MHz (2.6 GHz) band in the UK, which is now planned for re-award. As a result, Ofcom will require wireless camera use of this spectrum to cease.

5.2.4 Due to the reduced amount of spectrum allocated to PMSE in the 2-3GHz range, there is interest in considering the feasibility of using higher frequency spectrum for wireless cameras. This topic has been covered in detail in a separate study conducted for Ofcom in January 2008[11]. There is also potential for using higher frequencies, such as 7 GHz and 60 GHz, in conjunction with fibre optic transmission, which is a scenario we consider in this report.

5.2.5 Figure 5.1 illustrates the approximate number of wireless cameras used at Sydney, Athens and Beijing by the host broadcaster for sports coverage. Our estimate for Beijing is based on the total number of wireless cameras used in the production for each discipline to which we then applied assumptions on resource sharing between certain disciplines.

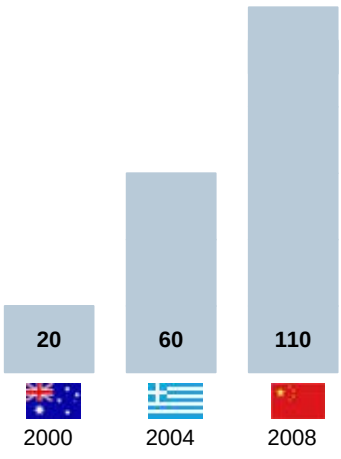

Figure 5.1: Approximate number of wireless cameras used at the Olympic Games since Sydney 2000 [Source: Analysys Mason]

5.2.6 In Beijing a further 28 wireless cameras were used in total by the RHBs, the main ones being NBC and the Chinese state broadcaster (CCTV), across the competition venues. The final element not included in Figure 5.1 is the ENG wireless camera requirement for RHB news

10 7 GHz has been use successfully for golf, football and motorsports coverage, for example.

11 Examining the potential to use SHF and EHF spectrum to support wireless camera PMSE applications, Sagentia report for Ofcom, January 2008.

teams. These are located at interview areas in the venues, broadcasts from around the venues and the Olympic park, and around the host city.

5.2.7 The use of wireless cameras accelerated between the Sydney 2000 Games (where a handful of wireless cameras were used, essentially for live testing) and the Athens 2004 Games. However, as recently as 2006, manufacturers, vendors, and broadcasters were still struggling with bandwidth limitations, serious latency issues, signal interference concerns and power consumption challenges that prevented widespread adoption for live outside broadcasts. Since then a number of advances in the relevant technologies has resulted in a proliferation of wireless camera take-up and they have become commonplace for live sports and ENG productions, as we saw in Beijing.

5.2.8 We would expect the numbers of wireless cameras to increase by a lower order for London 2012 as take-up approaches peak levels for some disciplines. We anticipate an increase in wireless mini-cameras to account for much of any rise in overall use.

5.2.9 The number of cameras does not represent the number of channels needed to support wireless camera use. The number of channels depends on not only the number of cameras, but also the frequency reuse distance and the competition schedule. We explore the implications of the number of wireless cameras on total channel requirements in Section 6.

Types of wireless camera in use

5.2.10 The term ‘wireless camera’ refers to the system that replaces the cable used on a standard camera for the transmission of signals to/from the camera and the power supply. It consists of a transmitter and a separate battery pack that both clip onto the back of the camera body, or are mounted on the tracking vehicle carrying the camera; the lens and camera body remain the same as a cabled camera.

5.2.11 Wireless cameras can be handheld or used in conjunction with the numerous types of camera mount and sophisticated remote camera systems available which enables them to be mounted on various types of vehicle, airborne transport or mechanical device. The cameras themselves and their associated mountings make up a family of specialty cameras that are gradually being engaged for specific purposes in Olympic competition. One such speciality camera is the flown wire camera, the ‘wire-cam’, which is described in this section. Essentially, most cameras can function via a triax or fibre optic connection, but, if necessary, will also interface with an RF transmitter to give them wireless functionality.

5.2.12 The different categories of broadcasters use various camera configurations to serve different purposes. The table in Figure 5.2 provides a general overview of the typical scope of the different deployments of wireless cameras at Olympic Games venues. Images of these cameras in use at Beijing are provided in Figure 5.3, and further details and images included in Annex A: Wireless cameras – example pictures.

5.2.13 The justification in each case for using an RF camera over a cabled camera for sports production usually falls into one or more of the following categories:

i. **Safety concerns**: Using RF cameras prevents cables and camera assistants occupying the sensitive areas on the field of play (FOP). This tends to be driven by the sports federations' guidelines rather than a production requirement. For example FINA[12] discourages technology cables on the pool deck.

ii. **Production requirement**: For example eliminating cables from view across the field of play.

iii. **Commercial reasons**: Avoiding the need for a camera assistant or cable utility – also known as a 'cable basher'. In Beijing that meant extra 75 individuals to hire, accommodate, feed, insure and travel.

iv. **Practicality**: For example, when a Steadicam[13] is needed. Attaching a cable would destroy the special equilibrium the operator uses to steady the camera.

v. **Area covered**: The area may be too large to cover with a cabled camera. The live broadcasting of the marathon, walks, road cycling, sailing and rowing fall into this category.

5.2.14 Some current uses, such as medal ceremonies, do not especially demand RF technology, but if they are used for the competition then they will certainly be used for the non-competition formalities. A detailed assessment of the need for wireless cameras is included in Section 6.

Flown wire camera systems

5.2.15 The most prominent of the wireless cameras used in Beijing was the CAMCAT™, which is a type of flown wire system. There were six of these aerial camera mechanisms provided to the host broadcaster by an Austrian firm that specialises in special effects, and each was used in conjunction with HD RF links. The systems were used at the opening and closing ceremonies, above the main stadium during the athletics, the Olympic Green (outside the stadium), the slalom canoeing, the BMX track, the mountain biking and the road cycling.

5.2.16 The remote-controlled camera buggy runs along parallel wires, and reaches speeds up to 130 km/h and can manoeuvre on a length of 1,000 metres in a horizontal direction and 300 meters in the vertical direction. Some of the images from this camera system are provided in Annex A: Wireless cameras – example pictures.

12 FINA is the international governing body of swimming, diving, water polo, synchronized swimming and open water swimming.

13 A Steadicam is a stabilising mount for a camera that mechanically isolates the operators movement from the camera, allowing a very smooth shot even when the operator is moving quickly over an uneven surface.

	Scope, service description, comments	*Movement within venues*	*Typical system*
Handheld	A standard portable camera channel and lens fitted with an RF transmitter and battery pack.	Each handheld is assigned an area or specific purpose within a venue. Ad-hoc movement – freedom to follow the action closely and react to unpredictable events.	The transmitter clips to the back of the camera. 2 or 4-way diversity receive – antennas placed at appropriate positions around stadium to provide transparent coverage.
Steadicam	A stabilising mount for a camera, which mechanically isolates the operator's movement from the camera, allowing a very smooth shot even when the operator is moving quickly over an uneven surface.	As above. Ad-hoc movement – freedom to follow the action closely and react to unpredictable events.	As for handheld, with additional stabilising mount. Usually line-of-sight to receiver, but not guaranteed.
Airborne	Filming platform providing aerial coverage of live broadcast events. Also used as a mid-point for relay of signals to their final destination.	Limited and predictable movement in a defined area above the venue. Helicopters minimum 1,000 ft above the ground; blimps 500ft – 700ft above ground level.	Remotely controlled HD gyro-stabilised camera fitted to helicopter, aeroplane, blimp or airship. Blimps: Downlink can be via fibre optic transmission.
Vehicle-mounted	RF camera mounted onto an tracking vehicle / motorcycle / buggy.	Follow the course of the race – typically used for wide-area events.	Remotely controlled HD camera that is used with stabilised camera mounts. Signals relayed back to a central receive site.
On-board	RF Camera mounted on a boat.	Rowing: relatively predictable movement along the full length of the course Sailing: unpredictable movement across the course.	Remotely controlled HD camera which is horizon stabilized against movement
Minicam	A compact, remote camera. Mounted on a remote head or other means that allow low angle capture of passing subjects in ‘awkward’ environments, or mounted on athletes’ equipment for POV shots.	Either stationary or move with athlete for the duration of the event.	Examples include ‘Polecam’ and mini ‘Pan & tilt’ (e.g. ‘Goalcam’). These can be wired or wireless.
Flown wire systems	A camera system suspended over the field of play providing a 'bird's eye' view of the game below, or beauty shots.	Standard system: up to 70 km/h (44 mph) High-speed system: up to 130 km/h (81 mph)	Remote controlled camera system designed to run between two fixed points on a horizontal or vertical axis. Can be used with RF or fibre optic cameras.

Figure 5.2: Examples of RF camera deployment for competition venue productions [Source: Analysys Mason]

Handheld RF camera at the aquatics venue [source: Gigawave]

Steadicam captures Usain Bolt's reaction to his world record in the 100m [source: Gigawave]

ENG broadcast using a wireless handheld camera system [source: Link Research]

Vehicle-mounted RF camera [source: Link Research]

On-board RF camera at the sailing venue [source: Gigawave]

Flown-wire system (the CAMCAT™) at the Birds Nest Stadium [source: Brains & Pictures]

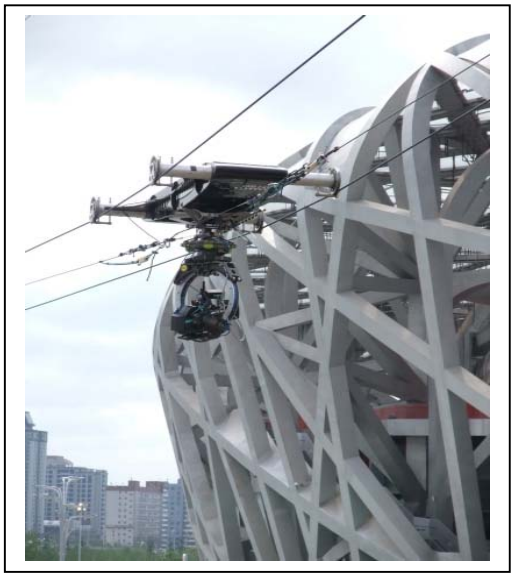

Figure 5.3: Images of wireless cameras in use at the 2008 Beijing Games [Source: Gigawave and Link Research]

RF cameras in Beijing

- *Host broadcaster*

5.2.17 We believe that a total of up to 110 wireless cameras were used by the host broadcaster at 24 of the 40 sports disciplines in Beijing, plus the opening and closing ceremonies. We have arrived at this figure by investigating the wireless camera systems used in the broadcast production for each discipline and applying certain assumptions on the sharing of wireless camera systems between disciplines taking place at the same venue[14]. The complete list of Olympic and Paralympic sports disciplines and London 2012 venues is provided in Annex E: London 2012 Competition and non-Competition Venues.

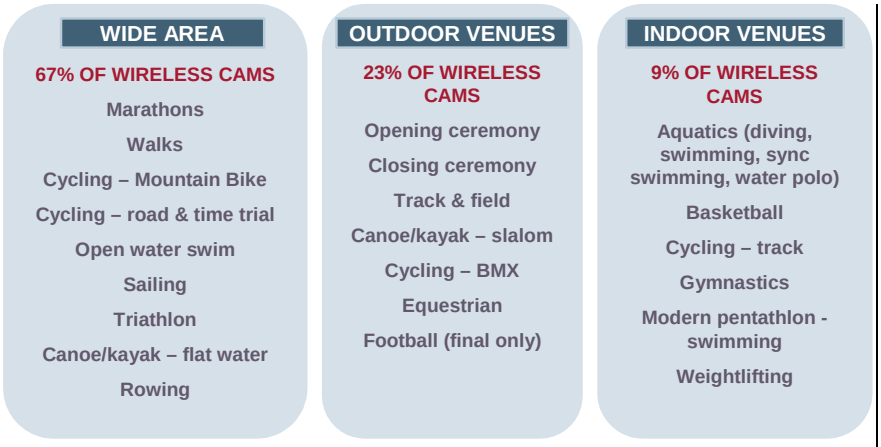

Figure 5.4: Wireless camera use for coverage of Olympic disciplines in Beijing [Source: Analysys Mason]

5.2.18 All cameras were HD and we believe all used 10 MHz channels between 2 and 3 GHz.

5.2.19 Figure 5.4 shows the disciplines for which the host broadcaster's production included the use of wireless cameras. Over two thirds of the wireless cameras used by the host broadcaster in Beijing (Beijing Olympic Broadcaster, 'BOB') were for the coverage of the wide area events. Wide area events are the source of most spectrum demand from wireless cameras for three reasons:

i. they use a large number of wireless cameras.
ii. pairs of frequencies are required (camera to airborne unit; airborne unit to ground receive point).
iii. frequency reuse potential on the ground is limited for the channels used for the aerial relay of signals.

[14] A 'camera system' equates to the number of transmitters. In some cases, such as onboard a boat, there might be more than one camera, but only one transmitter. This would count as one camera system.

5.2.20 Although frequencies for wireless camera systems will be re-used between sports disciplines on the basis of distance separation and timing of the events, the camera equipment itself is rarely shared between venues. Equipment is often shared between disciplines that take place within the same venue if they have non-parallel schedules. The level of equipment sharing depends on whether the broadcasting teams contracted by BOB are producing multiple disciplines, the similarity in broadcast production plans, and the timing of the events.

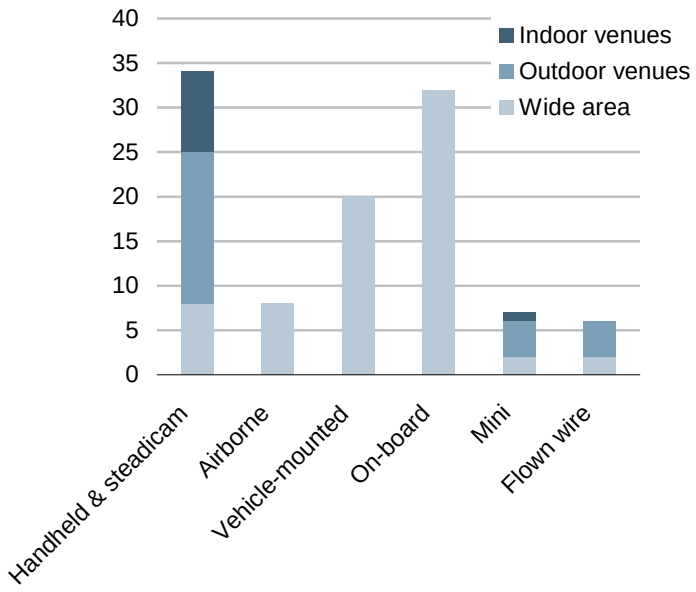

Figure 5.5: Wireless camera use in Beijing by camera type [Source: Analysys Mason]

5.2.21 Figure 5.5 gives the breakdown of wireless camera use in Beijing by camera type. Approximately a third of wireless cameras are the standard portable handheld or Steadicams. The remaining 'speciality cameras' are predominantly vehicle or onboard cameras, which are usually mounted on the chase vehicles or boats at wide area events.

5.2.22 The detailed list of the wireless cameras used by type and by sports discipline is provided in Annex B, Table B1. There are many more specialist camera systems in existence than the ones listed; the table includes only the ones in use at the recent Summer Olympic Games. Others that have been used on sports productions in the past include rail cameras and various forms of mini POV cameras and remote heads such as 'mask-cams' and 'post-cams'.

5.2.23 Annex B: table B2 provides detail on the justification for using wireless instead of wired in each situation.

- *Rights holding broadcasters*

5.2.24 In terms of its outlay on TV rights, NBC is the principal RHB[15], and is in a strong position when negotiating with the host broadcaster for access to the field of play for its own directable cameras. NBC would have used around ten wireless camera systems, and perhaps eight frequencies in Beijing between the ceremonies, artistic gymnastics, aquatics and athletics. This is likely to have been reduced significantly from previous Games; previously NBC would cover a wider range of events, but are believed to have reduced their plans because of the high costs and complex logistics of OB production as a foreign broadcaster in Beijing.

5.2.25 The other RHB to have extensive access to venues was CCTV, the Chinese state broadcaster. We believe CCTV used around eight wireless systems inside the venues in Beijing.

5.2.26 We estimate the total number of wireless cameras between all the other RHBs for sports coverage to be 10 systems in total.

- *ENG*

5.2.27 The full extent of ENG wireless camera use has been difficult to establish with certainty, as it involves many different broadcasters. This information is best obtained directly from the relevant spectrum authority in China. As an indicator, one of the major RHB news organisations would normally expect to have two ENG wireless handheld cameras in total and be allocated two frequencies for these cameras.

Operational and quality requirements

5.2.28 In this section we give an overview of the characteristics of the wireless camera links currently in use. It is not within the scope of this project to assess the RF system technology in detail[16], but it is important to highlight certain aspects of the current specifications, against which we can consider the characteristics of the potential alternative systems, particularly those that involve the use of the EHF frequency bands.

5.2.29 The commercially available wireless camera systems can be configured to operate in a number of the bands between 1 GHz and 7.5 GHz. Performance and characteristics of the systems vary between the lower to the upper limit of the range, and systems operating at above 3.5 GHz are not currently used extensively. However, there is evidence of increasing use around 7 GHz, and it appears that OB hire companies are starting to purchase this equipment. In Japan, the broadcasters use up to 10 GHz.

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15 NBC contributed a significant proportion - $900 million - of the IOC's income from selling the TV rights, and, as such, has a strong influence in some aspects of the planning. NBC has even been able to influence the start times of some events.

16 The technical parameters are dealt with in detail by Sagentia in their report for Ofcom: Examining the potential to use SHF and EHF spectrum to support wireless camera PMSE applications, January 2008.

5.2.30 Wireless camera links allow complete freedom of movement under the most demanding production conditions. The systems in use offer bi-directional digital transmission and eliminate adverse effects from multipath reflections while providing HD picture quality at low latency. Low latency is essential when integrating wireless shots into the production with undetectable video-to-audio delay. The lowest acceptable delay normally depends on the broadcaster but is typically between 1 to 4 frames delay.

5.2.31 As a rule, to fulfil specific requirements in different environments, the wireless camera systems maintain a balance between the robustness of wireless transmission, picture quality, and low latency. To reduce latency further than the current levels would compromise picture quality or require much more bandwidth.

5.2.32 Using systems above 3 GHz or higher presents a generally greater level of complexity in terms of the venue RF solution, for example more receivers, more precise placement of receivers and higher transmit powers might be needed. From our discussions with the OB facilities providers and broadcasters who use the equipment, we understand that these systems have been proven to maintain a robust RF link with very low delay on major live broadcast events, but the non-line-of-sight performance becomes relatively more unreliable towards the higher end of this scale.

5.2.33 For venue applications the receiving set is equipped with a 2- 3- or 4-antenna diversity system. MRC (Maximum Ratio Combining) is used for optimal transmission robustness. For the lower frequencies both transmitting and receiving antennas are omni-directional, so there is no need for alignment or tracking. With the 7 GHz systems there can be a need for tracking – i.e. someone pointing a high gain helical antenna in the direction of the transmitter.

5.2.34 Adding a second antenna set can extend the coverage area, letting the operator move, for example, from a stadium to a dressing room. The system switches automatically and seamlessly between the two antenna sets.

5.2.35 In summary, the typical characteristics of the current wireless camera systems are listed below.

i. **High definition**: The wireless systems typically support 720p or 1080i[17] HD video display resolutions.
ii. **Compression**: Typically MPEG2. Some are hopeful of moving away from MPEG2 compression by 2010, perhaps using MPEG4 and DVB-T modulation. MPEG4 has a reduced bit rate and therefore less bandwidth is needed. The current MPEG4 systems need further work to reduce size, weight, heat and power consumption.
iii. **Modulation**: COFDM physical layer, used with 16-QAM or 64-QAM modulation.
iv. **Bandwidth**: 10MHz raster. 8MHz or 9.5 MHz within this raster, depending on the modulation codec used.
v. **Data rates**: In a single channel the HD equipment provides 18 to 24 Mbit/s when using a robust modulation system, e.g. 64 QAM, with ½ or 2/3 FEC. LMS-T[18] gives 18 Mbit/s

[17] 1080i is a High Definition TV mode with 1920 horizontal samples and 1080 active lines in an interlaced scan.

using 16 QAM. The full uncompressed HD-SDI bit rate is 1.485 Gbps. Development over the last two years has focused on providing acceptable HD quality at low bit rates.

vi. **Transmitted power**: Typically around 60mW transmitted power / 22 dBm (150 mW) EIRP.

5.2.36 The connection between a base station and the wireless system's antenna set uses conventional triax cable, which enables the separation between antenna set and base station of up to 600m. Increasingly this is being replaced by optical fibre, which does not have these limitations.

Telemetry (for OB camera control)

5.2.37 Wireless camera links are usually bidirectional – they provide a return path for the camera control systems that carry camera painting instructions, camera return video and tally. Camera control uses the UHF frequency range 450MHz to 470 MHz, typically with a 12.5 kHz bandwidth and with rates of 28.8 kb/s.

5.3 Audio links

Wireless microphones

5.3.1 Wireless microphones are used by presenters at Olympic venues and also for ENG. Wireless microphone systems typically operate in spectrum interleaved with other broadcasting transmissions and, as a result, typically use channels within either use VHF Band III (174–216MHz), or, more commonly, UHF bands IV and V (470–862MHz) spectrum, which wireless microphones share with analogue and digital terrestrial television.

5.3.2 Spectrum availability in the UK for radio microphones in VHF Band III has been affected by the allocation of additional spectrum for digital audio broadcasting (DAB) in recent years - VHF equipment availability is also understood to have declined in recent years, and most manufacturers focus on UHF, which is used elsewhere in Europe and the wider world, as well as in the UK.

5.3.3 Each TV channel is 8 MHz wide, enough for at least eight wireless microphones. In some circumstances it is possible to squeeze up to 16 per channel at a given venue because they now have improved front-end filters, better antennas, higher sensitivity and selectivity, digital tone squelch and improved diversity. It is harder to do this in adjacent TV bands. Microphones can be adjusted to work nearly anywhere, and newer all-digital wireless models offer even better interference protection.

[18] LMS-T is a proprietary modulation codec from Link Research.

5.3.4 As a general rule, the only wireless microphones used by the host broadcaster would be those mounted on a wireless camera RF unit. The microphone signal is embedded into the transmit chain, gathered by the receive point and delivered to the production vehicle via fibre.

5.3.5 More detail on these systems is provided in Annex D.

In-ear monitors or IFB circuits

5.3.6 In-ear monitoring systems can be wired or wireless and provide a combination of audio sources to the user. The system came about in the 1980s, and was used to replace floor monitors and side fill loudspeakers, that were feedback-prone, with a small wireless device that would convey the mix directly into the ear. This enables the user to control the volume, allows the user to move around freely, requiring less equipment on stage and an overall improvement in sound quality.

5.3.7 The audio is transferred wirelessly via a VHF or UHF radio frequency. In general, the UHF systems have a better sound quality and are less susceptible to frequency interference compared to a VHF system.

5.3.8 In-ear monitoring is not used at all by the host broadcaster because there is no in-vision talent or guide commentary service provided by the host broadcaster. NBC and other unilaterals used wireless IFB circuits, but only for talent who have a 'roving' type role in a studio or field of play environment. This use is generally discouraged because it is an essential audio link that cannot fail without risking the presentation of the show.

5.3.9 More details on these systems are provided in Annex D.

Outside broadcast talkback systems

5.3.10 Talkback systems have characteristics similar to private business radio (PBR) and tend to use similar frequency bands to PBR systems (i.e. VHF and UHF). Outside broadcasts usually use UHF frequency bands and, like the wireless microphones, share with analogue and digital television.

5.3.11 All operators on the field of play benefit from the talkback system carried in the fibre or triax of the camera cable. All roving wireless camera units would use radio talkback, as well as key members of the production and venue management crew. Operators using hand held camera devices with RF transmitters, the floor manager and perhaps a spotter would use radio systems to listen and speak to the director.

5.4 Temporary point-to-point video and data transmission

5.4.1 Temporary video links are used to carry high definition programme feeds from the OB location to the IBC or other transmission points and typically use spectrum between 2–20GHz. They are designed for outside broadcasts and can be used for helicopter downlinks to static receive points such as OB vehicle or fixed base stations, between OB vehicles, between an OB vehicle and fixed base station and ENG vehicle to a fixed base station.

5.4.2 We understand that fibre was deployed extensively in Beijing to connect the competition and non-competition venues, and that these links were used for transmission of HD video wherever possible. Most links from venues to the IBC were fibre.

5.5 Private Business Radio (PBR)

5.5.1 Private business radio is used to support voice communications over radio at Olympic venues. PBR systems typically use spectrum in a number of bands in the VHF and UHF portions of the radio spectrum.

6 Analysis: Wireless cameras

6.1.1 Our brief for this study was to identify and analyse wired technology options to replace or complement the existing wireless applications, with a view to capturing all potential alternatives from the tried-and-tested to pioneering technologies and techniques.

6.1.2 First we present our estimate of the potential demand for wireless cameras and wireless camera spectrum at the London Games. We then identify a set of alternative options and present an analysis of each in the context of the specific venues or ENG uses at London 2012.

6.2 London 2012: Potential demand for wireless cameras

Number of wireless cameras

6.2.1 We developed a base case for wireless camera demand by mapping the wireless camera use in Beijing onto the proposed venues for London 2012. This allowed us to form the geographical picture of the minimum level of demand for wireless cameras at the London Games, illustrated in Figure 6.1.

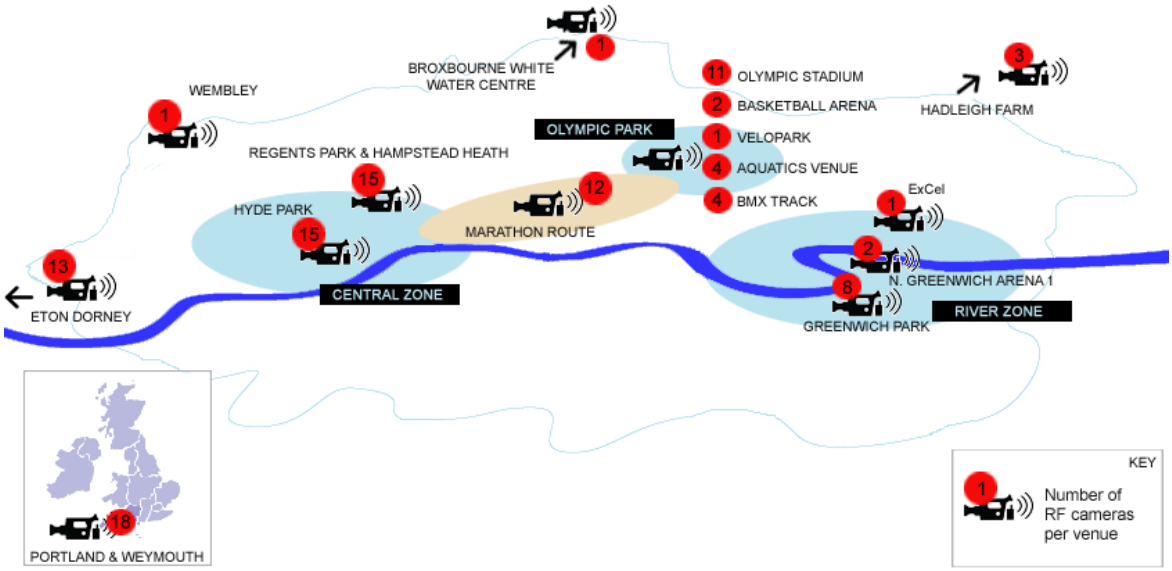


Figure 6.1: Beijing wireless camera use mapped onto the London 2012 venues [Source: Analysys Mason]

6.2.2 Note that this diagram shows only the venues where the host broadcaster used wireless cameras to cover the corresponding disciplines in Beijing. Venues with no wireless cameras are not shown. The diagram indicates the number of wireless camera systems used at the venues and does not indicate the number of channels that will be required to meet this demand.

6.2.3 Figure 6.1 clearly indicates that the key areas of high demand on which to focus are the Olympic Park and the wide area routes in central London. The River Zone also has a potentially high demand but it has the advantage of separation from the Olympic Park, no airborne cameras and two of the venues in question are indoors, which already allows good potential for frequency reuse.

Proposed London 2012 venue	*Discipline(s)*	*HB total*	*Port-able*	*Air-borne*	*Vehicle*	*On-board*	*Mini*	*Wire*
Olympic Stadium	Ceremonies, track & field	**11**	✓					✓
Central Zone to Olympic Park	Marathons and walks	**12**	✓	✓	✓			
Olympic Basketball Arena	Basketball	**2**	✓					
North Greenwich Arena 1	Basketball and artistic gymnastics	**2**	✓					
Hampstead Heath & Regent's Park	Cycling - road race, cycling - time trial	**15**	✓	✓	✓			✓
Olympic Park Velodrome	Cycling - track	**1**					✓	
Olympic Park BMX Track	Cycling - BMX	**4**	✓					✓
Hadleigh Farm, Essex	Cycling Mountain Bike	**3**	✓	✓				✓
Olympic Park Aquatics Centre	Swimming, diving, synch swimming, water polo, modern pentathlon swimming	**4**	✓					
Greenwich Park	Equestrian	**8**	✓				✓	
Eton Dorney	Flat water canoe/kayak and rowing	**13**	✓	✓	✓	✓		
Wembley Stadium	Football final	**1**	✓					
Hyde Park	Open water swim	**7**				✓		
Weymouth and Portland	Sailing	**18**				✓		
Hyde Park and Green Park	Triathlon	**4**	✓				✓	
ExCeL	Weightlifting	**1**	✓					
Broxbourne White Water Canoe Centre	Slalom canoe/kayak	**1**						✓

Figure 6.2: Base case demand for London 2012 – host broadcaster only [Source: Analysys Mason]

6.2.4 Some assumptions have been made on the sharing of cameras between disciplines by studying the venue locations and provisional event timetable. As a rule, equipment remains at a venue for the duration of the Games, and it is not common to share between disciplines that are not located at the same venue. The following assumptions were made on sharing resources at the London Games:

i. The three handheld cameras used for ceremonies would be re-deployed for the track and field.
ii. The flown wire camera systems used at Beijing would be deployed in a similar way at the London 2012 Games. This includes the systems at the main Olympic stadium remaining in place after the opening ceremony for use at the track & field events.
iii. The road cycling and the road time trial would share resources.
iv. The final of the basketball is taking place in the same venue as the artistic gymnastics and will share its wireless handheld cameras.
v. Schedules for diving, swimming and water polo will overlap, and so these disciplines within the aquatics centre will not share resources. Synchronised swimming will share.
vi. Modern pentathlon swimming will share aquatics resources.
vii. Rowing and flat-water canoeing share resources.
viii. There would be some sharing of resources between triathlon and the open water swim.

Number of wireless camera channels

6.2.5 We combined the base case wireless camera use with the proposed competition schedule for London 2012 to determine the maximum number of frequency assignments needed on any one competition day (Figure 6.3). This calculation includes requirements for the host broadcaster and RHBs' sports production, but not the ENG requirements.

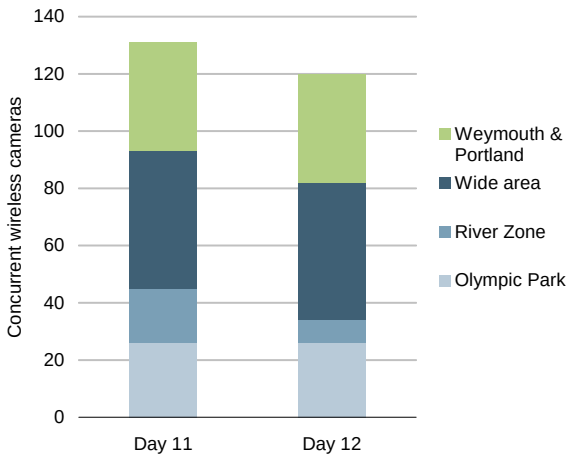


Figure 6.3: Maximum number of frequency assignments needed for wireless cameras on a single competition day, for HB and RHBs (Day 11 and Day 12) [Source: Analysys Mason]

6.2.6 The number of channels is higher than the total number of wireless cameras in use because the wide area events require pairs of channels for each camera to relay the signal from the camera to an aerial mid-point, and then from this mid-point to a fixed receive point on the ground.

6.2.7 We have made assumptions on frequency reuse in relation to distance separation between venue zones, in order to estimate the maximum number of channels needed at any one time.

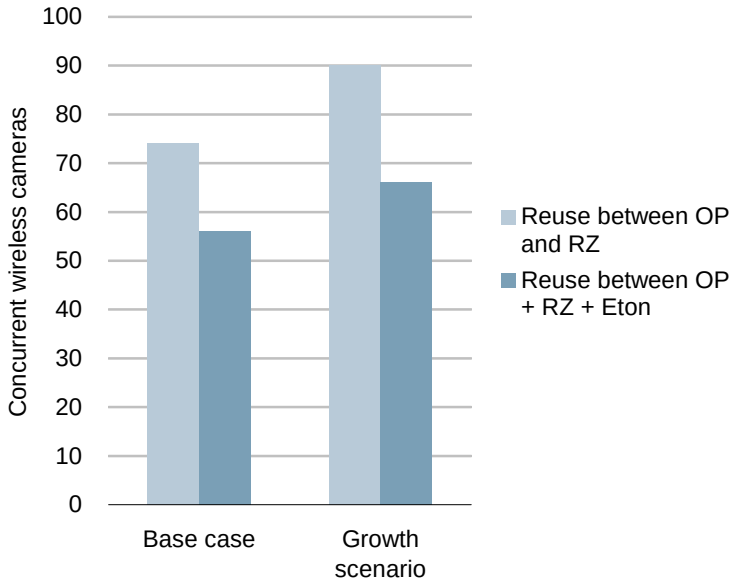


Figure 6.4: Maximum number of concurrent wireless camera channels required – base case and growth scenario [Source: Analysys Mason]

6.2.8 The charts in Figure 6.4 compare the base case with a growth scenario. The growth scenario is based on assumptions on general growth in wireless camera use combined with assumptions on new applications of wireless camera technology, resulting in an overall increase of 30% on the number of cameras used in Beijing.

6.2.9 If 100% frequency reuse can be achieved between the Olympic Park and the venues in the River Zone (i.e. all frequencies used in the Olympic Park venues can be reused in the River Zone without co-channel interference), then we estimate that the maximum number of wireless channels that Ofcom would need to plan for the host broadcaster and RHB sports use would be 74 in the base case and 90 in the growth scenario. This estimate covers the HB and RHB channels, but not the ENG requirement.

6.2.10 If frequencies can also be reused for the wide area events at the outlying venues – namely the rowing park at Eton Dorney – then the maximum number of wireless channels would be 56 in the base case and 66 in the growth scenario.

6.3 Technical analysis

6.3.1 The technical analysis has been conducted on three levels to answer the following questions:

i. Is the wireless camera link necessary?
ii. Are there any existing wired technologies, used currently in live broadcasting, that could replace the wireless link or make more efficient use of the spectrum?

iii. Are there any relevant wired or hybrid wired-wireless technologies on the horizon that could be developed and tested sufficiently on live broadcasts by 2010[19]?

6.3.2 We initially assessed the rationale for each wireless camera system, and then looked at the ways in which existing and new wired techniques could be used instead, and for which general category of wireless camera usage: wide area, outdoor venues, indoor venues and ENG.

6.4 Wireless cameras: alternative deployment options

6.4.1 We identified three strategic deployment options of varying technical feasibility for alternatives to the wireless camera base case, which are summarised in Figure 6.5. The table indicates the types of venue for which each deployment option has the potential to reduce the overall channel requirement in licensed bands. Please note that this is *not* indicating our view on the *feasibility*. Some options are feasible, but are unlikely to present any benefits for spectrum planning.

	Deployment option	*Benefits to spectrum planning*	*Wide area venues*	*Outdoor venues*	*Indoor venues*	*ENG*
1	Replacement of wireless cameras with wired wherever possible	Reduce channel requirement	✓	✓	✓	X
2	In-venue hybrid wired-wireless solutions					
a	With roving cameras using 2 to 7 GHz	Could allow improved frequency reuse	✓*	✓	X	✓
b	With roving cameras using EHF, e.g. 60 GHz	Move to less congested bands	X	X	✓	X
c	With fixed trajectory cameras using EHF, e.g. 60 GHz	Move to less congested bands	X	✓	✓	X
3	City-wide cellular receive system	Reduce the demand for aerial relay downlinks	✓	X	X	✓

* limited use for wide-area venues; could be considered for the rowing/canoeing, but not practical for true wide-area events such as the marathon.

Figure 6.5: Summary of the alternative strategic deployment options we have considered for wired technologies for wireless cameras [Source: Analysys Mason]

[19] 2010 is not only LOCOG's 'technology cut-off' date, but also the time at which OBS would be finalising venue production requirements and placing contracts with suppliers.

6.5 Option 1: Replacement of wireless cameras with wired cameras

6.5.1 This strategic option applies to:

Competition venues: wide area	✓
Competition venues: outdoor	✓
Competition venues: indoor	✓
ENG	X

Option 1: Potential scope

6.5.2 We assessed the potential to reduce the number of wireless cameras by using wired cameras as a substitute. We did not attempt to make a judgement on whether the camera itself is necessary. Similarly, it was not possible to reach a firm conclusion on specific cameras at specific venues without having sight of the venue layout plans or the broadcast production plans. However, it was possible to make general observations.

6.5.3 We have considered the scope for using a wired camera instead of wireless for each of the 110 wireless camera systems that we understand were used in Beijing. These we have categorised into six general 'types' listed below with the proportion of the total they represent:

i. Portable (handheld or Steadicam) – 32%
ii. Onboard – 30%
iii. Vehicle-mounted – 19%
iv. Airborne – 7%
v. Mini-cam – 7%
vi. Flown wire ('wire-cam') – 6%.

Option 1: Technical analysis

- *Portable wireless cameras (handheld and Steadicams)*

6.5.4 Our main focus was on the portable wireless cameras that accounted for approximately one third of the wireless camera requirement at the competition venues in Beijing. We have considered the scope for reducing the level of the portable wireless camera systems on a case-by-case basis. The detailed results of this analysis are provided in Annex B - Table B2, and the results are summarised in this section of the report.

6.5.5 The key criteria that affected the potential to replace the wireless link was the level of mobility required. As we expected, mobility is a key requirement for the majority of the wireless cameras. However, we believe that *some potential* exists to explore the feasibility of wiring three of the 34 portable camera systems by providing wired access points to the required cameras position. This solution would make use of underground ducting to allow a safe and protected cable run from the camera to the OB vehicle.

6.5.6 It is important to stress however that the opportunity to implement this solution requires detailed knowledge of the venue layout plans and a thorough understanding of the environmental features specific to the venue that could affect the implementation.

6.5.7 We believe that there is potential to use a cabled (either fibre optic or coax) camera for three of the handheld systems used to cover the throwing, horizontal jumps and vertical jumps disciplines at the Olympic Stadium (Olympic Park).

- *On-board and vehicle-mounted cameras*

6.5.8 We ruled out cabling the onboard and vehicle-mounted cameras for obvious reasons, which make up the majority of the wireless cameras used for wide-area sports. The detailed use of these types of camera is provided in Annex B, Table B3.

- *Airborne cameras*

6.5.9 Wireless cameras are used with helicopters and aeroplanes fitted with a gyro-stabilising camera system to provide aerial coverage for live broadcast events. Details of the airborne wireless cameras used in Beijing are provided in Annex B, Table B4. We found some potential, albeit with certain limitations, to use wired cameras in conjunction with a tethered blimp to replace the helicopter or aeroplane aerial shots. These blimps use the fibre lines in the tether to transmit HD video and all the relevant control data for the blimp and camera system between the control position on the ground and the blimp payload.

6.5.10 At present most of these systems are used for sponsor-funded live aerial filming. Where possible the fibre is run between the blimp and the OB vehicle. If this is not possible, an RF link is used to transmit pictures and camera control. This requires a line-of-sight path between the OB or RF receive position at the venue and the blimp when it is airborne.

6.5.11 We understand from the providers of these systems that the most useable blimp camera shots are generally obtained from a position no greater than 1km away from the main event venue at a blimp flying height of between 500 ft and 700 ft above ground level. Flying limitations include those related to high winds, especially when launching and retrieving. Low cloud and thunder or lightening also affect this system, however these factors can also limit helicopter operations.

6.5.12 The blimp does have some advantages to the broadcaster over a helicopter:

i. It is a completely silent operation
ii. It has a far higher flying endurance (many hours, as opposed to refuelling every two to three hours)
iii. It operates below 1,000 feet (typically 500 to 700 feet), which enables the camera operator to get much closer shots than from a helicopter, which are generally limited to a minimum of 1,000 feet
iv. The blimp can be branded, and therefore fully funded by sponsorship[20].

[20] For the Olympic and Paralympic Games, the sponsorship opportunities are controlled by LOCOG and IOC, and not the broadcasters.

6.5.13 We concluded some potential exists to use gyro-stabilised wired cameras on tethered blimps to replace the eight helicopter camera systems used for aerial shots. We **did not include this in our potential channel savings** because:

i. blimps are affected by high winds and may need a back-up wireless solution.
ii. more information is needed on the venues to determine if the blimp can be positioned less than 1km away from the subject, and also if there is the required 22m radius operating space.

- *Mini-cams*

6.5.14 Details of the mini-cam wireless cameras used in Beijing are provided in Annex B - Table B4. We believe there could be an opportunity to run a cable from the remote mini-cams to the OB truck by providing an appropriate cable access duct to the required location.

6.5.15 We identified one venue where this option could apply: the four mini-cams at the equestrian disciplines at Greenwich Park (River Zone). The actual potential is difficult to assess without knowing the precise positioning of the cameras for London 2012, or details of the environment in which they would be placed. However, we know that Greenwich Park is a temporary venue, and we believe that in this case the greatest barrier to deployment would be obtaining the permissions to carry out the required civil engineering works.

- *Wire-cams*

6.5.16 Finally, we also looked at the potential to use fibre optic cameras with the wire-cams systems, such as the CAMCAT™ systems that were used in Beijing. The ability to do this is limited by the speed the camera buggy needs to travel, and the length of the guiding wire. Details of the wire-cam wireless cameras used in Beijing are provided in Annex B, Table B4.

6.5.17 Rail-cams are often used for sports event OBs, and the majority of these systems use cable management systems fitted inside the rail. These usually operate over no more than 200m and the cable camera system operates very well. The wire-cams do not work quite as well with cable management systems because the speed of the buggy and the distance travelled is a key factor in creating a reliable and safe cable management system.

6.5.18 The CAMCAT™ system was developed for use in film production, so originally camera cables to the buggy were not a requirement. Other complications include static build-up and reliability, and to overcome these adds significant development costs and cost to the end user.

6.5.19 We believe that the company that operates the CAMCAT™[21] had been experimenting with fibre and power transmission to the buggy, but given the development and reliability of HD links, has not had the pressure on them from industry to progress this solution. The operators of CAMCAT™ have established themselves in the market with the RF solution both in terms of flexibility, reliability and safety.

Option 1: Potential channel saving

6.5.20 In summary, we believe that two venues offer potential to use a cabled (either fibre optic or coax) camera to replace wireless cameras:

i. Three of the handheld systems used to cover the throwing, horizontal jumps and vertical jumps disciplines at the Olympic Stadium (Olympic Park).

ii. Four mini-cams at the equestrian disciplines at Greenwich Park (River Zone).

6.5.21 These two events have parallel competition schedules, and both take place on the busiest competition day for wireless cameras, so this would give rise to a saving of between three and seven channels depending on the level of frequency reuse between these two zones. This represents between a 4% and 5% saving on the base case.

6.5.22 It would appear that the Olympic Park and the River Zone have sufficient geographic separation for the frequencies to be reused between these zones, which would result in a saving of only three wireless camera channels if these seven cameras were wired. Detailed radio modelling would be needed to confirm this, outside the scope of this study.

Option 1: Advantages and disadvantages

6.5.23 Here we identify the advantages and disadvantages of using wired instead of wireless cameras, including the conditions that are helpful to achieving the objective of reducing spectrum requirement, and the risks and barriers that might prevent this solution.

ADVANTAGES

- ODA's new venue builds are at an early stage – it is not too late to plan and install dedicated ducts and access points for cables. The ODA has indicated extensive provision of in-venue and between-venue ducts at the new build venues.
- At a rate-card level, the cost of hiring HD wireless is three times the cost of HD wired - any effective solution for using a cabled camera in place of a wireless camera would be viewed favourably by broadcasters.

DISADVANTAGES

- Sports governing bodies strongly discourage the use of cables on and around the field of play.
- Reluctance to make significant changes to the approach that currently works well.
- Installation of ducts and wired access points within temporary venues (e.g. equestrian) might not be permitted.
- Reduced mobility is not an option for the majority of wireless cameras, and the production quality would

[21] The Austrian firm 'Brains and Pictures'.

- Continued use of telecoms/broadcast infrastructure after the 2012 Games could improve the case for investment in building fibre ducts to wired access points.

be reduced as a result.

- Wireless cameras help maximise flexibility and minimise additional equipment and rig time – these benefits would be lost.

Figure 6.6: Advantages and disadvantages of Option 1

Option 1: Costs and benefits

6.5.24 It is difficult to assess the feasibility and estimate civil engineering cost to build ducts without view of the detailed venue plans.

6.5.25 For new build venues the incremental cost of installing the necessary ducts and access points is small if the implementation is well-planned. For the existing or temporary venues a number of factors affect the cost of installing underground ducts, and each venue will have its own set of requirements and specific variables.

6.5.26 To the broadcaster, the cost of using fewer wireless cameras would be favourable in terms of the lower equipment cost. The cost that is more difficult to measure is the impact of any settling for inferior productions as a result of scaling back the use of wireless camera systems.

6.5.27 The benefits could include legacy infrastructure for the permanent venues, if used by broadcasters after the London Games.

Option 1: Legacy

6.5.28 The legacy benefit in relation to building ducts for wired access points for cameras at the athletics field events and the equestrian events is low. The Olympic Stadium is to be converted to a much smaller venue after the Games, and it is not clear at present what events will be hosted in the new venue, and therefore whether the wired access points could be used after the Games.

6.5.29 Similarly, the equestrian venue is temporary, and there is no obvious use for the wired access points after the Games.

6.6 Option 2: in-venue hybrid wired-wireless solutions

6.6.1 A hybrid wired-wireless solution is a network of antennas positioned around the field of play and fibred back to a receiver(s). We have defined three sub-options for the purposes of this analysis, which are variations of hybrid wired-wireless solutions, and they are suitable for different types of venue:

	2a	2b	2c
Competition venues: wide area	✓*	X	X
Competition venues: outdoor	✓	X	✓
Competition venues: indoor	X	✓	✓
ENG	✓	X	X

* limited use for wide-area venues; could be considered for the rowing/canoeing, but not practical for true wide-area events such as the marathon

6.6.2 All three sub-options are for in-venue applications, and the solutions are essentially different combinations of two key characteristics:

i. The level of mobility required: roving cameras or fixed trajectory
ii. The frequency of the RF link: current bands (typically 2 GHz to 7 GHz) or EHF band (e.g. 60 GHz).

6.6.3 The three sub-options are:

i. **2a**: In-venue hybrid wired-wireless solutions for use with **roving cameras** using **2-7 GHz**.
ii. **2b**: In-venue hybrid wired-wireless solutions for use with **roving cameras** using **EHF** bands, e.g. 60 GHz.
iii. **2c**: In-venue hybrid wired-wireless solutions for use with **fixed trajectory** cameras using **EHF** bands, e.g. 60 GHz.

Option 2: Potential scope

6.6.4 This section addresses two key concepts:

i. The use of wired receiver points to shorten the transmission distance between camera and receiver. The benefit is improved frequency reuse possibilities between venues. It does not help to reduce the number of wireless camera systems in use. This is relevant to outdoor venues and ENG. It could also be deployed at indoor venues, but this would result in little benefit because the frequency reuse opportunity is already very good when the RF signals are contained within the building.

ii. The use of fibre distribution as an enabler for Extra High Frequency (EHF) camera systems, and specifically those using spectrum in the 60 GHz band. The use of 60 GHz for wireless cameras is an area in which interesting developments for broadcast applications are emerging. The question of whether these developments will be sufficiently mature in time for use at the London 2012 Games is contentious, and has been explored in some depth in a previous Ofcom study[22]. We include an analysis for two broad types of EHF camera systems, based on our knowledge of working systems at different stages of development for roving wireless cameras and fixed-trajectory (rail-cam) wireless cameras.

22 Examining the potential to use SHF and EHF spectrum to support wireless camera PMSE applications; Sagentia report for Ofcom, January 2008.

6.6.5 Option 2a relates to the first concept. Options 2b and 2c relate to the second concept. We have considered the roving and guided systems separately because they have very different technical characteristics, potential applications, barriers to deployment and costs.

6.6.6 The full scope in terms of the venues for which each sub-option could be considered is outlined in Figure 6.7.

Sub-option	*Scope*
2a: Roving cameras using 2 to 7 GHz	**Outdoor competition venues and ceremonies:** Olympic Stadium, BMX track, mountain bike cycling, equestrian, rowing park (also used for flat water canoe/kayak), football, slalom canoe centre. **ENG:** outdoor interview area(s) in the Olympic Park. *The systems would work equally well at the indoor venues, but would have little benefit for spectrum planning*.
2b: Roving cameras using EHF, e.g. 60 GHz	**Indoor competition venues:** The indoor venues that currently use wireless cameras – basketball arena, gymnastics, aquatics, equestrian show jumping, weightlifting. *Outdoor venues: Potential for use in 2012 is less certain because these roving systems have not been tested in outdoor stadium environments, but, in theory, might be suited to venues where the course and the areas covered by the RF cameras were predictable.* *ENG: We believe that current developments include ENG applications, but we do not see these systems being ready for 2012.*
2c: Fixed trajectory cameras using EHF, e.g. 60 GHz	**Indoor and outdoor competition venues and ceremonies**: This system could be used in conjunction with a wire-cam where HD RF links are currently used, such as the Olympic Stadium, BMX track, slalom canoe centre, mountain biking and road cycling.

Figure 6.7: Hybrid wired-wireless solutions – scope for each sub-option of Option 2 [Source: Analysys Mason]

Option 2: Technical analysis

6.6.7 The use of ground-based receiver stations with fibre optic transmission is already well established for outside broadcasts for providing transparent coverage across multiple receivers. This type of system is used for the live broadcasting of many sports, including the Oxford-Cambridge boat race, and golf coverage. It also has extensive use in motor sports, including the Le Mans 24-hour race and touring car racing.

6.6.8 At the Euro 2008 football tournament, all wireless cameras in all the venues used RF-on-fibre[23] technology to link the receivers located around the stadium back to the OB truck outside the stadium. The receive antennas plug into a stadium fibre box and this provided a direct

[23] Source: Discussions with Presteigne Charter, the OB hire firm that delivered the Euro 2008 RF solutions.

connection to the OB truck without the need for any receive equipment (or technicians) in the stadium and full control at the OB truck.

6.6.9 The technical analysis of Option 2a covers the ground-based receiver and fibre distribution systems already in use. The analysis of Option 2b and 2c addresses the new technologies that are either still in development, or used in very limited or controlled environments at present.

***Option 2a**: In-venue hybrid wired-wireless solutions for use with roving cameras using 2-7 GHz*

6.6.10 A typical system is illustrated in Figure 6.8. Multiple two-way or four-way receive points are positioned along the course or around the stadium/track.

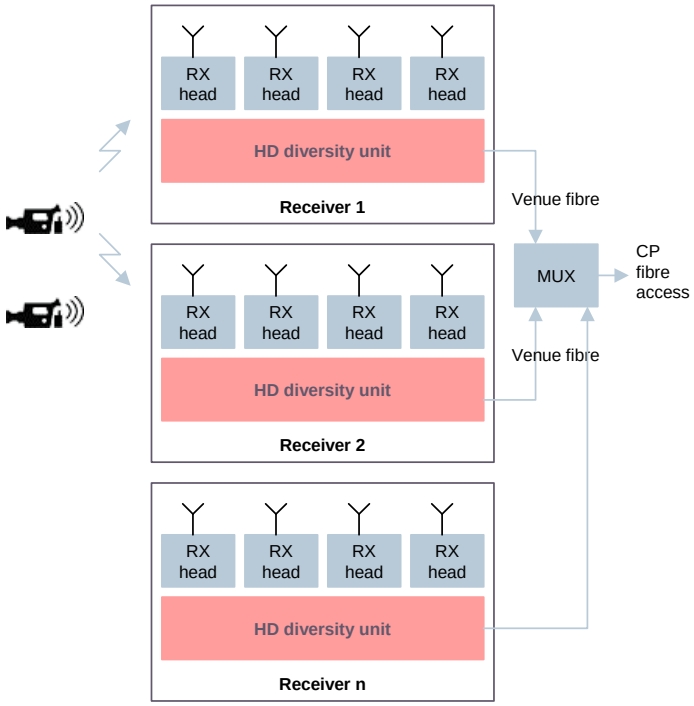


Figure 6.8: High level schematic of the in-venue ground based receiver stations and wireless camera system [Source: Analysys Mason]

6.6.11 The HD diversity unit uses maximal ratio combining (MRC), a method of diversity combining in which the signals from each receive channel are added together, the gain of each channel is made proportional to the rms signal level, and inversely proportional to the mean square noise level in that channel, and different proportionality constants are used for each channel. The signals from each receive unit are fed back by fibre to the multiplexer to combine into single stream.

6.6.12 Down converters are often used at the receive antenna end to convert the received signal to an intermediate frequency (IF) to perform the filtering, which improves frequency selectivity.

6.6.13 We noted in Section 6.2 that the key areas of high demand for wireless cameras are the Olympic Park and the wide area routes between central London and the Olympic Park[24]. If this type of wireless and optical fibre system were to be deployed at Olympic venues solely for the purpose of efficient use of spectrum, the optimal deployment scenarios would be at the outdoor venues at the Olympic Park, namely the Olympic Stadium (11 wireless cameras in the base case) and BMX track (four wireless cameras in the base case).

6.6.14 This system could also be used to good effect for ENG broadcasts from defined areas within the Olympic Park for instance. It is common for broadcasters to set up an area near the main Olympic concourse to be used as an interview area for the duration of the Games, and the broadcaster will usually set up one receiver to cover this common domain. The system as described for the competition venues above could also improve this current ENG solution. The ODA has indicated plans for an extensive network of ducts to support communications systems around, and between, the new build competition and non-competition venues. By setting up receivers at appropriate points in the common domains it could be feasible to provide a direct fibre link via wired access points between the receive antennas and an OB truck, or even the IBC, where the receive equipment would be located.

- *EHF spectrum (Option 2a)*

6.6.15 The prospect of using EHF spectrum for HD wireless live broadcasting is very attractive: the availability of (licence-free) spectrum coupled with multi-gigabit RF links, which would support uncompressed wireless transmission of 1.485Gbit/s, i.e. enough to support HD 1080i video format.

6.6.16 Operation at 60GHz incurs significant free space losses, inhibiting long range transmissions and has a higher sensitivity to environmental conditions such as rain. However, EHF offers opportunities for compact antennas, significant bandwidths, high data rates and the opportunities for much greater frequency reuse and spectral efficiency afforded by the path losses. The latter is an enabler for the BAE Systems multiple cellular architecture, described later in this section, which achieves a wide area coverage by using multiple Remote Antenna Units (RAUs).

6.6.17 One of the benefits of COFDM modulation is that it overcomes multipath effects. However, the key issue here is one of transmit power requirements. Increasing bandwidth and transmission distance both lead to an increased power requirement. In general terms, the power requirement can be traded against bandwidth, the antenna's beam width (coverage area) and distance covered. The choice of encoding and error correction schemes can also help reduce the power requirement.

[24] These are proposed routes at this stage; they have not been confirmed.

6.6.18 There are some encouraging developments in this area, notably in Japan, where the public broadcaster, NHK, has working systems for various live sports OBs – all for applications where the camera follows a fixed path along a specialised track or wire.

6.6.19 The driver behind the development of 60 GHz broadcasting applications in Japan is the availability of licence-free spectrum reserved for broadcasting in the 42 GHz and 55 GHz bands, and the unavailability of, and increasing congestion in, the lower bands. NHK was able to develop a practical and cost-effective system because they could leverage existing commercially-available 60 GHz chipsets and devices that had been developed for a wide range of markets.

6.6.20 Further information on NHK's 60 GHz wireless camera systems are provided in Annex C: NHK - EHF wireless cameras.

6.6.21 With cameras that follow a fixed course, such as the NHK systems, the problem of multipath propagation can be mitigated through the use of high gain directional antennas. It is more challenging to develop a roving camera application with 60 GHz technologies, but a working system in a TV studio environment has been developed by BAE Systems. An overview of the system is provided in the section below.

***Option 2b**: In-venue hybrid wired-wireless solutions for use with roving cameras using EHF bands, e.g. 60 GHz*

6.6.22 The potential for using a 60 GHz camera system in conjunction with optical RF-on-fibre transmission technology has been demonstrated by BAE Systems in their RF on Fibre Mobile Data Network Demonstrator project (ROFMOD), which was funded by the DTI LINK programme.

6.6.23 The project, which ran between 2004 and 2006, achieved its objective to design and demonstrate a 60 GHz fibre radio TV studio system that used 60GHz free space links to distribute high bandwidth signals from wireless cameras, suitable for carrying multiple bi-directional HD TV signals, to fixed remote antenna units (RAU), as illustrated in Figure 6.9.

6.6.24 The mobile data terminals (in this case located at the wireless camera systems) send wideband data at 60GHz to embedded remote antenna units (RAUs) in the studio ceiling. The RAUs provide continuous overlapping coverage across the studio. The video data modulated on the 60GHz carrier received from the mobile transmitter at the RAUs are then sent along optical fibre to a base station in the control room. The key features of the system are summarised below.

i. The studio demonstrator used 60 GHz mobile and fixed antennas, 1 base station, 2 RAUs and 2 mobile data terminals which provided an operating area of approximately 30m x 22m

ii. A 6:1 compression ratio is applied to the 1.485Gbit/s HD-SDI video stream to fit it into a 270 Mbit/s SD-SDI channel. Ideally, uncompressed video would be transmitted, but limitations in the modem meant that a compromise was reached that allowed full broadcast quality video with only modest compression

iii. A 16-QAM COFDM modem handling the compressed HD video stream, operating at 270Mbit/s and requiring a 200MHz channel bandwidth

iv. Each RAU 'cell' has a 15m range when the RAU is placed 5m above the floor. Multiple base stations with associated RAUs are used to provide wide area wireless coverage

v. RF-on-fibre network structure

vi. Modulation and coding schemes to minimise the effect of multipath propagation

vii. Lossless cell handover between RAUs.

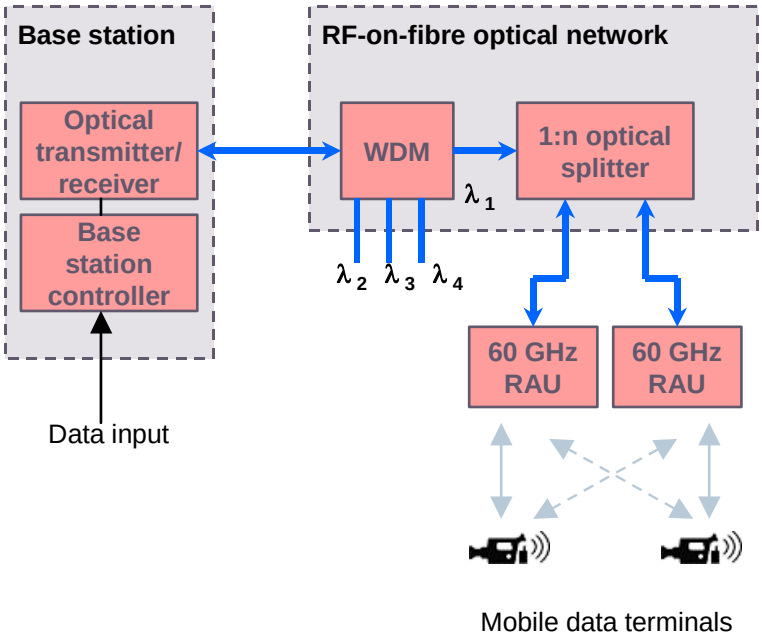


Figure 6.9: Basic architecture of the 60 GHz fibre radio TV studio system [Source: BAE Systems]

6.6.25 The number of cameras that can be used within the coverage area of a base station and associated remote antenna units (RAU) is dependent on the bandwidth of the individual cameras. The number of cameras is limited by the spectrum available and the bandwidth required by the individual cameras within the coverage area of a base station and associated remote antenna units (RAU).

6.6.26 The studio demonstrator worked with two HD bidirectional wireless camera systems, but up to 45 unidirectional or 20 bidirectional cameras using a 200 MHz channel could, in theory, be used with each base station – this calculation is based on a 10 GHz allocation of spectrum and 20% guard bands between camera channels.

6.6.27 Due to the high free space attenuation at 60GHz a second base station with corresponding remote antenna units (RAU) could also support 20 bi-directional cameras.

6.6.28 The potential for this pioneering technology is difficult to assess until more is known about its performance in different environments, and, ideally, this would need to happen by the end of 2009 to remain in contention as a potential technology for use at the London 2012 Games.

6.6.29 If a system could be brought to the necessary stage of development in time for 2012, we believe that it would most likely be deployed at an indoor venue, because this will be closest to the conditions under which it has been tested so far, and would provide the most stable environmental conditions.

6.6.30 A high level estimate of the funding required from the present stage to a system ready to commit to use with confidence by 2010, the Olympics technology cut-off date, is £1.5m to £2m. The estimate includes employment and facilities costs, consumables and capital for development platforms and testing.

6.6.31 The final level of funding required will depend on the camera data rates that need to be supported, the range and coverage area, availability/suitability of the modems, 60 GHz transmit/receive devices and modules or the need to develop custom devices.

***Option 2c**: In-venue hybrid wired-wireless solutions for use with fixed-trajectory cameras using EHF bands, e.g. 60 GHz*

6.6.32 NHK started developing a 60GHz transmission system for uncompressed HDTV signals in 2004, and used the system with a rail camera mechanism for covering the speed skating at the Winter Olympics in Torino, 2006. NHK has also used a similar wireless 60 GHz system with a flown wire system to cover athletics events. More information on both these systems is provided in Annex B.

6.6.33 NHK continues to use these systems a number of times per year to cover events from the Japanese national swimming championships, the national track & field championships and concerts.

6.6.34 In Torino the system transmitted uncompressed HD-SDI signals without delay along more than half of the race track. The pseudo no-delay system permitted live switching between the rail camera and other cable cameras. The key features of this system are:

i. use of commercially available 60 GHz transmitter and receiver devices. These were not designed for mobile transmission, where the multipath effects and narrow beam width of the antennas could fatally degrade the link.
ii. use of single carrier (ASK) modulation - very simple and easy to make devices.
iii. uses high gain directional antennas (ASK format requires a high signal-to-noise-ratio).
iv. three reception points along the track, each with diversity reception and diversity processors.
v. bandwidth: up to 2.5 GHz, transmit bit rate: 1.5 Gbps.
vi. transmit power: 10mW.

6.6.35 Of the Summer Olympics sports, NHK has used this system for track & field and for aquatics. The most obvious applications for this system at London 2012 would be in conjunction with the CAMCAT™ systems, assuming that the host broadcaster would wish to deploy a similar system to those used in Beijing. If the system were deployed for track & field or aquatics, then the type of footage it provides would be in addition to that provided at present by the current wireless camera systems.

Option 2: Advantages and disadvantages – split by sub-option

6.6.36 Here we identify the advantages and disadvantages of the hybrid wired-wireless solutions, including the conditions that are helpful to achieving the objective of reducing spectrum requirement, risks and barriers that prevent this solution.

***Option 2a**: In-venue hybrid wired-wireless solutions for use with roving cameras using 2-7 GHz*

ADVANTAGES

- Reduces the amount of equipment (and technicians) needed inside the stadium/ on the course – attractive option for broadcasters.
- The technology is already used on sports OBs.
- At existing, permanent venues that are used again for televised events the investment opportunity in fibre infrastructure could be attractive.
- Could simplify ENG productions around the Olympic park – attractive for broadcasters.

DISADVANTAGES

- More antennas and diversity units – higher cost.
- The cost-benefit might not be positive for all venues.
- The benefits for spectrum planning could be minimal, as it doesn't reduce the number of channels required.

Figure 6.10: Advantages and disadvantages of Option 2a

***Option 2b**: In-venue hybrid wired-wireless solutions for use with roving cameras using EHF bands, e.g. 60 GHz*

ADVANTAGES

- On the whole the component availability for 60 GHz systems is increasing considerably with time.
- BAE Systems has indicated their internal product would be ready in 2009, and that they are focusing effort on engaging commercial partners.
- Signal processing can be done in the 1.5 GHz to 3.5 GHz range, with up-conversion later to 60 GHz. This could allow compatibility with current RF camera systems by slotting a further module onto the back of the camera.
- Atmospheric attenuation limits ranges at 60 GHz, so frequency reuse distance is short.
- Very high data rates, dependent on range.

DISADVANTAGES

- 60 GHz band transmission system not easy to operate on outside broadcasts due to the sharp directivity and short transmission waves of millimetre waves.
- Very tight timescales for development - challenging to have a robust system that suppliers would adopt by 2010.
- Historically high technical costs.
- Large investment needed, and the source of this investment is not clear at present.
- R&D capability within camera manufacturers too small to progress the technology to a sufficient level by 2010; already 100% occupied on development of

low-latency MPEG4 codec.

- Line of sight is a necessity, but not always a problem in all venues.
- Key industry partnerships will need to be formed immediately to explore and develop the potential uses for these systems in time for the London 2012 Games.
- History of slow development of new technologies; wireless HD took around four years to become stable.
- UK-only specialist equipment is not an attractive investment – wider non-UK adoption is essential.

Figure 6.11: Advantages and disadvantages of Option 2b

***Option 2c**: In-venue hybrid wired-wireless solutions for use with fixed trajectory cameras using EHF bands, e.g. 60 GHz*

ADVANTAGES

- NHK proprietary system in use since 2006, developed in-house at very low cost (~£3k).
- Antennas can be small and directional.
- Very high data rates, dependent on range.

DISADVANTAGES

- Lack of applications at the Summer Olympics at present. Would be in addition to current RF use; not a replacement.
- No buy-in at present from the major camera vendors.

Figure 6.12: Advantages and disadvantages of Option 2c

Option 2: Potential channel saving

6.6.37 In Section 0 we concluded that the maximum number of wireless channels that Ofcom would need to plan for the host broadcaster and RHB sports use would be 56 in the base case, if 100% frequency reuse can be achieved between the Olympic Park and the venues in the River Zone, and 75 if no frequencies can be reused between these two zones.

6.6.38 The summary table in Figure 6.13 below outlines our estimates for the number of channels, and the percentage by which this base case could be reduced through deploying each sub-option at all the relevant venues.

Hybrid wired-wireless option	*Potential reduction in maximum concurrent channels in licensed bands* *(i) 100% freq reuse between OP and RZ* *(ii) No reuse between OP and RZ*
2a: In-venue hybrid wired-wireless solutions - roving cameras using 2-7 GHz	(i) 2 channels (4% saving) (ii) 7 channels (9% saving)
2b: In-venue hybrid wired-wireless solutions - roving cameras using EHF bands	(i) 8 channels (14% saving) (ii) 19 channels (25% saving)
2c: In-venue hybrid wired-wireless solutions - fixed trajectory cameras using EHF	(i) 2 channels (4% saving) (ii) 2 channels (3% saving)

Figure 6.13: The potential channel saving in licensed bands through use of hybrid wired-wireless options
[Source: Analysys Mason]

Option 2: Legacy

6.6.39 The degree of legacy benefit as a result of deploying hybrid wired-wireless solutions is high in terms of the infrastructure legacy if the venue is permanent, and if the venue will be used for televised sports on a regular basis.

6.6.40 Another legacy benefit for live HD outside broadcasting, and for Ofcom, is the opportunity to use the London 2012 Olympics to promote and accelerate the development of new wireless broadcasting solutions that can be sustained in the long term and become widespread, particularly those using hybrid wired-wireless technology in conjunction with the EHF band for HD wireless cameras.

6.7 Option 3: City-wide cellular receive system

6.7.1 A city-wide system combines multiple receivers connected into a fibre network to create a cellular network for receiving wireless camera signals across a wide area. The option applies to:

Competition venues: wide area	✓
Competition venues: outdoor	X
Competition venues: indoor	X
ENG	✓

Option 3: Potential scope

6.7.2 A city-wide network could facilitate efficient spectrum use for wide-area events and for ENG broadcasts within the coverage area by eliminating the need for aerial relays of signals back to the studio or International Broadcast Centre (IBC) in the Olympic Park.

6.7.3 The wide-area events, such as the marathon, sailing and road race, and some ENG broadcasts, present the biggest challenge for spectrum planning. Where aerial relays are used, pairs of

frequencies are needed for each camera (uplink to airborne receive site, downlink to static receive site). The frequencies used for broadcasts to the midpoint, and the aerial shots, consume a lot of spectrum, and these frequencies cannot be re-used at ground level.

Option 3: Technical analysis

6.7.4 The concept of this system is identical to the hybrid wired-wireless option presented for in-venue applications in sub-option 2a, but here we apply it over a wider area and as a shared network.

6.7.5 The basic architecture is the same as that shown in Figure 2.2, where a number of fixed receive points are set up to cover the required area and connected into a fibre network.

6.7.6 Each receive site consists of a diversity receiver and up to four antennas. These receive sites link to a master decoder that performs diversity on the incoming video streams to provide transparent coverage from the mobile wireless cameras. A wireless camera's transmitter will be seamlessly tracked as it crosses from one 'cell' boundary to the next.

6.7.7 City-wide receive systems are not a new broadcasting technology. The concept has been proven with the RF solution deployed at the Oxford-Cambridge rowing this year, where five receive sites along the course picked up the signals transmitted from onboard wireless cameras on the chase boats and race boats. Each of the receive sites linked to the mobile OB unit via BT's fibre network.

6.7.8 For ENG broadcasts, individual broadcasters have deployed single receive points in a number of cities, including London. These are independent systems and the wireless cameras do not roam between cells.

6.7.9 Tests have been carried out in Central London by a wireless camera system vendor in which a reliable non-line of sight operation within a 1km radius around a single receive site was reported. This distance can be increased to 2.5km with a booster amplifier mounted in the camera operator's backpack.

6.7.10 The vendor believes that most of the key locations for ENG crews in London can be covered using four simple receive sites. If we extend this to cover the proposed routes for the wide-area events, then it would be reasonable to assume that a further two receive sites would also provide sufficient coverage for the sports OBs.

Option 3: Advantages and disadvantages

6.7.11 In the following table we identify the advantages and disadvantages of the city-wide receive network, including the conditions that are helpful to achieving the objective of reducing spectrum requirement, and the risks and barriers that prevent this solution.

ADVANTAGES	*DISADVANTAGES*
• Relatively simple solution. • Already implemented for sports and ENG OBs. • Flexible – different types of antenna can be combined to achieve the specific coverage profile needed. • Proven post-Games applications.	• Difficulties with establishing and funding a shared network.

Figure 6.14: Advantages and disadvantages of Option 3

Option 3: Potential channel saving

6.7.12 The potential for this solution to realise a significant channel saving is founded on the principle that the aerial links that are almost always required for many of the wide area events could be replaced with a fixed network of receivers that are connected into a communications provider's fibre network.

6.7.13 We estimate a 15 channel, or 27% saving, on the base case of 56 concurrent channels for wireless cameras, if the requirement for all aerial relays used for wide area disciplines can be fulfilled by the city-wide receive network system.

Option 3: Costs

6.7.14 We believe the main challenge is the funding of a shared cellular network of these receive points. We believe a city-wide system would cost between £0.5m and £1m to design and implement, plus the costs of connecting into a fibre network and the recurring managed service cost.

Option 3: Legacy

6.7.15 In terms of infrastructure, there are significant legacy benefits in deploying the shared city-wide cellular network of receive points for broadcast signals. A city centre and/or Olympic Park fixed receiver network would remain in place beyond the Games and provide the underlying network to support an application for which there is a proven ongoing need, both for ENG and sports broadcasting. A shared network would offer significant advantages for broadcasters who are currently using individual city networks for ENG broadcasts.

7 Analysis: Temporary video and data links

7.1 Potential scope

7.1.1 Temporary video links are one option for carrying high definition programme feeds from the OB location to the IBC or other transmission points, and typically use spectrum between 2–20GHz. They are designed for outside broadcasts and are used in various situations, such as:

i. helicopter downlinks to static receive points, such as OB vehicle or fixed base stations.
ii. between OB vehicles.
iii. between an OB vehicle and fixed base station.
iv. ENG vehicle to a fixed base station.

7.1.2 We believe that the requirement for these types of links for linking competition venues will be small at the London Games. The tendency at recent Olympic Games has been to deploy fibre extensively to connect the competition and non-competition venues to the IBC, and we understand that these links are used for transmission of HD video wherever possible.

7.1.3 Some point-to-point radio links might be required for PMR transmission in areas outside the Olympic Park, but the base station sites are likely to be linked into the fibre route in the Park.

7.1.4 Point-to-point links are most relevant to the temporary venues. Further analysis to map the temporary venues onto current and proposed fibre routes could give a more precise indication of the number of venues that are likely to be served by temporary radio links, but we believe that a deep analysis at this stage is unnecessary because demand will be low.

7.1.5 Although it is not a wired technology, we provide a brief analysis of the potential for Free Space Optics (FSO) technology as an alternative to RF or microwave temporary links. Some sports and ENG broadcasters in the US are trialling this technology – for example there is an interest in using FSO links to connect receive points on buildings for marathon coverage, to eliminate need for expensive aerial relays.

7.2 Fibre optic links

7.2.1 Fibre optic is the transmission medium of choice for the broadcasters - wireless is more open to problems than fibre, and does not compare in terms of bandwidth or resilience.

7.2.2 Although BT is the official telecoms partner for London 2012, it is not yet clear how OBS will provide services, and whether they will seek to procure underlying services from BT. It is also too early to speculate on what OBS will specify as their requirements.

7.2.3 In general, the ability to provide a fibre optic alternative to a wireless link depends on where the fibre is needed, and the extent to which it will be used over time. A cost/benefit analysis would usually have to be undertaken as to the approach taken, and although the answer might vary by venue site, we believe it is likely that for most of the venues wired alternatives will be the broadcasters' first choice. It is greatly superior to any wireless alternatives, especially at higher bandwidths and where there are resilience concerns.

7.2.4 The costs of providing fibre links are difficult to determine at this stage as the variables include the locations, distances, bandwidth, electronics and resilience requirements, which have not been clarified.

Free space optics

7.2.5 Although Free Space Optics (FSO) technology has had its problems in the past, there have been some interesting recent developments that we believe Ofcom should monitor. We summarise the technology and its relevance here, but a detailed analysis is not within the scope of this study.

7.2.6 In the past, while FSO systems have shown encouraging results in controlled tests, reliability in field conditions has been poor – they tend to be susceptible to weather conditions including fog, rain, damp atmospheres and scintillation/heat haze. As a result these systems have been mostly limited to short-range links, such as building-to-building across streets (500 to 1,000m).

7.2.7 Adaptive optics (AO) systems have been developed specifically to eliminate the effects of near field atmospheric distortions. Vendors are claiming that the result of this technology is a system that can transmit ten times the data rate and distance in various weather conditions with a very high reliability.

7.2.8 In relation to sports OB, one vendor has carried out successful demos with a major US sports broadcaster to carry live uncompressed HD video using a 2.5Gbit/s bidirectional link over a distance of 4km. Further tests on live sports OB productions are planned for early 2009, in addition to tests with this technology for mobile network backhaul.

7.2.9 We have also learned that a major US broadcaster asked a vendor to demonstrate applications for broadcasting from Tiananmen Square during the Beijing Olympics. The broadcaster intended to use a utility cart to drive around the Square with the roving camera equipment to conduct interviews with the public. In the end they took a mutual decision to pull out the FSO link deployment in Beijing because of difficulty in obtaining the permission to set up the links.

7.2.10 If the reliability of this technology can be proven, the benefits of FSO could include simplified deployment, lower set-up times, lower power generation requirements and reduced hardware costs (a basic system costs in the region of $50k). It also offers new options in wireless network configurations that would have been too slow and costly previously, as long as line of sight can be guaranteed.

8 Conclusions

8.1.1 We have explored the potential to use wired instead of, or to complement, wireless technologies to assist Ofcom in its objective of making the most efficient and effective use of radio spectrum to accommodate the wireless applications required by the Olympic Family. In doing so we have:

i. captured users' operational and quality requirements with particular reference to broadcast operations at the Beijing 2008 Olympic Games.
ii. developed alternative deployment options for the applications identified for use within venues, around venues and between venues.
iii. presented an evaluation of each deployment option, focussing on wireless camera requirements, including technical feasibility, advantages and disadvantages of deployment, costs and legacy benefits.

8.1.2 The main focus of the study is on wireless cameras used by the broadcasters, because this is the application with by far the largest spectrum demand, and whose use has proliferated in recent years.

8.1.3 We investigated the wireless camera use in Beijing, and predicted levels for the London Games, and analysed the potential for replacing some of this use with wired alternatives. We also looked at how the deployment of wired technologies could help Ofcom develop an effective spectrum plan that would accommodate the current and predicted future levels of use.

8.1.4 In summary, we have reached the following conclusions:

i. We do not believe a reduction of the key broadcasting applications from the usage levels seen in Beijing is a viable option
ii. We have found that broadcasters are, to an extent, united with Ofcom in their goal of limiting wireless camera use because of the additional costs, reduced reliability, and increased complexity they can introduce
iii. Certain wired technology options are feasible and could reduce the number of channels needed to support the broadcasters' requirements, or enable a move to less-congested channels
iv. Maximum spectrum savings will be realised by focusing on wireless camera use at the wide area sports events and the Olympic Park
v. Implementation of proven alternative technology options, i.e. those that are already in use, could result in a channel saving of 35% on the wireless camera base case
vi. The host broadcaster does not normally operate fixed point-to-point wireless links – fibre is the medium of choice
vii. New technologies or approaches will only be adopted for London 2012 if the long-term viability and benefits to broadcasters can be proven.

8.2 Wireless cameras at the Beijing 2008 Games

8.2.1 We have established that the use of wireless camera systems for the competition coverage at the 2008 Beijing Olympic Games use almost doubled from the 2004 Athens Olympic Games to approximately 110 wireless camera systems, used at 24 of the 40 sports disciplines. This reflects the increasing popularity of these systems over the last few years for sports and ENG applications. We believe that a lower order of increase in demand for wireless cameras is likely between Beijing and London, and that mini-cams will be the key growth area.

8.2.2 This popularity has been driven by the freedom of movement these systems provide, and technology developments which mean a high quality HD result can now be achieved in reasonable bandwidths. All wireless cameras used by the host broadcaster in Beijing (BOB) were digital HD, and all used 10 MHz channels and operated in the bands between 2 GHz and 3 GHz.

8.2.3 Although these current wireless systems can increase the cost of a solution by up to a factor of two, the benefits they bring in terms of flexibility and greater depth of coverage mean that they have become a key part of many OB sports productions. The host broadcaster does not encourage unwarranted use of wireless applications, but recognises that wireless cameras have become a crucial element of the broadcast production plans. As an example of this, BOB approved the use of six CAMCAT™ wire-cam systems in Beijing that were used with high definition wireless links to capture dramatic shots from the opening and closing ceremonies, beauty shots, and from four competition venues.

8.2.4 To scale back on the wireless camera levels from the previous Games would be viewed by the broadcasters as a significant setback, particularly given the vast worldwide audiences, and the increasing range of devices and on-demand services through which the live footage can be viewed.

8.2.5 We found that two thirds of the wireless cameras in Beijing were used for covering wide area events. Wide area events are the source of most spectrum demand from wireless cameras because they use large numbers of cameras, and these cameras often need pairs of frequencies because they are used in conjunction with aerial relays to the receive the video signals at a mid-point and then transmit them to their final destination. Frequency reuse potential for the channels used by wide area events is limited because of the large distances over which the signals travel.

8.3 Wireless camera demand for the London 2012 Games

8.3.1 Only a proportion of the 110 wireless cameras used in Beijing by the host broadcaster would be in use on any single competition day. By making some basic assumptions on frequency reuse in relation to distance separation between venue zones, and by mapping this onto the provisional venue plan and the provisional competition schedule for London 2012, we found that up to 75 concurrent channels of at least 10 MHz would be needed to maintain this level of use at the London 2012 Olympic Games.

8.3.2 This figure could be as low as 56 if the frequencies used at the rowing venue in Eton Dorney can be reused at the Olympic Park and River Zone. This will depend on the location of the receive point for the TV signals from this event in relation to these zones. A 30% growth scenario results in concurrent channel requirement of 66 (or 90 in the worst-case).

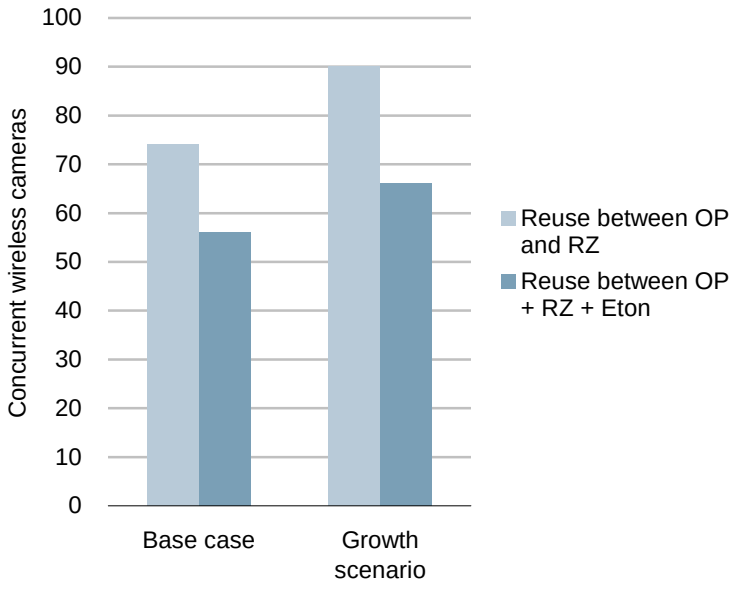


Figure 8.1: Maximum number of concurrent wireless camera channels required – base case and growth scenario [Source: Analysys Mason]

8.4 Potential to replace some of the wireless cameras with wired cameras

8.4.1 As expected, we found that mobility is a key requirement for the majority of wireless cameras. When looking for examples of non-essential use of wireless cameras, we found that some current users do not especially demand wireless technology, but if they are used for the competition then they will certainly be used for the non-competition formalities.

8.4.2 We believe that *some potential* exists to explore the feasibility of wiring seven of the 34 handheld / Steadicam wireless camera systems that were used in Beijing by providing wired access points that make use of underground ducting to a static position. This could give rise to a channel saving of between three and seven channels. A detailed knowledge of the venue layout plans, and a thorough understanding of the environmental features specific to the venue that could affect the implementation are required in order to assess the actual potential. This solution

addresses the safety concerns caused by trailing cables on the field of play, but the mobility from which the majority of the wireless cameras benefit would still be restricted.

8.4.3 We also believe that the use of tethered blimps with fibre optic cameras in some venues could replace the requirement for aerial cameras, such as those mounted on helicopters and planes to capture aerial shots of the venues. However, we did not include this in our calculation of channel savings because we cannot be certain that the venues can accommodate the practical requirements for launching these systems without seeing the venue plans.

8.4.4 There could be an opportunity to run a cable to the remote mini-cams by providing an appropriate cable access duct to the required location. The potential is also difficult to assess without knowing the precise location or details of the environment in which they would be placed.

8.5 Hybrid wired-wireless solutions

8.5.1 We have explored the use of fixed receive points for wireless cameras in conjunction with fibre transmission ('hybrid wired-wireless solutions'), either within a venue, or over a wider area. These solutions are already well established in sports and ENG broadcasts in the 2 to 3 GHz bands, and if applied to certain outdoor venues can help improve frequency reuse potential, and therefore reduce the number of concurrent channels needed for wireless cameras.

8.5.2 Hybrid wired-wireless solutions using the 7 GHz band are undergoing live tests with onboard cameras travelling at speeds of up to 200 mph. If these tests continue to go well, a move to less-congested channels, such as those in the 7 GHz band, would become an attractive and feasible option, presenting significant benefits to spectrum planners and broadcasters alike. The reduced interference, and the potential for wider bandwidths would facilitate optimum quality high definition live broadcasting, but the key drawback is the extensive investment needed by broadcasters, and the companies that supply them, to replace their current equipment.

8.5.3 Ofcom asked us to rule nothing out when exploring alternative wired solutions. The more radical options we considered involved the use of the 60 GHz band in conjunction with optical fibre transmission technology. The Olympic Games would represent a high stakes test of this technology, and the timescales to progress these technologies to a sufficient level by 2010, the date identified by LOCOG and the host broadcaster for a technology cut-off, are extremely challenging.

8.5.4 We found that an application of 60 GHz technology has been used successfully with a fixed-trajectory camera at the Torino Winter Olympics in 2006, but we concluded that there is no obvious application for the system at the Summer Olympics that would directly replace any of the current wireless systems.

8.5.5 It is technically more challenging to develop a roving, completely mobile camera solution for use at 60 GHz; research and development is in progress, and systems have been tested in a controlled studio environment. If a practical system is developed, it would represent a major breakthrough for live HD sports and ENG broadcasting.

8.5.6 We believe that Ofcom should remain open-minded about these solutions and encourage the development of 60 GHz technology. We believe an investment of at least £2 million over the next 18 months, and the formation of key industry partnerships, is necessary for these systems to remain in contention for use at London 2012.

8.5.7 We also believe that the 60 GHz technologies are relevant to broadcasters outside the UK, as congestion in the bands currently used by wireless cameras is not a UK-only problem. If 60 GHz wireless camera systems can be proven to work effectively, and the broadcasters have the means to adopt the technology, then we believe that these solutions can be a key element of production plans for major sports events beyond London 2012.

8.6 60 GHz technology

8.6.1 The prospect of using EHF spectrum for HD wireless live broadcasting is very attractive: the availability of (licence-free) spectrum, coupled with multi-gigabit Radio Frequency (RF) links, including uncompressed wireless transmission of 1.485Gbit/s that will support HD 1080i[25].

8.6.2 Whether EHF systems can be developed sufficiently for live broadcasting at London 2012 is arguable, and has been addressed in previous Ofcom studies. We have established that NHK has been using fixed-trajectory 60 GHz wireless camera systems to cover various outdoor and indoor sports since 2005, and there are certain synergies between these and the CAMCAT™ flown-wire systems used in Beijing to suggest that this *could be* a potential application for the 60 GHz system if the necessary partnerships were in place.

8.6.3 A roving EHF wireless camera system supported by a RF-on-fibre distribution network has been demonstrated by BAE Systems, and offers the benefit of wide bandwidth bidirectional transmission and the ability to handle multiple uncompressed HD video signals. The system has been tested successfully in a controlled studio environment.

8.6.4 Its engineers are optimistic about the potential of this system for sports broadcasting applications, but its readiness for live outside broadcasting has not been established. The propagation of these transmissions might be affected by environmental factors that are as yet difficult to quantify, such as, for example, the difference between operating in a full stadium to an empty one, and reflection off the water in an aquatics venue. The choice of COFDM modulation is likely to mitigate these issues, but this would need thorough investigation.

[25] 1080i is a high definition TV video mode with 1920 horizontal samples and 1080 lines in an interlaced scan.

8.6.5 Although the demonstration of the BAE Systems 60 GHz camera and RF-on-fibre solution is very encouraging for spectrum planners, the fundamental problem in the context of London 2012 is one of time and investment. Within the timescales for development, which is effectively up to mid-2010, to develop a tried-and-tested system before OBS (and, in turn, the OB companies and broadcasters) start placing contracts with suppliers, the system is probably most suited to the indoor venues. However, the cost-benefit assessment for deploying an expensive system at an indoor venue, where the spectrum planning could present fewer challenges than the outdoor events, might not make a compelling case at present.

8.6.6 To have a mature system by 2010 is incredibly challenging, considering that discussions between the developers and the broadcasters or camera manufacturers have not yet progressed beyond an embryonic stage. Ideally both would need to partner with BAE Systems for an intensive 18-month period to achieve an operationally acceptable system within the timescales available.

8.6.7 Our estimate of the funding required between the current stage of development and a system ready to use with confidence is £1.5m to £2m. This is a high sum for the R&D operations of camera manufacturers or broadcasters alone to bear.

8.7 Channel savings vs. technical feasibility

8.7.1 We identified three deployment options of varying technical feasibility for alternatives to the wireless camera base case that would reduce overall channel requirements in the licensed bands.

	Deployment option	*Technical feasibility by 2010*
1	Replacement of wireless cameras with wired, wherever possible	HIGH
2	In-venue hybrid wired-wireless solutions	
a	Roving cameras using 2 to 7 GHz	HIGH
b	Roving cameras using EHF, e.g. 60 GHz	LOW
c	Fixed trajectory cameras using EHF, e.g. 60 GHz	MEDIUM
3	City-wide cellular receive system	HIGH

Figure 8.2: Summary of deployment options

8.7.2 We have estimated the channel saving that could be realised through each option and the cumulative result in relation to technical feasibility is illustrated in Figure 8.3. By concentrating on technologies that are used now, what we have labelled ‘high feasibility’, we believe Ofcom could save up to 35% of the base case concurrent channel requirement.

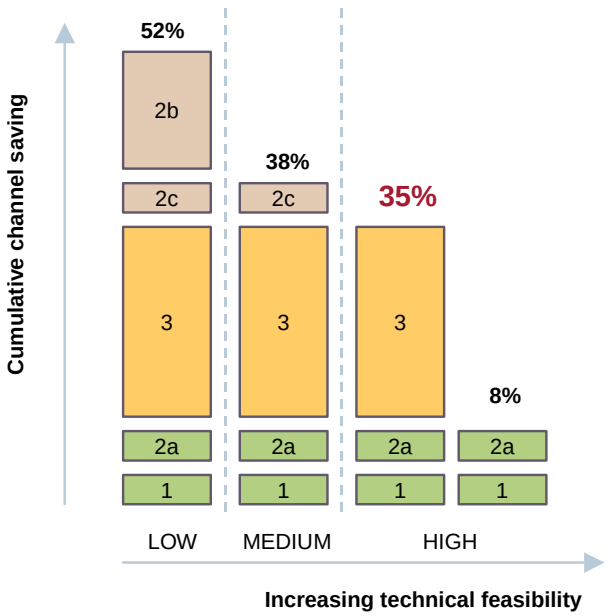


Figure 8.3: Channel saving vs. technical feasibility [Source: Analysys Mason]

8.7.3 As the figure above illustrates, we have concluded that the best opportunity, from a technical feasibility perspective, for reducing wireless camera channel requirements is to deploy a city-wide cellular receive system (Option 3), in which a number of fixed receive points are set up around a city and connected into a fibre network. This system could be applied to the wide-area sports and ENG applications in central London to eliminate or reduce the need for aerial relays of signals back to the studio or International Broadcast Centre (IBC) located in the Olympic Park.

8.8 Temporary video and data links

8.8.1 We have found that wired technologies will be the broadcasters' first choice for temporary video and data links. These are generally superior to wireless alternatives, especially at higher bandwidths, and where there are resilience concerns. It is impossible to predict the costs of wired or wireless solutions at this stage, as it varies depending on many things, including the locations, distances, bandwidth, and resilience requirements.

8.8.2 In Beijing, most links from venues to the IBC were fibre. Wireless was more open to problems than fibre, so this was the transmission medium of choice for the broadcasters. The host broadcaster does not normally operate fixed point-to-point radio links.

8.9 Legacy and costs

8.9.1 We concluded that the degree of legacy benefit as a result of deploying hybrid wired-wireless solutions (strategic option 2) is high in terms of the infrastructure legacy if the venue is permanent, and if the venue will be used for televised sports on a regular basis.

8.9.2 In terms of infrastructure, the most significant benefits would be realised through the deployment of the shared city-wide cellular network of receive points for broadcasting signals (strategic option 3). There is a proven requirement for this infrastructure, and a shared network would offer significant advantages for broadcasters who are currently using individual city networks for ENG broadcasts.

8.9.3 A new technology or approach, whether at 2-3 GHz, 7 GHz or 60 GHz, will only be adopted if the long-term benefits can be proven; new systems that can be used only for the duration of the London Games will not be realistic options. A sustainable legacy of benefits will not only encourage broadcasters to invest in new approaches, but also help attract the necessary external investment to enable these to become viable options for the London Games.

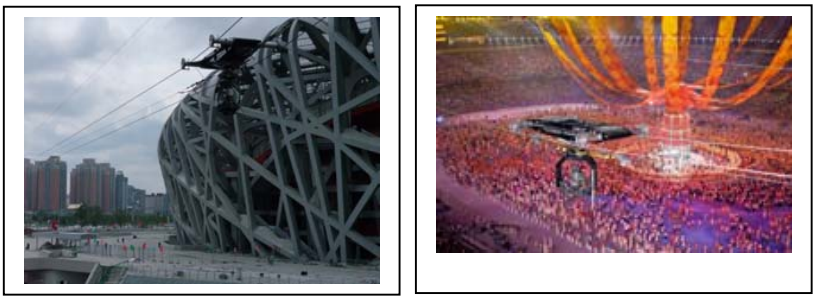
8.9.4 A legacy benefit for live HD outside broadcasting and for Ofcom is the opportunity to use the London 2012 Olympics to promote and accelerate the development of new wireless broadcasting solutions that can be sustained in the long term and become widespread, particularly those using the higher frequencies for HD wireless cameras.

Annex A: Wireless cameras – example pictures

Handheld and ENG systems

Figure A.1: Images of handheld, ENG and onboard wireless cameras systems at venues in Beijing [Source: Link Research]

Flown wire system



The ‘Bird’s Nest’ Stadium

Beauty shots

The slalom canoe competition

The BMX track

Figure A.2: Images of the CAMCAT™ in use at venues in Beijing [Source: Brains & Pictures]

Annex B: Detailed wireless camera use in Beijing

B1: Breakdown by discipline and by wireless camera category

		Portable RF systems		***Specialist RF systems***			
	RF cameras	*Handheld / Steadicam*	*Airborne*	*Vehicle mounted*	*On-board*	*Minicam (e.g. POV)*	*Flown wire*
Ceremonies	**5**	✓					✓
Athletics – stadium	**11**	✓					✓
Athletics marathon	**12**	✓	✓	✓			
Athletics - road walks	**4**			✓			
Basketball	**2**	✓					
Cycling Road Race	**11**		✓	✓			✓
Cycling Time Trial	**12**	✓	✓	✓			
Cycling Track	**1**					✓	
Cycling BMX	**4**	✓					✓
Cycling Mountain Bike	**3**	✓	✓				✓
Diving	**2**	✓					
Equestrian Dressage	**7**	✓				✓	
Equestrian Eventing	**4**	✓					
Equestrian Show jumping	**8**	✓				✓	
Flatwater kayak / canoeing	**9**	✓	✓	✓	✓		
Football[26]	**1**	✓					
Gymnastics Artistic	**2**	✓					
Modern Pentathlon - swimming	**1**	✓					
Open water swimming	**7**				✓		
Rowing	**8**		✓		✓		
Sailing	**18**				✓		
Slalom kayak/canoe	**1**						✓
Swimming	**2**	✓					
Synchronised swimming	**2**	✓					
Triathlon	**15**	✓	✓	✓		✓	
Water polo	**2**	✓					
Weightlifting	**1**	✓					
TOTAL IN USE	**155**	51	12	38	35	11	8

Figure B.1: Breakdown by discipline and by wireless camera category [Source: Analysys Mason]

[26] Used in the final match only

B2: Level of use and rationale for handheld and Steadicam wireless camera systems

Discipline	*Safety and/or sports federation regulations*	*Production requirements*	*Wired alternatives*
Ceremonies	Safety: 40,000 performers and athletes from 204 competing nations – cables would present safety risk	• RF Steadicams - need freedom to move between performers and close-up shots.	No – complete mobility required.
Athletics – stadium	No cables on FOP	• Integrated Feed: HH units - roving on the FOP and athlete cutaways • RF units for track feed, throws, horizontal jumps, vertical jumps.	No alternative for integrated and track feed - position and movement of subject is not predictable. Depending on the range of movement required, it might be acceptable to provide wired access points at appropriate positions for the throws, horizontal jumps and vertical jumps. **Potential: up to 3 units wired**.
Athletics marathon	No cables on FOP	• Steadicam and RF hand held at the finish area.	No. Although finish area is in the stadium, the position and movement of subject is not predictable.
Basketball	No cables on FOP	• RF units for player intros, bench, coach and officials	No – a static camera would be subject to obstructions between camera and subject.
Cycling Time Trial		• Steadicam at start and finish area and handheld RF back stage in the team area.	No – complete mobility required.

Discipline	*Safety and/or sports federation regulations*	*Production requirements*	*Wired alternatives*
Cycling BMX		• RF handhelds for the pre-start, replays and ceremonies; finish for winner shot, pre and post unilaterals and ceremonies; roving in the infield within curve.	No – complete mobility required. Difficult to assess potential for wiring the infield HH because this is broadcast plan specific to the course.
Cycling Mountain Bike		• HH for the start presentation, finish, second, third, pre/post unilateral, medal ceremony and during the race close to the finish area.	No – complete mobility required. Position and movement of subject is not predictable.
Diving	FINA regulations – no cables on pool deck	• HH and Steadicam for exits, ceremonies and unilaterals.	No – complete mobility required for access to these areas.
Equestrian Dressage	No cables on FOP	• HH: holding arena for dismount, kiss and cry, pre and post unilateral; on the FOP for the horse's entry; in the warm up arena for competitor preparation.	No – complete mobility required for access to these areas.
Equestrian Eventing	No cables on FOP	• HH RF for the warm up area/start gate; HH RF and RF Steadicam at various points along the course.	No – not practical to build wired access points over wide outdoor area. This will be a temporary venue.
Equestrian Jumping	No cables on FOP	• RF HH for FOP coverage.	Some potential to provide wired access points depending on the particular course and environment. Potential: up to 4 units wired, depending on location of the arena and future use.
Flatwater kayak / canoeing		• RF HH unit at the end of the course.	No – complete mobility required for access to this area.
Football	No cables on FOP	• Steadicam for the touch line - for the final only.	
Gymnastics Artistic	No cables on FOP	• Integrated feed: HH RF cameras for tracking athletes both on and around FOP.	No – complete mobility required across entire arena and ability to follow ad-hoc movement.
Modern Pentathlon - swimming	FINA regulations – no cables on pool deck	• RF Steadicam for intros, exits, ceremonies and unilaterals.	No – the position of the camera is dependent on which lane needs to be covered; this is a factor of the race and cannot be planned. Intros – the camera passes between the blocks and the competitors – a restricted space that cannot have cables trailing across.

Discipline	*Safety and/or sports federation regulations*	*Production requirements*	*Wired alternatives*
Swimming	FINA regulations – no cables on pool deck	• RF HH for intros, exits, ceremonies and unilaterals; 1 Steadicam	No – As above.
Synchronised swimming	FINA regulations – no cables on pool deck	• RF HH for intros, exits, ceremonies and unilaterals; 1 Steadicam.	No – as above.
Triathlon		• RF HH: unit on start pontoon, unit on the ramp from swim finish to transition, units on start/finish, transition area.	No – complete mobility required across entire arena and ability to follow ad-hoc movement.
Water polo	FINA regulations – no cables on pool deck	• RF HH and RF Steadicam for benches, coaches, officials, unilaterals.	No – complete mobility required across entire arena and ability to follow ad-hoc movement.
Weightlifting		• RF HH unit .	No – roving between warm-up area, athlete's entrance, and onto the stage for judges' reactions.

Figure B.2: Rationale for the use of handheld and Steadicams [Source: Analysys Mason]

B3: Use of on-board and in-vehicle wireless camera systems

	Vehicle mounted	*On-board*
Athletics marathon and road walks (shared)	RF units on motorbikes and vehicles.	None
Cycling - road race and time trial (shared)	RF units on motorbikes and on parked vehicles on the course.	None
Flatwater kayak / canoeing	RF units on parallel vehicles from start to finish.	RF units on chase boats.
Open water swimming	None	RF units on chase boats and boats around the course markers.
Rowing	None	RF units for chase boats and on-boards in total (assume 3 shared with flatwater kayak).
Sailing	None	RF cameras for chase boats. RF units for on boards RIBs.
Triathlon	Assume resources shared with road cycling. RF units on motorbikes, leader vehicle on cycle leg and close up of leader on cycle leg, and on parked vehicle for come-and-go shot..	None.

Figure B.3: Use of on-board and in-vehicle wireless camera systems [Source: Analysys Mason]

B4: Use of airborne, wire-cam and mini-cam wireless camera systems

	Airborne	*Wire-cams*	*Mini-cams*	*Wired alternatives*
Ceremonies	n/a	CAMCAT systems: A vertical system up side of the Ling Long Pagoda. A horizontal system from the pagoda to a specially constructed tower.	n/a	Use wired camera with cable management system with the wire-cam if the total length <200m.
Athletics - stadium	n/a	CAMCAT systems: as above plus a third aerial system going directly above the pool and the stadium.	n/a	Use wired camera with cable management system with the wire-cam if the total length <200m.
BMX	n/a	CAMCAT system	n/a	Use wired camera with cable management system with the wire-cam if the total length <200m.
Cycling – mountain bike	RF unit on helicopter for flying between certain sections	CAMCAT system	n/a	Use tethered blimp for aerial shots if operating space >22 metres in radius available. Use wired camera with cable management system with the wire-cam if the total length <200m.
Cycling – road race and time trial	RF units on helicopters	CAMCAT system	n/a	Use tethered blimps for aerial shots if operating space >22 metres in radius available. Use wired camera with cable management system with the wire-cam if the total length <200m.
Cycling – track	n/a	n/a	Mini RF unit on lead buggy	No wired alternatives
Equestrian	n/a	n/a	Mini RF units: 'low centre line' from both sides; unit on top of judges box; unit positioned on offsite building.	Small potential to run fibre or coax cable between camera and OB position. This type of outdoor terrain and the setting would present significant problems for implementing ducting.
Flat-water kayak	RF unit on helicopter	n/a	n/a	Use tethered blimp for aerial shots if operating space >22 metres in radius available.
Rowing	RF unit on helicopter (shared with canoeing)	n/a	n/a	Use tethered blimp for aerial shots if operating space >22 metres radius available.
Slalom canoe/kayak	n/a	CAMCAT system	n/a	Use wired camera with cable management system with the wire-cam if the total length <200m.
Triathlon	Shared with road cycling	n/a	Pole-cam on boat during the swim. Pole-cam in transition area	No wired alternatives.

Annex C: NHK - EHF wireless cameras

NHK has been developing 60 GHz wireless HDTV solutions since 2004. The 60 GHz wireless systems it has used so far for live broadcasting have been of the fixed-trajectory type, in which a camera buggy is guided by a fly-wire or fixed rail.

In Japan, there were three drivers for developing camera technology for use in the EHF bands:

i. the shortage of spectrum in the lower bands
ii. the allocation of licence-free spectrum to broadcasters in the EHF bands
iii. the potential for uncompressed HD transmission at these higher frequencies.

Its first EHF camera system was demonstrated at the Japanese National Athletics championships in 2005. For the Torino Winter Olympic Games in 2006, NHK developed a 'pseudo no-delay wireless HDTV transmission system' using the 60 GHz band to cover the speed skating competition. Both systems are summarised in this Annex.

Since Torino, NHK has continued to develop its 60 GHz wireless camera solutions and its systems have been used for a number of sports (indoor and outdoor) and non-sports events. For example, in 2007, NHK used a 60GHz link at the Japanese national swimming championships, the Japanese national track-and-field championships plus one other track-and-field meeting in Japan, and a Christmas concert/show in Tokyo.

In Japan there are currently 16 channels at 42 GHz and 55 GHz allocated to broadcasters, providing approximately 120 MHz per channel. For this reason, NHK had already developed a 42 GHz camera system prior to Torino.

Track-and-field 60 GHz application - Japanese National Athletics championships, 2005

The national athletics championships at the Yoyogi-Olympic stadium was the first time NHK used its 60GHz link on a live TV production before the Torino Winter Olympics.

The camera system was mounted on a remote-controlled buggy and suspended above the athletics track on two 5mm-diameter fly-wires separated by 60cm, to capture the sports action from a new perspective, as illustrated in **Error! Reference source not found.**. The system is summarised in Figure C.4.

Camera equipment	Ikegami HDL-40
Video transmission	60 GHz band ASK transceiver
Buggy motion	Distance: 10 to 300m; Speed: up to 25 km/h
Operating range	Pan: 360°; Tilt: +10° ~ -100° (horizontal position 0°)
Camera control	2.4 GHz band radio control of motion, pan, tilt, zoom, focus, iris
Transmitted power	<10mW
Total weight	~ 45kg

Figure C.4: Athletics application – 60 GHz camera system data [Source: NHK, IBC2006 Conference Publication]

The positioning of the camera in relation to the stadium is illustrated in Figure C.5. The positioning was sufficient to capture a birds-eye view of the sprint finish line to help determine the race winners in the event of a close finish, as well as the other medium and long distance track events and the throwing disciplines.

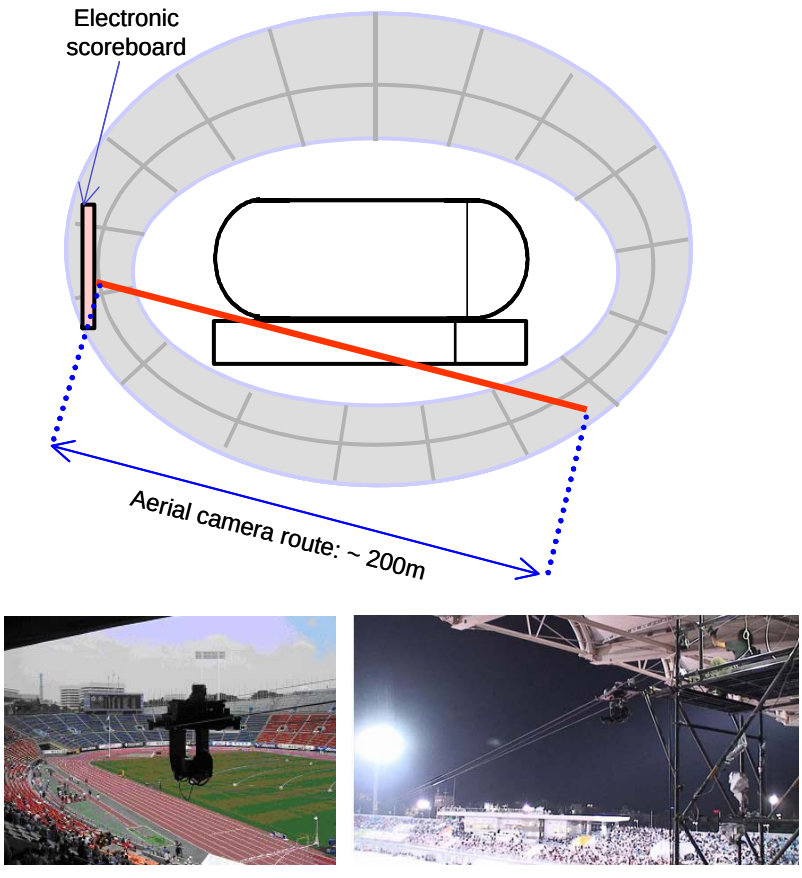


Figure C.5: Positioning of the aerial wire-cam above the National stadium [Source: NHK, IBC2006 Conference Publication]

The 60 GHz transceiver allowed the seamless integration of the wireless camera signal with images from the other standard (cabled) cameras because minimal delay (latency) was introduced. This close-to-zero latency is a result of processing uncompressed HD-SDI signals - the MPEG2 processing, which usually introduces latency in systems working with restricted bandwidth, is not required.

The 60 GHz receive system consists of three diverse antennas that receive the uncompressed HD-SDI signals from the camera transmitter, and these signals are relayed to a diversity receiver, which also performs error correction. The antennas provide overlapping areas of coverage in a vertical direction as illustrated in Figure C.6. Transceiver data is provided in Figure C.7 and receive antenna data in Figure C.8.

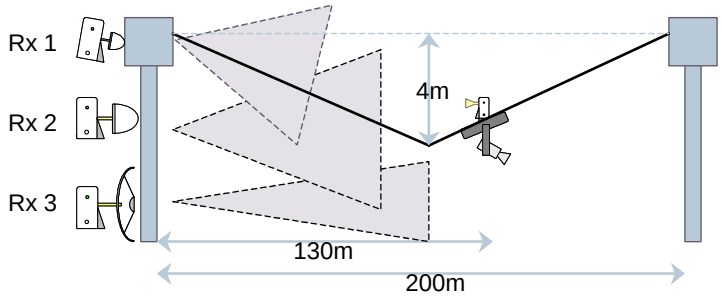


Figure C.6: The transmit and receive antenna positioning
[Source: NHK, IBC2006 Conference Publication

Transmit frequency	60.25 GHz
Transmit power	8 mW
Modulation	ASK
Occupied frequency bandwidth	2.5 GHz
Transmission bit-rate	1.5 Gbps

Figure C.7: Transceiver data
[Source: NHK, IBC2006 Conference Publication]

The distance of the aerial camera path is 200m, and its useable range is 130m. The camera path is not straight, it travels in an 'inverted V' path, with the lowest point in the centre of the path at a vertical distance differential of 4m from the start point.

	Diameter	*Gain*	*Half-value angle*
Receiver 1: Sprint (dielectric lens)	8 cm	32 dBi	4.2°
Receiver 2: Intermediate range (dielectric lens)	10 cm	33 dBi	3.2°
Receiver 3: Long distance (Cassegrain)	20 cm	38 dBi	1.8°

Figure C.8: Receive antenna data
[Source: NHK, IBC2006 Conference Publication]

Torino Winter Olympics – 60 GHz wireless camera system used for the speed skating broadcast production

The host broadcaster appointed NHK to produce the multilateral broadcast feeds for the speed skating event at the XX Winter Olympics hosted in Turin (Torino) in February 2006.

NHK deployed an innovative wireless rail-cam system, and this was a key element of their production, providing unprecedented dynamic shots of the athletes in HD[27]. The speed required of the system meant that a cable management system could not be deployed, and a wireless camera was the only option. NHK sought an alternative to the conventional wireless cameras, because the delay that is introduced in the processing of the compressed signals that these cameras transmit would have made live switching with the other (cabled) cameras in the production very difficult.

NHK developed a 60 GHz link system to use in conjunction with the rail-cam and transmitted uncompressed HD signals without delay along over half of the race course. The HD-SDI signal (1.485 Gbit/s) would usually have to be compressed in order to reduce the data rate for wireless transmission or broadcast, and this compression is usually achieved by MPEG2.

The wireless camera system (the devices and diversity reception techniques) itself was based on the system that NHK developed for use at the National Athletics Championships, described in the previous section.

[27] The system was presented at IBC2006 and the paper presenting the technical solution is available in the Conference Publication.

System overview

The 60 GHz HDTV wireless camera system comprised a 60 GHz transmitter and receiver, an HD-SDI diversity processor that employed a 'majority decision algorithm', and high gain lens antennas. The transmitter and receiver used existing 60 GHz band components. High gain antennas were necessary to overcome the high C/N required by the ASK modulation.

Multipath effects were overcome through the use of diversity reception, which achieved a stable transmission – multiple receivers were installed at each reception point, as shown in Figure C.10, and the transmitted signals were picked up by one or more of the receivers. An image of one of the base stations is provided in Figure C.11.

The summary specification is provided in Figure C.9.

Tx frequency	60 GHz
Tx output	Up to 10 mW
Modulation	ASK
Occupied bandwidth	Up to 2.5 GHz
Tx bit-rate	1.5 Gbps
Input/output	HD-SDI 1080/50i, 1080/59.94i
Weight	1.2 kg (both Tx and Rx)
Power consumption	Up to 10W (both Tx and Rx)

Figure C.9: Torino 60 GHz wireless camera system specification [Source: NHK, IBC2006 Conference Publication]

The camera rail followed approximately half of the total length of the speed skating course, as illustrated in Figure C.10.

Two transmitters were installed on the camera buggy:

- one transmitting in the direction of travel
- one transmitting at 90 degrees perpendicular to the direction of travel, facing the centre of the curve. This was for the purpose of covering the area of the turn.

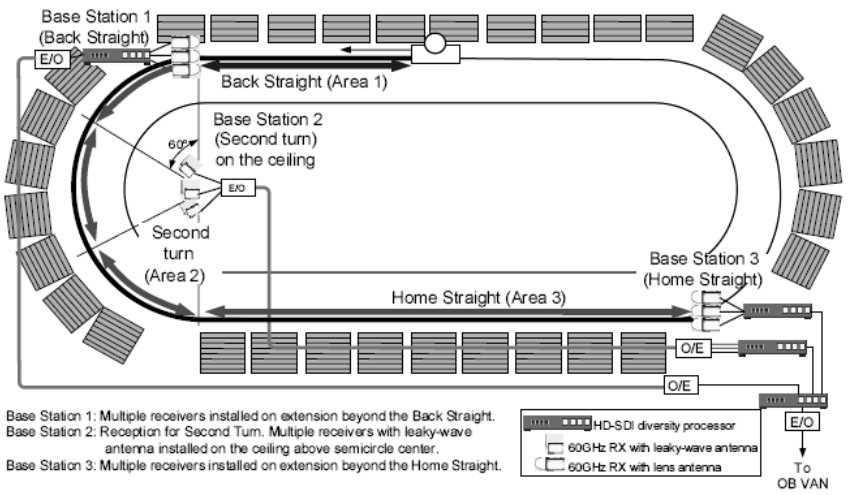


Figure C.10: Diagram showing the NHK 60 GHz camera system layout used for the Torino 2006 speed-skating broadcast production
[Source: NHK, IBC2006 Conference Publication]

The three base stations each served an area of the track: the back straight, the second turn, and the home straight. The base station serving the area of the turn was positioned on the ceiling above the centre point of the turn. The antenna used for this base station, which was designed specifically for Torino, was a leaky-wave antenna. This allowed simple adjustment of the elevation angle and provided the optimum beam pattern. Multiple leaky-wave antennas were used to cover the turn, each providing horizontal coverage of 60 degrees.

Figure C.11: One of the base stations used in NHK's 60 GHz rail-cam wireless camera system in Torino. Each base station had multiple receivers.
[Source: NHK]

Each base station was connected to one or more diversity processors which performed bit error correction on the input signals using a bit-basis majority decision algorithm. Before and after this bit error correction process, each input had a Cyclic Redundancy Check (CRC) to ensure an error-free output signal.

Base stations 1 and 2 were connected by optical fibre to base station 3 (the home straight), to the master diversity processor. A fibre optic link carried the final HD-SDI signal from the master diversity processor to the OB van outside the arena. The overall system design is illustrated in the schematic diagram in Figure C.12.

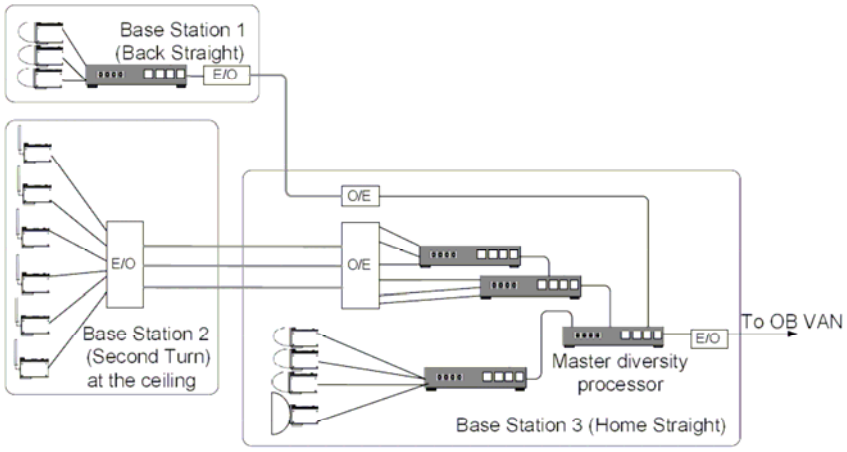


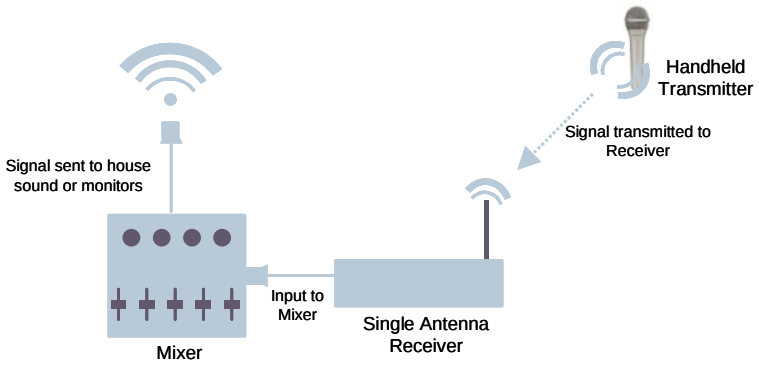
Figure C.12: Torino 2006 – 60 GHz camera system: schematic diagram of the technical solution.
[Source: NHK, IBC2006 Conference Publication]

Annex D: Wireless microphone and in-ear monitor technology

Wireless microphones

There are many different types of wireless microphones that use AM, FM, infrared, and a variety of other digital modulation schemes. Although the infrared wireless microphone system is low cost, it requires line of sight to the receiver.

Wireless microphone systems can use true diversity receivers, where two separate and independent receiver modules, each with their own antenna, are used to pick up the transmission, or non-diversity modules that have only one antenna. In diversity systems the antennas are placed apart on the unit and the strongest signal received will be used. This reduces drop outs caused by phase cancellation and effects caused by radio wave reflection. Non-diversity modules have only one antenna.



There are two types of wireless microphones; bodypack and handheld. The bodypack or belt-pack wireless microphone has a small case housing the transmitter and battery pack, and has a wire going to a headset or lapel (lavalier) microphone, while the handheld wireless microphone is similar to a normal microphone but includes a transmitter and battery pack. Some systems also allow a plug-on transmitter for existing wired microphones to become ‘wireless’. It plugs into the XLR output of the microphone and transmits to the manufacturer’s standard receiver. This allows the removing of a cable connection when using, for example, a highly directional rifle microphone.

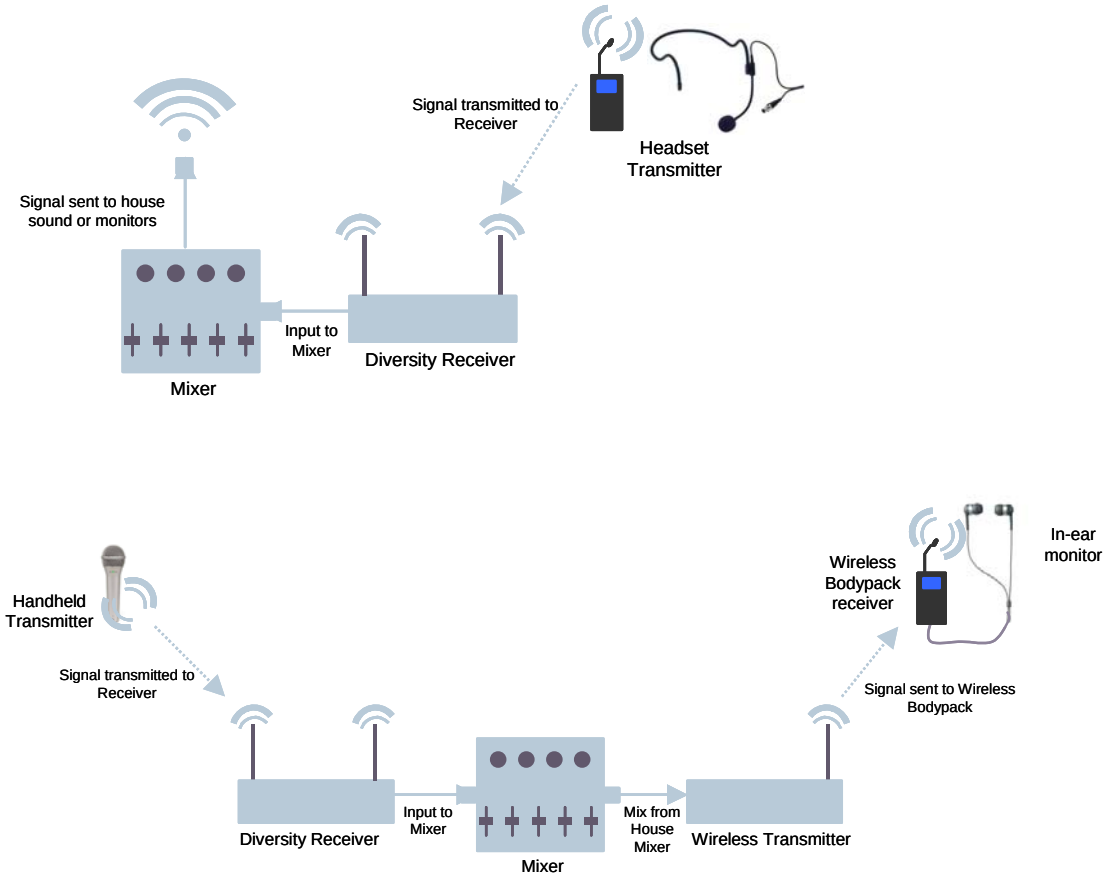
Broadcast applications may require either of the different types of wireless microphones to allow for flexibility and mobility. For example, field reporters may prefer handhelds or plug-ons, while bodypacks could be used to pick up a single talent.

Receivers used with video cameras are often fitted on to the hot shoe slot on the camera. Diversity receivers are a standard choice for broadcasting applications, even for portable or camera-mount use. The location of the antenna must be well planned, especially in a studio environment where there are large metal structures and lightings.

Omni-directional wireless microphones may be used in conditions where noise is minimal, as this reduces the handling sensitivity and allows adaptability in arrangements and locations. However, a unidirectional microphone is needed when ambient noise may be a factor, and where there is a higher chance of feedback. For ENG purposes, it is important to consider other crews that may be using wireless microphones, as well as interference from other broadcast transmitters in the area.

In-ear monitors

A typical system would use a wireless system to send the mix to the monitors. It consists of a transmitter, a receiver and the monitor.



In general, there is a transmitter for each monitor mix and a receiver for each monitor, although more than one receiver can receive a single mix. The transmitter and a receiver that is worn by the user, as a belt-pack, which is battery powered (9V batteries) allows up to six to ten hours of operation. The receiver is designed and can be custom-fitted to the user's ears. The transmitter is switchable between a number of operating frequencies in the UHF band. A local monitor allows the engineer to listen into the user's mix. The mix is transmitted in one stereo mix or two mono mixes. Also, to prevent sounds exceeding a preset limit for safety, the system has an on-board variable slope compressor which protects the user from sudden volume surges. The receiver audio output performs a fast-fade down, rather than switching off audio abruptly when it is at the edge of the range.

This avoids ‘pop and click’ noise in the ear-piece and gives an immediate silent shutdown. Depending on local conditions, the typical operating range of the in-ear monitoring system is up to 100m.

There are systems on the market that combine all the features required for an in-ear monitoring system in a single and compact device with integrated signal processing capabilities, while allowing the input signals to be processed individually.

Annex E: London 2012 Competition and non-Competition Venues

Venue	*Olympic Sports*	*Paralympic Sports*
Broxbourne Canoe Centre	Canoe/Kayak (Slalom)	
Central Zone to Olympic Park	Athletics (Marathons)	
Earls Court	Volleyball	
Eton Dorney	Canoe/Kayak (Flatwater), Rowing	Rowing
Eton Manor		Archery, wheelchair tennis
ExCeL	Boxing, Fencing, Judo, Modern Pentathlon (Shooting/Fencing), Table tennis, Taekwondo, Weightlifting, Wrestling	Boccia, Judo, Powerlifting, Table tennis, Wheelchair fencing,
Greenwich Park	Equestrian – Eventing- Dressage and Jumping, Modern Pentathlon	Equestrian
Hadleigh Farm, Essex	Cycling (Mountain Bike)	
Hampstead Heath & Regent's Park	Cycling (Road), Cycling (Time trial)	Cycling (Road)
Horse Guards Parade	Beach Volleyball	
Hyde Park	Open water swim, Triathlon	
Lord's Cricket Ground	Archery	
North Greenwich Arena 1	Basketball (finals), Gymnastics (Artistic), Gymnastics (Trampoline)	Wheelchair basketball
North Greenwich Arena 2	Badminton, Gymnastics (Rhythmic)	Volleyball (sitting)
Olympic Basketball Arena	Basketball (quals)	Wheelchair rugby
Olympic Park Aquatics Centre	Diving, Modern Pentathlon, Swimming, Synchronised Swimming, Water Polo	Swimming
Olympic Park BMX Track	Cycling (BMX)	
Olympic Park Handball Arena	Handball	Goalball,
Olympic Park Wheelchair Tennis Centre		Wheelchair tennis
Hockey Centre	Hockey	Football five-a-side, Football seven-a-side
Olympic Park Velodrome	Cycling (Track)	Cycling (Track)
Olympic Stadium	Opening ceremony, Closing ceremony, Athletics (Track & Field)	Athletics
Stadia nationwide	Football (quals)	
The Royal Artillery Barracks	Shooting	Shooting
Victoria Park & Olympic Park	Athletics (Walks)	
Wembley stadium	Football (finals)	
Weymouth and Portland	Sailing	Sailing
Wimbledon	Tennis	

Non-competition venues

Venue
Olympic Village
Other athlete accommodation
IBC/MPC
Training venues
Hotel accommodation
Airports